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INTEGRATING OPEN INNOVATION STRATEGIES WITH QUANTUM ECONOMIC ANALYSIS

Master's Thesis

Examiner(s): Marko Torkkeli, Professor
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ABSTRACT

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The objective of the concept selection stage is to provide the idea that has the most commercial potential. Therefore, companies spend a lot of time at this stage to select the right ideas. Unfortunately, the concept selection tools used in this stage do not consider the dynamic synergies between the product, the organisation commercializing the product and the market that this product intends to serve, due to which new products fail despite doing the right things. These synergies are necessary to consider during this stage to reduce the rate of innovation failures. On the other hand, open innovation is a popular approach known to increase innovation success rates of new products through its several strategies and mechanisms. However, it lacks a tool that recommends what open innovation strategy is suitable in which specific situation. This study attempts to close the gap by integrating a tool known as Quantum Economic Analysis (QEA) that considers the dynamic synergies between the product, the company that commercialises the product and its market at the concept screening stage. Currently, this tool does not provide any strategic insight to increase the probability of commercial success. This research modifies QEA to equip it with strategic insights that increase its managerial usefulness. Now, the tool not only provides the different conditions needed for increasing the probability of commercial success but also suggests a suitable open innovation strategy if a company fails to meet a specific QEA condition. The tool provides a universal method that applies to any given product, company, or market. The research investigates and highlights the fallacies and challenges of existing concept screening methods and open innovation. Then, it elaborates on QEA, its characteristics and usability. It analyses several case studies through an exploratory qualitative design to extract open innovation strategies and mechanisms used to commercialise products. Lastly, the study provides some guidelines to implement this tool within an organisation's existing innovation processes.

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Nikhil Phadnis

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1 Introduction

1.1 Background

The word “innovation” has become popular in the last few decades in the industry and academia due to globalization, advances in digital technologies, access to shared knowledge and the change in market and customer perceptions (Chesbrough, 2003). Today, it may be impossible to find an industry or a segment that does not mention innovation.

Innovation brings inherent risks along with its rewards. On the face of things, companies talk about how innovation is a driver for survivability, beating the competition and achieving stable growth for their future (Schumpeter, 1934). However, internally, innovation can be challenging, especially for middle management (Heyden, Sidhu and Volberda, 2018). It is almost as if companies must go through a Goldilocks test (Berger, 2016). For example, radical innovation may give better returns but is accompanied by high risk. In contrast, incremental innovation may not persuade the customer as they are unwilling to pay for small changes and, conversely, lead to failure (Mcdermott and O’Connor, 2002).

Innovation often fails. Empirical studies conducted since the 1960s suggested that new product development failure rates were as high as 90% (O’Meara, 1961; Tomb *et al.*, 1997). One of the most popular and well-cited articles was published in the 1990s, where Stevens and Burley, through an empirical study, claimed “3000 ideas equals one commercial success!” (Stevens and Burley, 1997, p. 17). They concluded that the innovation process was inefficient, leading to a loss of effort and money.

Later in the 2000s, Clayton Christiansen, a Harvard business school professor, quoted that innovation's failure rate is as high as 95% (Christensen, 2011). Although in 2013, a statement from the professor himself said that the failure rate is, in fact, lower, and he and his colleagues did not empirically validate the data (Castellion and Markham, 2013). An in-depth study conducted by Castellion and Markham, 2013 shows that innovation's actual failure rate for new product development (NPD) is down to 40%. Additionally, the study also reports NPD failure rate varies by industry and can range between 35% to 45% (Castellion and Markham, 2013). The evidence suggests that today's success rate of innovation is far better than it used to be.

Nevertheless, the industry is now transitioning to an age of “systematic innovation” as various popular innovation methodologies have made their way into the corporate world. Though the NPD failure rate has dropped to 40%, the competition has increased exponentially. A survey of 1590 representatives of major industries and domains conducted by Boston Consulting Group in 2010 says that 72% of the respondents stated that innovation is one of the top three priorities for their company (Foo *et al.*, 2013). Additionally, 61% of these companies plan to increase their investments in innovation-related activities (Andrew *et al.*, 2010). The above evidence emphasises the importance of selecting the "right" innovation projects is crucial in the early phases of innovation.

Companies must deal with their existing competitors and upcoming threats from start-ups and new technologies that could potentially disrupt their entire business. For example, the evolution of battery technology and electric cars could kill many small component manufacturing businesses. Companies cannot afford to have such failure rates as high as 40% to ensure sustained growth and a secure future. As a result, we continue to push and explore research gaps that would provide practical tools and methodologies to increase the likely hood of success in the market.

Concept selection is one of the critical stages where companies must capitalise on projects and make heavy investments for scaling up. Companies must commit to the products and concepts they have chosen, making it a critical stage for performing feasibility studies to reduce the risk of failure. Many different tools and approaches are used to screen the right ideas and concepts in the stage-gate process (Pommer, 2015). Some well-known ones are risk vs reward matrix, financial analysis, sensitivity analysis, profitability calculations, criteria-based screening, technical assessment, market studies, et cetera. However, the problem lies in the implementation stage of these tools. These assessment methods are used in the late phases of the stage-gate process or at the end of the fuzzy front end (Cooper, 2002).

Moreover, these approaches do not consider the product's life-cycle stage, which could be an important factor for its success. Apart from being time-consuming, the existing tools do not consider the synergies between external and internal factors necessary for an innovation's success. Lastly, the current tools and methods used for idea screening do not offer an insight into what the company must do to commercialise their ideas successfully.

A company may develop products for the right market, build a profitable business case, conduct critical risk analysis based on data, have well-developed innovation processes, and still fail in the market. Valuable time, resources and investments have been lost after doing all the right things. Therefore, it is necessary to develop a dynamic tool that considers the internal and external factors to provide strategies necessary to commercialise the idea successfully.

A lesser-known method known as Quantum Economic Analysis (QEA) may effectively solve the problems mentioned above. It identifies a set of combinations (conditions or premises) for products, companies and markets that are more likely to commercialise successfully based on their S-curves positions (Topchishvili, Katsman and Schneider, 2003). QEA was created for investors to capitalise on the right project and product concepts. It claims to identify inevitable innovation failures before they are commercialised, i.e., at the fuzzy front end (Topchishvili, Katsman and Schneider, 2003). QEA states that “for a business to be successful, the combined levels of development of the company, target market and the product must fall within the set of allowed combinations” (Abramov, Markosov and Medvedev, 2018, p. 2). The QEA method has found thirteen such combinations of (1) product, (2) company and (3) market that are more successful as compared to other combinations. If the business idea, solution, or concept falls within this “allowed set”, then the likelihood of success is better (Topchishvili, Katsman and Schneider, 2003). Currently, QEA does not provide any recommendations on what steps a company must take based on a specific combination. This research will attempt to develop a modified version of QEA that will provide what a company must do at a specific state of QEA.

On the other hand, Open Innovation (OI) has received plenty of academic interest in the past decade, making it one of the most cited literature in academia (Chesbrough, Vanhaverbeke and West, 2014). OI approach has been widely adopted by industry and provided firms with various new tools such as open business models, strategies and mechanisms to boost innovation since 2003. It has helped many companies accelerate research and development, increase speed to market, and innovate better by developing commercially successful products. However, this method is not perfect and comes with challenges of its own that have been extensively researched (Trott and Hartmann, 2009; Vrande et al., 2009; Sieg, Wallin and von Krogh, 2010). Some of them are regarding the degree of openness of a firm, managerial challenges, identification of external sources of knowledge and many more. One of the challenges with open innovation is regarding its implementation stage of the strategies or principles. In theory, a firm may select any open innovation approach suited to its business; however, it is unclear which specific open innovation strategy or set of strategies suits a specific situation. Currently, there are no tools that recommend which open innovation strategy or mechanism is applicable for a given business system.

This research's primary objective is to improve the efficacy of open innovation adoption by providing a method that identifies the most appropriate open innovation strategy or a mechanism for any given product, company or market. QEA would provide the condition or premise of the idea by analysing its S-curve state, whereas open innovation will provide the necessary strategy for successfully commercialising the ideas. Secondly, the research also aims to reduce the innovation failure rates by combining the two methods. The research will allow us to select appropriate Open innovation strategies and recommend them to decision-makers to make them successful, specifically during concept selection phases of the fuzzy front end. Strategies are selected by analysing case studies of successful innovations in start-ups, small and medium scale enterprises and large multinational companies to reveal success patterns. The patterns are mapped to QEA combinations, allowing companies to know what changes they must make to reduce the risk of failure in new product development.

1.2 Method

In this exploratory study, the author uses a qualitative research approach (Saunders, Lewis and Thornhill, 2016). Firstly, it begins with a comprehensive theoretical literature review to familiarise the reader and justify the research relevance from a theoretical perspective. The literature review was carried out by analysing peer-reviewed research papers, articles, books, journals, and other scientific sources to highlight the research gap.

Post the literature review, secondary data is collected through several case studies from actual companies with different products, domains and sizes. A retrospective analysis design is used to map case studies to QEA combinations (Street and Ward, 2013). Additionally, an interview was conducted with one of the leading experts in the domain to support and validate the research findings to minimise subjectivity error. Additionally, another expert analysed the case studies independently to ensure the appropriate application of the QEA tool minimising the study's errors, adding to the work's validity and reliability.

The research methodology will be further discussed and elaborated on in chapter 6.

1.3 Research aim and questions

This research's primary objective is to improve the efficacy of open innovation adoption by providing a method that identifies the most appropriate open innovation strategy or a mechanism for any given product. Moreover, the recommended strategy may allow decision-makers to make radical changes to their company to reduce the risk of failure at the end of the project. Providing strategies at a fuzzy front end can help decision-makers make informed decisions, develop suitable business models and infrastructures, and create roadmaps aligning towards organizational goals, thereby reducing risk in later stages.

This research aims to empirically validate and verify the framework of Quantum economic analysis by using case studies. This may allow this methodology to be adopted widely in the innovation process and create value for businesses worldwide.

Given the current background, the research questions (RQ) are formulated.

RQ1: How can QEA and Open innovation be integrated?

RQ2: How can we identify the most appropriate set of Open innovation strategies for any given business system using QEA?

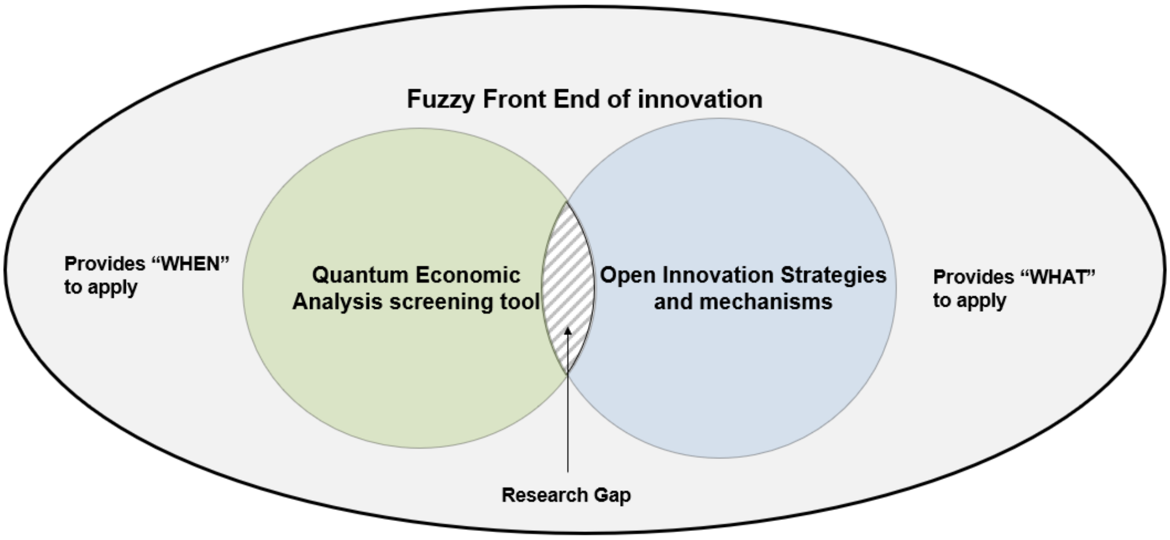


Figure 1. Illustration of the research gap

1.4 Research delimitations

This research does not change open innovation mechanisms and strategies or Quantum economic analysis in any way; instead, it merely integrates them to create new value. The research investigates several concept selection methods used in the industry and points out their fallacies. The research highlights that in the current situation of the innovation industry, concept selection tools and methods need to provide additional insights into strategies, innovation management and other aspects of the innovation process.

This research also investigates the possibility of combining two different domains: Theory of Inventive Problem Solving (TRIZ) and OI, that are scarcely integrated. The study deep dives into QEA, a universal method that could be used in innovation management, and its ability to solve the critical problems in the fuzzy front end of innovation. Moreover, in this study, some literature related to QEA has been translated from Russian books and cited appropriately.

This study also assumes one critical element of innovation: all concepts evaluated through any concept selection method or the QEA screening tool address an unsatisfied and vital need on the market for which the customer is willing to pay.

This research also does not cover any decision support systems, mainly since decision support systems are computerised. However, it has been stated that the decision support system for the integration of QEA and open innovation may be one of the directions for the future scope of work.

1.5 Research structure

In this study, chapter 1 begins with an elaboration of the background, an overview of the research method used, the research objective and research questions that we intend to answer, some de-limitations of this study. Chapter 2 and 3 elaborates on innovation and the fuzzy front end of the process. Additionally, two critical factors necessary for the success of new product development are identified. Chapter 3 also elaborates on each factor, namely, 'factor one - feasibility and potential assessment' and factor two- 'strategy and synergy'. Chapter 3 ends with a summary of the section highlighting the inadequacy of the methods used for feasibility assessment and idea screening tools in the world of 21st-century innovation.

Chapter 4 begins with open innovation and elaboration on the two main types of OI mechanisms: inbound and outbound open innovation. This chapter re-iterates some of the known challenges with OI in the context of this thesis and clarifies the research gap further. Lastly, it summarises the section and justifies the relevance and importance of integrating the OI and QEA.

Chapter 5 elaborates on Quantum economic analysis and explains its theoretical background and current research on the topic. It also elaborates on step-by-step indicators, meanings and explanations of different numbers of product, market and company-related stages. Lastly, it summarises and justifies selecting QEA to combine with OI and explains how it could help us answer the proposed research questions.

Chapter 6 explains the research methodology, research design, the selected research strategy and research approach applied in the study. Additionally, it also explains the selection of the case studies and the sampling procedure. This section also considers research ethics such as validity and reliability that pose threats to the study and explains various measures taken by the researcher to counter these threats. Lastly, an extensive data analysis section explains the case study research strategy used, and the retrospective analysis step-by-step by analysing two cases in detail, namely, Kodak digital cameras and Fuji film digital cameras. The section provides a detailed procedure to replicate the study if needed.

Chapter 7 presents the findings of the research that are divided into three separate parts. Product-related findings, market-related findings, and company-related findings provide a visual representation for ease of understanding and maximum practical utility for the reader.

Lastly, chapters eight and nine elaborate on this research's theoretical contributions, some managerial implications that involve an industry expert's interview using these methods, and re-iterate to summarise how the researcher answered the proposed research questions. The thesis concludes with some limitations and future work scope that other researchers could carry out.

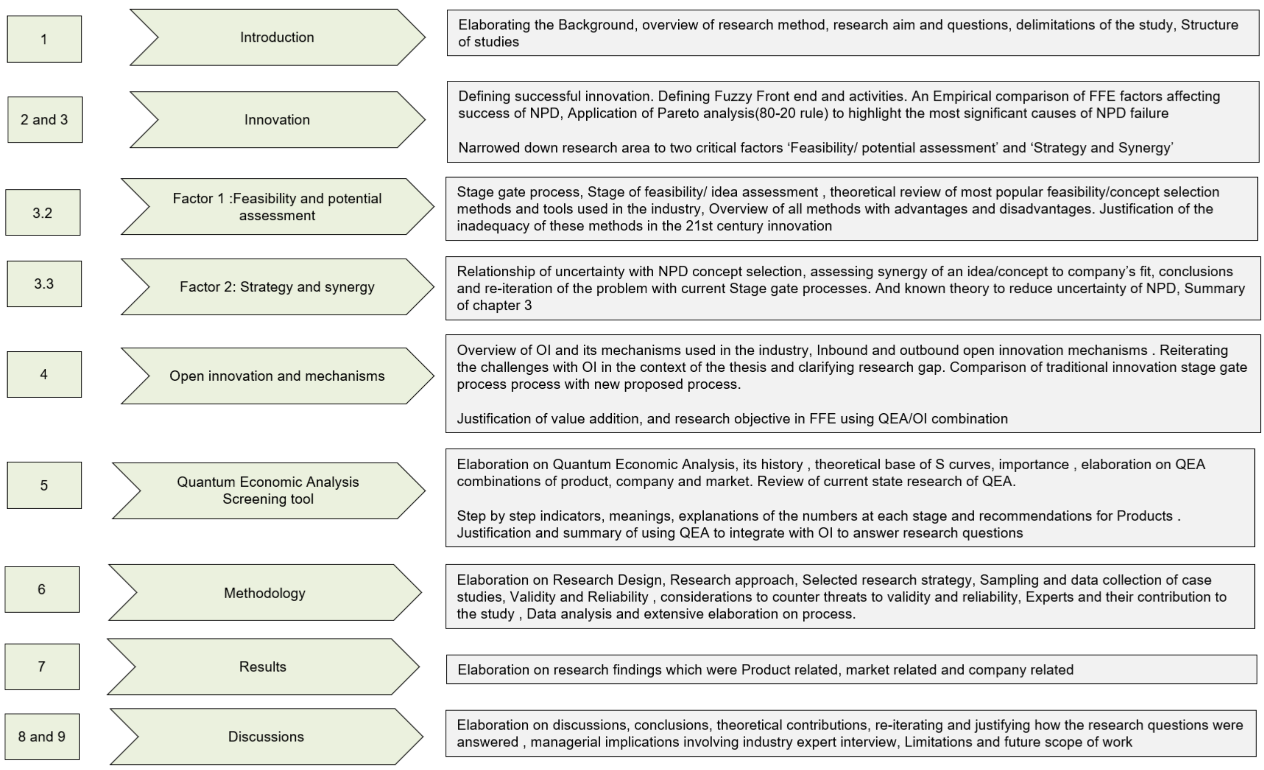


Figure 2. The structure of studies presented providing an overview.

2. Innovation definitions

This section introduces innovation, its definitions and operationalises a definition to be used throughout this thesis. It is also necessary to categorise innovation to articulate themes that could completely describe innovation. This is important because QEA as a tool covers all three elements that are used to describe the word innovation based on which we would term an idea successful or unsuccessful.

A detailed definition provided by Urabe in 1998 states, “innovation consists of the generation of a new idea and its implementation into a new product, process or service, leading to the dynamic growth of the national economy and the increase of employment as well as to a creation of pure profit for the innovative business enterprise.” (Urabe,1988, p. 3). Table 1 shows some common constructs that describe “innovation”, mainly consisting of three themes.

Table 1. Definitions of innovation that were highly cited in the literature since 1965.

Author and Year	Innovation Definitions	Product factors	Market factors	Company factors
Thompson, 1965, p.10	The generation, acceptance and implementation of new ideas, processes, products and services.	x	x	x
Rogers, 1983, p. 11	Innovation is an idea, practice or object that is perceived as new by an individual or other unit of adoption	x	x	
Lundvall, 1992, p. 354	Innovation is a pervasive phenomenon, which penetrates all aspects of economic life, and is a result of ongoing processes of learning, searching and exploring			
Edquist, 1999, p. 7	Innovation is a complex phenomenon, embracing products, processes and services. It includes technological as well as organisational innovations	x	x	x
Garcia and Calantone, 2002, p.112	Innovation is an iterative process initiated by the perception of a Newmarket and new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention	x	x	x
Economic and social research council (ESRC), 2008, p. 177	Innovation is the process by which new ideas turn into practical value in the world	x	x	x
National Endowment for Science, Technology, and Arts (NESTA), 2012, p. 8	The successful introduction of new services, products, processes, business models and ways of working	x	x	x
Taylor, 2017, p. 131	The creative process whereby new or improved ideas are successfully developed and applied to produce outcomes that are practical and of value	x	x	x

Almost all popular definitions seem to consist of product-related/technology related/offering related terminology, market-related/acceptance from the market and last, implementation/company related terminology. Though this statement seems obvious, it marks an important difference between innovation and invention. There cannot be innovation with a "technology push" without a "market pull" (Lyubomirskiy *et al.*, 2014). It means that innovation cannot exist without these three components. Most innovation methodologies already include these three components within their theories and frameworks knowingly or unknowingly.

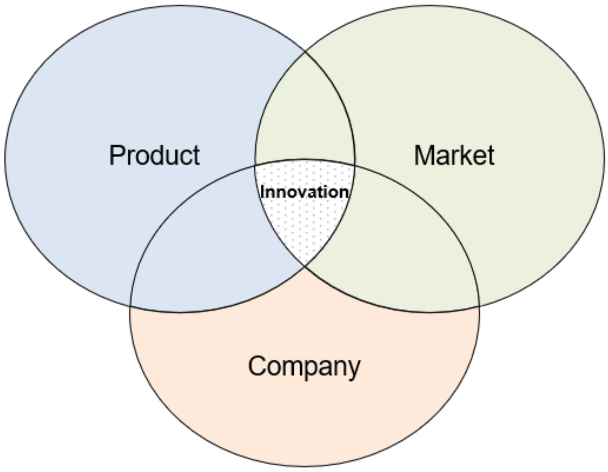


Figure 3. Entities explaining innovation.

Researchers analysed there are certain critical success factors or indicators that may help provide an understanding of 'successful innovation'. Often, product success is measured in terms of financial metrics. Cooper identifies financial performance, market impact and opportunity window as three macro dimensions, which contain ten critical success factors for product innovation that could be used to measure success (Cooper and Kleinschmidt, 1987, Montoya-Weiss and Calantone, 1994; Evanschitzky et al., 2012; Storey et al., 2016). Some meta-analysis studies identify as many as 82 indicators for product innovation, out of which 26 were used as assessment tools at the early stages of innovation (Dziallas and Blind, 2019).

Multiple classifications of indicators analysed by Dziallas and Blind (2019) include direct, indirect, soft and hard categories to define successful innovation. Company related indicators include the company's market share in domestic and foreign markets, relative sales, relative profits, payback period, et cetera. Product-related indicators include the percentage of commercialised ideas, newness or novelty of the product, intellectual property in terms of patents, the potential of the technology behind the product, et cetera. Lastly, market-related indicators include market demand, competitor analysis, customer satisfaction, knowledge level of the market, market growth rate, et cetera (Dziallas and Blind, 2019).

Although this research provides reliable and robust data, it fails in its implementation. Firstly, the time needed to incorporate all these indicators into the early stages of innovation, culture, and management is very high (Piller, Ihl and Vossen, 2011). Innovation teams have countless ideas during the fuzzy front end, even more so given the co-creation era where ideas may change or develop further during the commercialization phases. Companies cannot afford to build innovation processes that may take forever to implement and execute, which cause a delay in the launch of products. Secondly, speed to market has become a critical factor in staying in the game with cutthroat competition. Innovations are revised, products are killed, and new products are launched faster than ever before. Therefore, organisations cannot afford to implement such a long list of indicators even though they are reliable or accurate since it indirectly causes a business loss. Grupp and Schubert (2010), Patel and Pavitt (1995) stated that there is no "Catch-all" indicator to measure innovation success. Therefore, the attempt to analyse case studies that extract indicators or success factors and apply them during the innovation process is insufficient.

This research attempts to provide a "catch-all" tool that may not necessarily identify successful innovations but would identify those inevitably doomed to fail. The Quantum Economic Analysis approach utilises objective S-curves as a common language for all the indicators mentioned earlier. It provides us with a method that does not compromise speed to market and allows decision-makers to assess and evaluate winning concepts and ideas. We would be using a popular operational definition for this research's scope covering all three innovation constructs. "Innovation is a creative process whereby new or improved ideas are successfully developed and applied to produce outcomes that are practical and of value" (Taylor, 2017, p. 141).

3. Fuzzy front end of innovation

Often, the word “fuzzy front end” (FFE) relates to “uncertainty”, that is, the lack of information. Countless papers exist on the definition of the FFE with different perspectives and models that add to the phrase's vagueness. In the scope, we will utilise the most cited definition of FFE as “activities that take place before the formal, well-structured new product and process development or stage-gate process” (Herstatt and Verworn, 2003, p. 4). Research has proven that most projects do not fail in the end but at the beginning. Researchers strongly believe that successful innovation is strongly dependent on front-end activities' performance (Khurana and Rosenthal, 1997; 1998). The FFE of innovation acts as an inflexion point, because after this stage killing an idea is expensive. At the end of this stage, companies make heavy investments for activities like prototyping, scaleup and marketing activities for the selected ideas (Herstatt and Verworn, 2003). A wrong decision at the inflexion point may bring the company to its knees and fail its products resulting in a waste of investment and time or can skyrocket the company's value if successful (Herstatt and Verworn, 2003).

Researchers present many factors that lead to NPD failure during the front end, such as senior management involvement, alignment of NPD and strategy, project-specific factors, evaluation assessment of technology and others (Duin, Ortt and Aarts, 2014; Florén *et al.*, 2018; Zhang and Doll, 2001). However, some researchers analysed previous existing empirical studies and theoretical research to analyse the most commonly mentioned factors. Hüsig and Kohn, 2010 analysed 66 new product development studies, those that were most cited ones with large sample sizes and identified 30 factors in the fuzzy front end that affect a product's success. These factors were mainly divided into two groups, activity and phase-related factors and the global success factors. The activity and phase-related factors relate to a specific focus, whereas global success factors relate to the generalised innovation processes and innovation management (Zhang and Doll, 2001).

The fuzzy front end includes many activities such as:

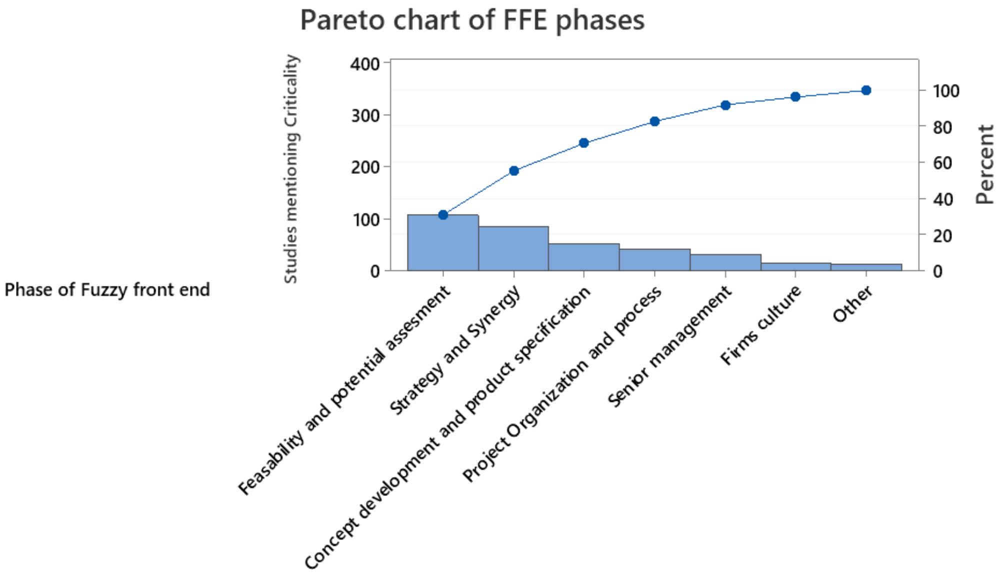
- Pre phase zero- Idea generation phase
- Phase zero - Preliminary assessment of market, technology, competition
- Phase one - Product definitions, project justification and action plan for the stage-gate review system.

The analysis in Table 2 shows the major phases of the FFE, which were cited to be the most critical factors for the success of new product development.

Table 2. Number of studies indicating the most critical phases within FFE

Phase of FFE	Activity performed	Impact on NPD success	Studies that mention "Criticality" of a factor on NPD
Idea Phase	Idea Generation and Idea Screening and filtering (as an explicit stage), customer involvement	Positive effect seen in many industries. Significant impact on product outcomes and supports a structured FFE process	13
Feasibility and potential assessment	Determining feasibility of ideas, market, customer, competitive strategies, technology uncertainty and accumulation of information and detailed	Noted as the highest factors for success with a significant effect.	108 (60 Market assessment 48 technical assessment)
Concept development and product specification	clearly defined product concepts, customer value, target markets and a final evaluation & go/no-go decision. Formulation of positioning strategy, project planning	Most expensive with heavy investments and important factor in FFE	53
Project Organization and process	Organization of innovation process and cross functional project teams, human resources, team leaders, champions	Positive effect mainly if core team is kept unchanged till the end of project	42
Senior management	Influence and commitment of senior mangers. Involvement in reviews and go/kill stages	Positive effect on over all activities of the project and resource allocation with support of senior management	32
Strategy and synergy	Goodness of fit with firm, existing markets, nature, and orientation of new product. FFE strategy focused on reducing risk and uncertainty , early vision and clear objectives	Positive effect if projects fit with firm's competency and existing products. Defined strategies for products or early roadmaps synergetic to the firm	85
Firms culture	Organisational culture, commitment, seeing of "pet projects"	Positive effect on other FFE activities with collaboration. Supporting factor to all other factors	15

Figure 4 represents a Pareto chart, wherein the phase of the FFE is plotted against the number of studies that mention which phase is the most critical in the fuzzy front end. Applying Pareto charts' logic, where 80% of problems are caused by 20% of the causes, we see which factors contribute significantly to NPD's success. The first two phases, feasibility/potential assessment and strategy and synergy, account for 55.5% (cumulative percentage) and are the most critical factors in all studies. Therefore, it is necessary to dive deeper into these two stages to clarify the research gap and review the existing literature for the same.



Studies mentioning Criticality	108	85	53	42	32	15	13
Percent	31.0	24.4	15.2	12.1	9.2	4.3	3.7
Cum %	31.0	55.5	70.7	82.8	92.0	96.3	100.0

Figure 4. The number of studies indicating critical phases in FFE.

3.1 Identified factor one: Feasibility and potential assessment

Robert Cooper revolutionised the innovation process in 1988 that served as a conceptual and an operational model to transform an idea into a product. The process was created to increase the efficiency of innovation-related investments. It was observed that resources were spread too thin over many innovation projects that often caused failure by the time they reached the market. To resolve the situation, it was necessary to build a method that allows the company to focus its efforts, time and investments on specific projects and reduce the risk of failure during development (Cooper, 2002). This process was known as the Stage-Gate process of innovation and countless companies today have embraced and bought order to the chaos of

NPD. It focuses on the core of innovation management to improve NPD's effectiveness and efficacy and structure the ad-hoc journey from idea generation to implementation stages. The stage-gate process is convergent, shaped like a funnel where constant periodic reviews take place to make sure only the most promising ideas transform into commercial products (Grönlund, Sjödin and Frishammar, 2010).

3.1.1 The Ideas-first approach- A never-ending debate

Companies follow two different approaches in the stage-gate process, namely the "ideas-first" approach and the "needs-first" approach (Ulwick, 2016). Selection of the most promising projects/concepts occur in both the mentioned approaches followed by the stage-gate process. As the name suggests, companies following the ideas- first paradigm, believe it is necessary to generate more ideas to create successful innovations. Companies would quickly and cheaply screen out the ideas that would likely fail. In this approach, it is believed that if the number of ideas is high, then the chance of breakthrough innovation is high. Failing fast and cheap has been supported by many industry experts and academic writers (Ulwick, 2016). Therefore, many companies conduct periodic brainstorming sessions, idea workshops and internal idea competitions wherein employees are encouraged to generate many ideas without criticism.

Therefore, these sessions are not targeted and focused on a clear objective, but they provide employees with the freedom to express and explore wild product improvement opportunities. Post the idea-collection phase, management and auditors select some of them to be explored in detail to assess their feasibility. These raw ideas are chosen based on the pre-defined criteria such as goodness of fit to the company's line of business, competitive advantage, novelty, and intuition. The evaluation results in an innovation project portfolio that distributes research and development projects over the short, mid and long term for innovation teams.

According to Ulwick (2016, p. 21), this process is "inherently flawed". He provides three valid reasons to criticise this method. First, the generation of more ideas does not increase the probability to satisfy an unmet customer need. On the contrary, it decreases the possibility of innovation substantially as the innovation's target is absent. The second reason is related to the screening process for selecting the most promising ideas is flawed. Evaluation and filtering criteria cannot be decided without taking the customers unmet needs into account. Lastly, “customers cannot articulate the solutions they want”, which means that the voice of the customer does not reveal the complete requirements of the customer (Ulwick, 2016, p. 24).

Therefore, this approach is not preferred for new product development because it increases risk rather than decreasing it. It also causes problems during feasibility and potential assessment of the ideas because we do not have a criterion against which we can assess its value proposition. It defies the end goal of innovation, that is, to address an unmet need of the market. As a result, there is a slight difference between the stage-gate processes of the ideas first, and the needs first approach.

The figure below provides the different stage- gate approaches used for innovation project selection post the idea generation phase:

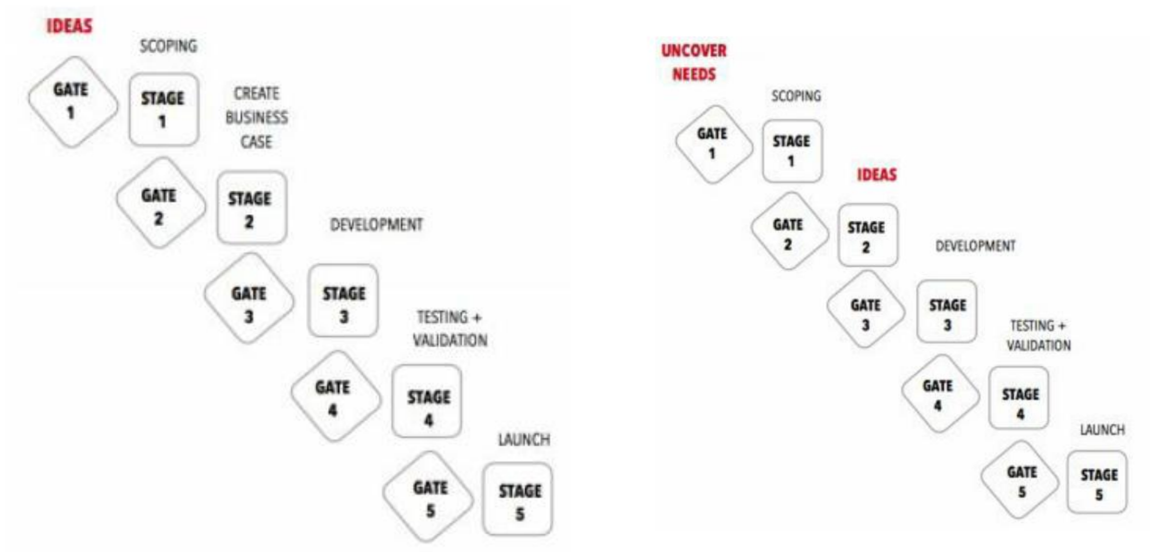


Figure 5. The difference in “Ideas-first” and “needs-first” approach (Ulwick, 2016)

3.1.3 Needs-first approach- an innovation necessity.

In the needs first approach, qualitative methods such as ethnographic studies, focus groups, in-depth interviews, and market surveys are employed to gather and uncover the customer's true needs. The main difference is that ideas are targeted towards the stakeholder's unmet needs rather than brainstorming without an objective. Targeted ideas often yield better results and indicate an efficient innovation process (Ulwick, 2016).

The stage-gate process consists of many phases consisting of various activities. Cross-functional teams carry out these phases, and each activity is carried out parallelly to increase speed to market. The stage-gate process consists of “gates” wherein senior managers or innovation managers make a go-no-go decision to evaluate the projects and decide the project’s future. The gates serve to cancel or redefine projects for those concepts that failed to deliver on their pre-defined objectives. The senior managers and other stakeholders can either kill the project or approve the decision at different stages depending upon the output of each stage (Cooper, 2002).

The innovation process in world-leading companies is divided into several stages. This number may increase or decrease depending upon the project's requirement, size, risk of investment, and market uncertainties. Also, increasing the number of stages may reduce risk as it provides more opportunities for managers to kill projects. However, it also may cost the company in terms of wasted time and effort, decreasing the overall efficiency of the stage-gate process (Grönlund, Sjödin and Frishammar, 2010). Many companies have built their own modified version of the stage-gate process suitable for their business and innovation departments. However, the stage-gate process's macro-level activities remain the same (Grönlund, Sjödin and Frishammar, 2010).

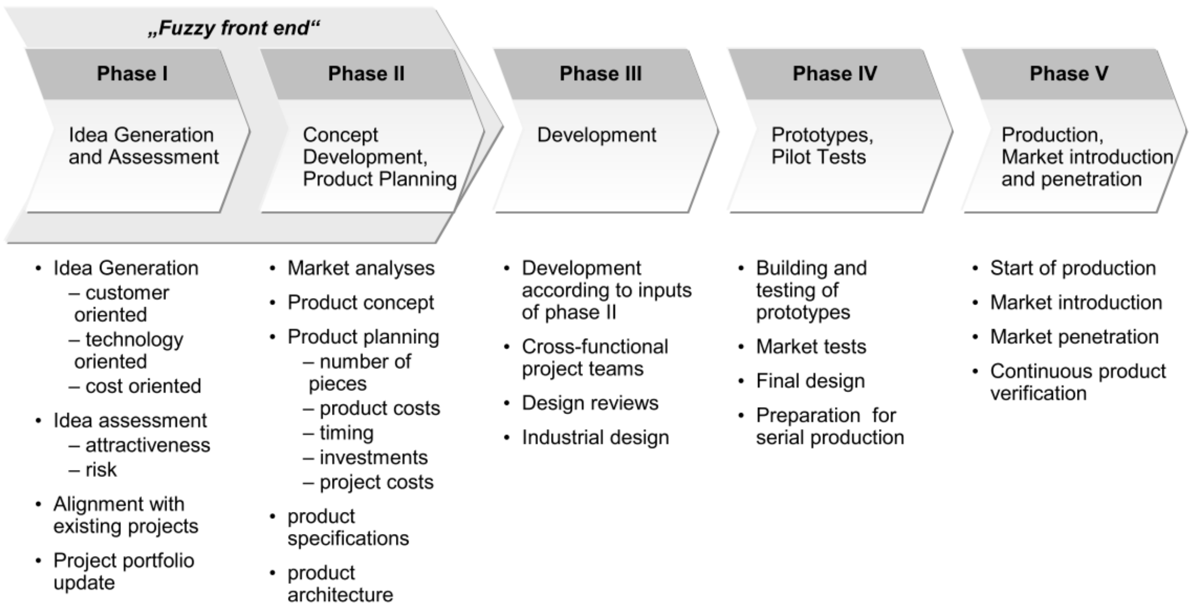


Figure 6. Stage gate process of innovation (Herstatt and Verworn, 2003)

Stage I- Idea generation and assessment

Although the figure shows that the first stage begins with idea generation, it is often preceded by gathering the appropriate stakeholder's requirements and needs. This stage is often known as opportunity recognition (needs-first approach) (Ulwick, 2016). The marketing teams gather the "voice of the customer" to establish a goal for the innovation departments to focus on. This is followed by an idea generation phase wherein cross-functional teams generate ideas for the product based on the customer's gathered needs. This stage is often divergent, wherein teams generate a vast number of ideas using different idea generation tools and methodologies such as brainstorming, morphological analysis, scamper, design thinking, brain writing and TRIZ, to name a few (Haiba, Elbassiti and Ajhoun, 2017).

A preliminary screening of ideas is performed, rejecting those that are not technically feasible or require significant resources to implement. Those that genuinely have good profit potential are selected and move on to the next stage. This stage is the first feasibility check that is performed throughout the stage-gate process. Here, the stage's nature is "convergent", wherein we try to filter out ideas that most likely will fail or do not have sufficient potential to create value for stakeholders. This innovation phase is also known as the fuzzy front end, where there is too much uncertainty regarding an idea success or failure (Herstatt and Verworn, 2003). The preliminary assessment of ideas performed is mainly based on the companies' domain knowledge and capabilities; thus, this part of the innovation process is very flexible. There is no rigid process or methodical approach that is applied at the end of stage I.

Stage II: Concept development and product planning

Stage II begins with the development of ideas and ends with the most promising ideas chosen for commercialisation. In this step, the fuzzy front end is set to end and is followed by the product development's concrete stage-gate process. The raw ideas that pass the preliminary screening at stage I typically lack precision, concreteness and are highly subject to change. They are converted into concretised practical concepts. Factual data and evidence support the concept development phase to prove the idea's feasibility. This phase consists of multiple small activities such as substantiation by research papers, asking experts, hiring consultants that possess the domain expertise, running numerical calculations and performing virtual simulations.

Amid stage II, it is necessary to select the most promising concepts for stage III. This is one of the most critical stages in the stage-gate process. Concepts that are not practically (mainly based on engineering constraints) feasible are eliminated. Evaluation and selection are critical at this stage due to the expensive implementation phase that follows it (Horton, Goers and

Knoll, 2016). Typically, the evaluation of projects is based on different methods employed by the organisation.

Relationship between concept evaluation and business feasibility

New products' success depends significantly on the product design that can make profits and be produced efficiently (Okudan and Tauhid, 2008). Many concept alternatives are generated during the concept development phase in NPD, assuming all concepts address the market's unmet need. Later, it is necessary to converge and select the best concepts amongst the proposed alternatives. At early design phases, innovation teams must consider the product functionality and manufacturing process and its costs, assembly of products, reliability, life-cycle assessment, and recently added sustainability considerations. Research suggests that 80% of the cost may be committed at this stage as it moves from concept development to implementation phases (Okudan and Tauhid, 2008). Once a product concept moves to prototype phases, it challenging for companies to back out and kill the project at late stages (Okudan and Tauhid, 2008).

A decision must be made at this stage to select the most promising concepts for stage III. This is one of the most important stages in the stage-gate process. The cost of each stage increases as we move forward in the innovation process. As a result, innovation teams must now commit and reduce the uncertainties to manage risk. This is one of the reasons for performing an in-depth feasibility study of the project.

Additionally, technical feasibility is not enough to justify the success of the new product. There are many technologies, products and innovation projects that are technically feasible and pass all the checklists. However, they are not feasible for a business to operate due to many different factors (Lyubomirskiy *et al.*, 2014). Some key macro-level factors are listed below:

- Economic limitations: It may be expensive to manufacture the product and economically unfeasible.
- Market limitations: The technology may be ahead of its time that poses a threat to business due to low market readiness even though the product addresses some unmet need. Therefore, market acceptance is low, and the product fails.

- Manufacturing limitations: The new product's manufacturing process either does not exist or is very difficult to manufacture commercially.
- Legislative limits: There may be legal limitations that prohibit using a product component that can cause failure to commercialize.
- Lack of market need and competition: a product does not address an unmet market need sufficiently. It may be because the customer does not need such a product.
- Unsuitable business model and value chain: perhaps one of the most prominent reasons for failure is the product's lack of value capture.

Therefore, a feasibility study is defined as a tool that supports technical, economic, and financial bases as an aid for decision-making, allowing us to choose whether we must continue to invest in the project. The feasibility study precedes the business plan, representing a less complex and faster means of analysing a business opportunity from the point of view of its viability, establishing whether it is worth it to continue the efforts for its capitalization (Ioan, 2010). Concept selection acts as the first step towards business feasibility from the technical perspective but is not limited by it. Some business, economic or financial factors may also be considered during concept selection.

3.1.4 Requirements for a concept/project selection model for a feasibility study

The appropriate choice to invest in projects is essential to run a sustained business. Typically, project portfolio management consists of project selection, whereas product development consists of idea or concept selection stages. In the scope of this thesis, we use the words concepts and projects interchangeably. This is mainly because the QEA tool is applicable to project portfolio analysis and idea screening. According to Meredith and Mantel, the same selection process can be applied to an organisation that requires specific selection out of competitive alternatives. Therefore, the theory that applies to project selection also applies to concept selection (Meredith and Mantel, 2009).

Project selection is defined "as the process of evaluating proposed projects or group of projects and then choosing to implement some set of them so that the parent organisation's objectives will be achieved" (Meredith and Mantel, 2009, p. 2). Applying this definition to concept selection may be remodelled as a process of evaluating a set of concepts and choosing some of them to fulfil the parent organisation's objectives (Meredith and Mantel, 2009).

This section explains different tools and techniques used for concept selection. However, it is necessary to understand the prerequisites needed to create such a model. Meredith and Mantel explain some critical characteristics of the project selection model. They are as follows:

1. Realism: the project selection model must reflect the reality of the firm's situation. This includes physical limitations such as access to capital, personal, technical risks, and market risks.
2. Capability: the project selection model must consider multiple factors that once and must possess the ability to incorporate various variables.
3. Flexibility: the model must give valid results in different changing situations and a wide range of application.
4. Ease of use: the model must be convenient to use and must not take long to implement. It should be understandable and easy to execute without requiring additional interpretation or data gathering.
5. Cost: the initial setup cost of the model and running cost of the model must be relatively low compared to the cost of the project.
6. Easy computerisation: the model must have the ability to operate on a computer database that is widely available such as Excel.

3.2 Review of feasibility study techniques and methods

Extensive research has been conducted comparing 48 different selection methods to assess the feasibility and potential of a concept (Mikkola, 2001). This research includes financial analysis, probabilistic models, strategic models, scoring models, optimisation, real options, scenario-based approaches and bubble plots. Nevertheless, methods continue to be developed with minor improvements over existing standards. (Chaparro *et.al*, 2019; Phadnis, 2020).

Concept selection models have been reviewed multiple times in research ranging from simple criteria-based scoring methods to complex computerised fuzzy logic-based mathematical programs. Badri *et al.*, 2001 provides a detailed comparison of 13 concept selection methods that include scoring models, priority ranking, mathematic programming, analytical hierarchal process, fuzzy logic game theory approach, decision trees and Delphi technique.

Meredith and Mantel, 2009 explain five concept selection models that include different financial analysis techniques, scoring and prioritisation models. Okuda and Tauhid, 2008 provide a detailed literature review for all concept selection methods published between 1980 and 2008 to provide advantages and limitations of each method. Other studies have provided as many as thirty techniques for concept selection and provide state-of-the-art to compare and contrast the different evaluation methods used during the stage-gate process (Ribeiro, 2015). Moreover, TRIZ and open innovation based concept selection models have bought novelty in concept selection phases to provide an idea landscape over the short, mid and long term to innovation management (Phadnis, 2020). Some of the newer approaches for concept selection also include hybridisation of two or more models to provide better results, thereby increasing the pool of concept selection methods further. Figure 7 provides classifications for concept selection models reviewed from 1980 to 2010. These classifications contain more methods to assess a concept and its feasibility, allowing decision-makers to invest more and predict success in the market.

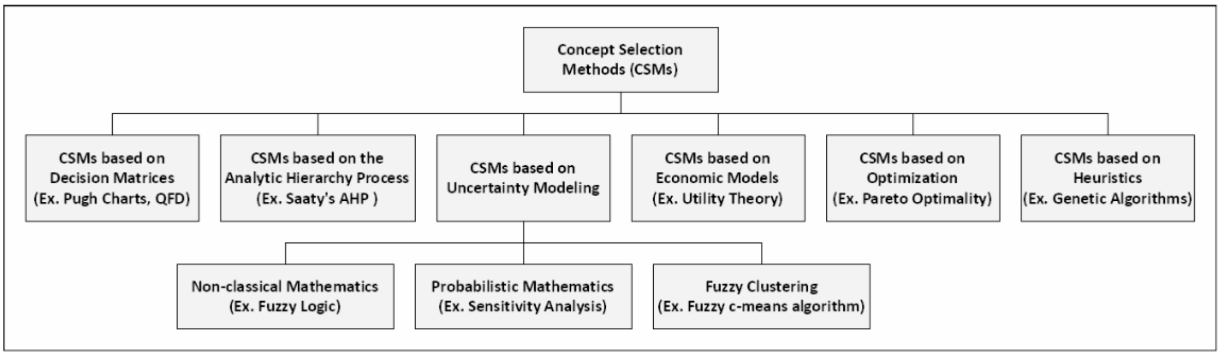


Figure 7. Categorization of concept selection models (Okudan and Tauhid, 2008)

The addition of new research makes it challenging to cover all the techniques under this thesis's scope. Therefore, we will consider and provide a brief overview of the most frequently used evaluation techniques.

An empirical study conducted by Cooper *et al.* in 2001 reveals the most frequently used portfolio selection methods. Figure 8 below identifies the most popular innovation portfolio selection models as financial methods. Financial methods mainly include calculating the Net Present Value (NPV), Internal Rate of Return (IRR) and Return on Investment (ROI) and payback periods of the project. Interestingly, these financial evaluation methods were more dominant among the worst-performing companies than the best-performing ones. On the other hand, successful companies focused more on business strategy or the goodness of fit of a project that aligns with the company goals. Criteria based scoring model was also identified as the most dominant method due to its ability to combine strategic and financial criteria (Ribeiro, 2015; Cooper, Edgett and Kleinschmidt, 2001).

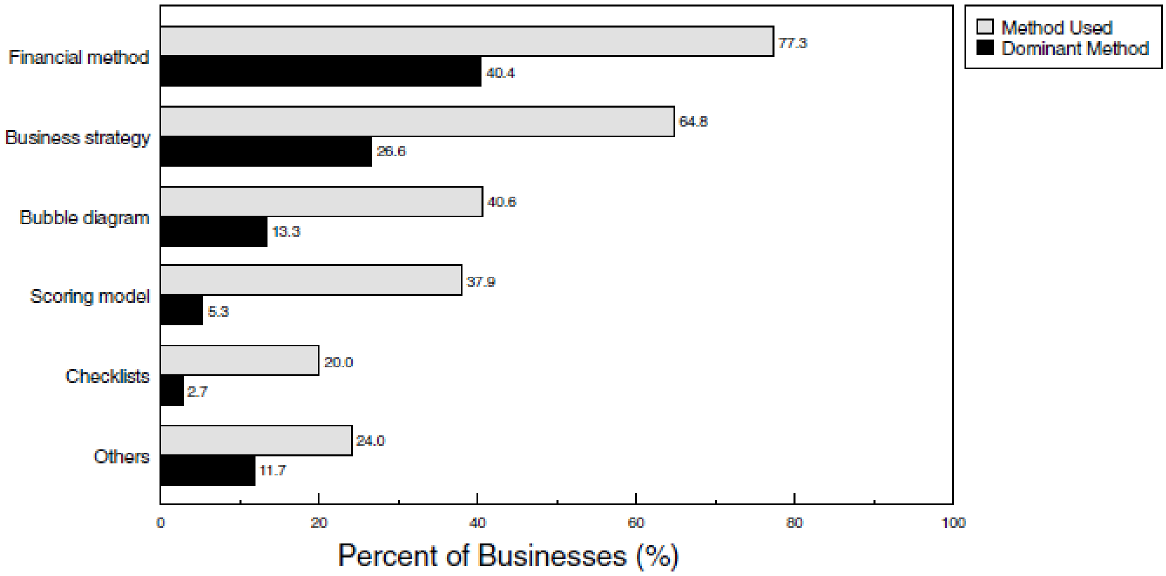


Figure 8. The popularity of different project selection models(Cooper, Edgett and Kleinschmidt, 2001)

3.2.1 Financial methods

Portfolio management using financial methods is considered one of the most important out of all methods because they are oriented towards any organisation's primary goal. These techniques are focused on maximising returns, research, and development productivity and achieving financial objectives set by the organisation. Making the most money, maintaining competitive positions in a business and effective resource allocation is considered as the core of innovation even today (Cooper, Edgett and Kleinschmidt, 2001). Techniques such as ROI, NPV and payback periods are used to prioritise and rank projects against each other to make a go/kill decision.

Meredith and Mantel (2009) present advantages and disadvantages of financial techniques used for project evaluations:

Advantages:

1. one of the main reasons why financial techniques are used is that most stakeholders are easy to use and understanding, acting as a common language for decision-making. Moreover, they are computerised and speedy to provide results.
2. Determination of cash flows for projects is easy through already available accounting data.
3. The output of these methods acts as a common language between decision-makers of the organisation, allowing them to make an “absolute” go/no-go decision. Often, decisions are clear and concrete.
4. Profit models are adjustable and can account for different risk factors in a project.

Disadvantages:

1. Financial models ignore non-monetary factors and intangibles.
2. The internal rate of return model can result in multiple solutions.
3. Financial models ignore cost versus benefit theory.
4. Payback type models ignore cash flows beyond payback periods.
5. Discounting models are non-linear, and the error in variables or parameters is not accounted for by decision-makers.
6. All financial models are based on an input that teams provide. Based on which we develop a cash flow determination, it is equally important to assess these models' input for reliable results.
7. Models that reduce cash flows to present value are strongly biased towards the short run.
8. Financial projections are easy to manipulate and adjust. It is straightforward to miss the demand in the market. As a result, the expected number of sales may be wrong, and therefore the cash flows depicted may be flawed.

3.2.2 Business strategy methods

In this method, a business strategy is decided, and money is allocated across different projects in buckets. The senior management forcibly splits money across different dimensions, such as product line, market segments, type of the project, et cetera. 6 to 10 buckets are created with spending limitations within each split. Lastly, projects are ranked based on either scoring methods, financial index and an expected commercial value of the project that is calculated before performing this method. This approach is also known as strategic buckets, wherein decision-makers collaborate and reach a consensus upon a project go/no-go decision.

There are no formal approaches that are used for business strategy alignment with innovation projects. Therefore, projects are not systematically ranked and prioritised, making the method subjective to the organisation. These techniques are often integrated within the scoring models under "goodness of fit" with the company's vision, mission, and goals. A study conducted by Cooper *et al.*, (2001) reveals that 64.8% of businesses use a strategic approach to select their projects portfolio. Table 3 shows an example of four splits, and within each split, there are 6 to 10 projects that are ranked. Therefore, this method forces organisations to measure their business strategy and align it with research and development expenditure. Some of the advantages and disadvantages are listed below (Jałocha and Wojtanowska, 2019; Cooper, Edgett and Kleinschmidt, 2001):

Table 3. Example of Strategic Buckets Method (Cooper, Edgett and Kleinschmidt, 2001)

New Products: Product Line A Target Spend: $8.7M	**New Products: Product Line B Target Spend: $18.5M**	**Maintenance of Business: Product Lines A & B Target Spend: $10.8M**	**Cost Reductions: All Products Target Spend: $7.8M**
Project A 4.1	Project B 2.2	Project E 1.2	Project I 1.9
Project C 2.1	Project D 4.5	Project G 0.8	Project M 2.4
Project F 1.7	Project K 2.3	Project H 0.7	Project N 0.7
Project L 0.5	Project T 3.7	Project J 1.5	Project P 1.4
Project X 1.7	**Gap = 5.8**	Project Q 4.8	Project S 1.6
Project Y 2.9		Project R 1.5	Project U 1.0
Project Z 4.5		Project V 2.5	Project AA 1.2
Project BB 2.6		Project W 2.1	

Advantages:

1. This model can effectively link business strategy and spending together in an integrated framework.
2. It comes for a limited nature of resources within an organisation, constraints and compromises between projects that consume these resources.
3. This model shows a wide range of applicability for new product development, product renewal projects, process improvement projects and is robust against different project types.

4. It can be easily applied to concept selection within an innovation project. If the organisation is interested in multiple concepts to be tried out and prototyped, different budgets can be located using this method.
5. It allows the organisation to “not kill” but explore different possibilities and opportunities they can create, resulting in a resource optimised portfolio.

Disadvantages:

1. The method is time-consuming and requires significant efforts from management in terms of implementation.
2. The method is only applicable if projects exist as the point of departure.

3.2.3 Bubble diagrams and matrix methods

Managers have strongly recommended using bubble plots and matrix plots for an effective supporting decision tool that is set to yield appropriate portfolio decisions. Graphical representation also allows senior managers to visualise and understand the entire portfolio of products in the same plane. Projects are categorised according to a quadrant or a zone post-analysis. Typically, the bubble's size represents the nature of resource allocation (significant or minimal) required to complete a project. Resource estimations can be based on previous projects.

Research suggests that 40.6% of businesses use portfolio maps to map out all possible selection and evaluation opportunities (Cooper, Edgett and Kleinschmidt, 2001). Matrices support decision-makers to find the right balance of portfolio projects in a unique way where it is possible to map projects into specific categories that depend on each other. Table 4 below shows the popularity of bubble plots in descending order. We see that risk versus reward matrix plots are among the most popular companies (Jałocha and Wojtanowska, 2019; Cooper, Edgett and Kleinschmidt, 2001).

Table 4. Different bubble/Matrix plots ranked by popularity in descending order(Cooper, Edgett and Kleinschmidt, 2001).

Rank	Type of Chart	Axis		Axis	%
1	Risk Vs. Reward	Reward: NPV, IRR, benefits after years of launch; market value	BY	Probability of success (technical, commercial)	44.4
2	Newness	Technical newness	BY	Market Newness	11.1
3	Ease Vs. Attractiveness	Technical feasibility	BY	Market attractiveness (growth potential, consumer appeal, general, attractiveness, life cycle)	11.1
4	Strengths Vs. Attractiveness	Competitive position (strengths)	BY	Attractiveness (market growth, technical maturity, years to implementation)	11.1
5	Cost Vs. Timing	Cost to implement	BY	Time to impact	9.7
6	Strategic Vs. Benefit	Strategic focus or fit	BY	Business intent, NPV, financial fit, attractiveness	8.9
7	Cost Vs. Benefit	Cumulative reward	By	Cumulative development costs	5.6

Figure 9 below shows the most popular risk versus reward matrix wherein, probability of technical success is on the Y-axis and the net present value (representing the market estimations) is on the X-axis.

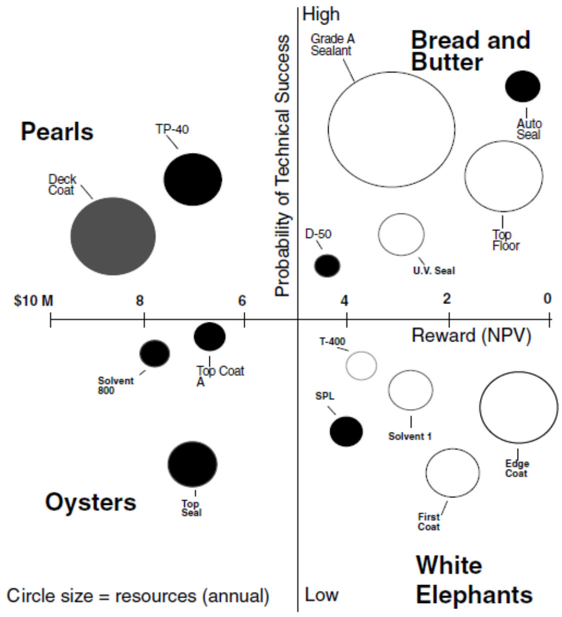


Figure 9. Typical Risk vs Reward plot(Cooper, Edgett and Kleinschmidt, 2001)

In figure 9, the bread-and-butter quadrant shows a high probability of technical success and low net present value. This means that these types of projects are incremental innovation projects that are done daily (no brainer projects) (Jałocha and Wojtanowska, 2019). The Pearl quadrant represents a high probability of technical success but high on rewards; this implies that companies must capitalise on these opportunities and win the market through these projects (Jałocha and Wojtanowska, 2019). The white elephant quadrant shows a low probability of technical success and low rewards. Companies must either drop these projects or ideas or identify new markets for them and capitalise in niche segments. Lastly, the oyster's quadrant shows a low probability of technical success and high rewards. Organisations must consider these opportunities as long-term commercial projects where research and development due diligence of new technologies overcome technical barriers for the technology to improve its functionality and improve its technical success (Jałocha and Wojtanowska, 2019).

3.2.4 Scoring models

The concepts are rated and are ranked according to a specifically selected criterion. This may be a Likert scale, low-and medium-high or scores from 0-10. Scoring models can vary according to the information requirement and complexity to evaluate concepts. They can be divided into three different categories. The unweighted 0-1 factor model, wherein the concept addresses a parameter or a requirement, gets a score of one. The method is very similar to a checklist. Secondly, the unweighted scoring model where scores allocated from the predefined scale. Thirdly, the most commonly used one is the weighted average or weighted factor scoring model, where a coefficient of importance is predefined and established. Ideas are rated based on a predefined scale. During the evaluation, the idea's score is multiplied by the coefficient of the importance of the criteria, and a summation of ratings is a final score for making ranking and selection decisions. According to Cooper et al. (2001), 37.9% of businesses use these models to select concepts. Research indicates a high dominance of this method and acceptance in research and development industries. The scoring method is rated as one of the most effective and efficient decision supporting system (Cooper, Edgett and Kleinschmidt, 2001).

Table 5 below shows the method of weighted averages. An importance coefficient is decided for the selected criteria, and scores are given jointly by team members. Ideas and concepts are selected based on final scores. The highest final score translates to the best idea.

Table 5. Example of the weighted scoring model (Meredith and Mantel, 2009)

Alternatives	*Appearance (0.10)*	*Braking (0.07)*	*Comfort (0.17)*	*Cost, operating (0.12)*	*Cost, original (0.24)*	*Handling (0.17)*	*Reliability (0.12)*	$\Sigma s_{ij}w_j$
Leviathan 8	3 × 0.10 = 0.30	1 × 0.07 = 0.07	4 × 0.17 = 0.68	2 × 0.12 = 0.24	1 × 0.24 = 0.24	2 × 0.17 = 0.34	3 × 0.12 = 0.36	2.23
NuevoEcon	3 × 0.10 = 0.30	3 × 0.07 = 0.21	2 × 0.17 = 0.34	5 × 0.12 = 0.60	4 × 0.24 = 0.96	2 × 0.17 = 0.34	4 × 0.12 = 0.48	3.23
Maxivan	2 × 0.10 = 0.20	1 × 0.07 = 0.07	4 × 0.17 = 0.68	4 × 0.12 = 0.48	3 × 0.24 = 0.72	1 × 0.17 = 0.17	3 × 0.12 = 0.36	2.68
Sporticar 100	5 × 0.10 = 0.50	4 × 0.07 = 0.28	3 × 0.17 = 0.51	2 × 0.12 = 0.24	2 × 0.24 = 0.48	5 × 0.17 = 0.85	2 × 0.12 = 0.24	3.10
Ritzy 300	4 × 0.10 = 0.40	5 × 0.07 = 0.35	5 × 0.17 = 0.85	2 × 0.12 = 0.24	1 × 0.24 = 0.24	4 × 0.17 = 0.68	5 × 0.12 = 0.60	3.36

However, it is important to note that this method depends strictly upon the criteria that the organisation defined. The criteria used for scoring models can be divided into many groups, namely strategy-oriented, financial, market perspectives, internal organisation perspective, project specifications and intangibles (Ribeiro, 2015). Moreover, these criteria are adaptable and are subject to change based on the company and the manager's subjectivity (Ribeiro, 2015).

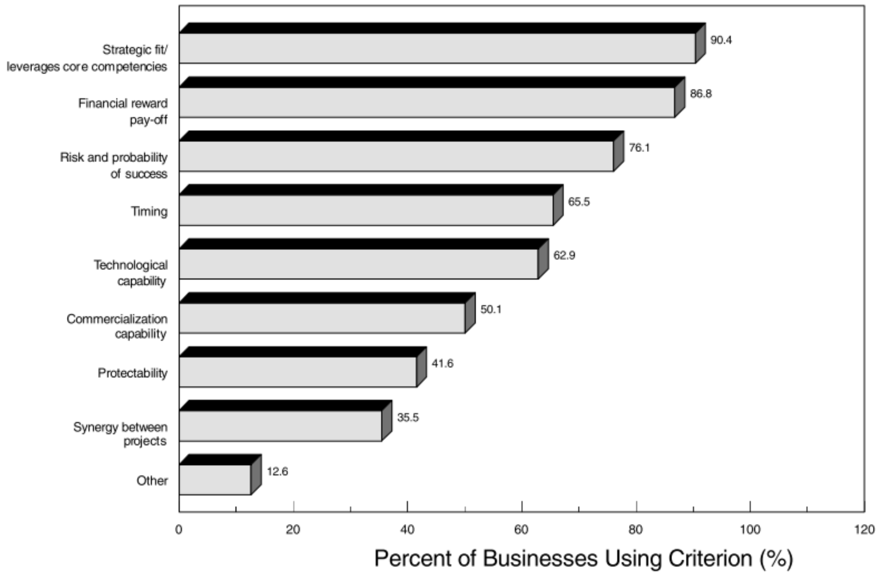


Figure 10. The popularity of criteria used to rank concepts (Cooper, Edgett and Kleinschmidt, 2001).

Figure 10 shows the popularity of the most frequently used criteria for scoring models. This research indicates that strategic fit and leveraging core competencies coupled with financial payoffs and probability of success are the most frequently used in companies (Cooper, Edgett and Kleinschmidt, 2001). Ribeiro, 2015 studies the existing literature and provides a common framework presenting a detailed breakdown of different types of criteria used in the innovation industry to evaluate an idea. All potential criteria used to assess ideas and concepts are shown in figure 11.

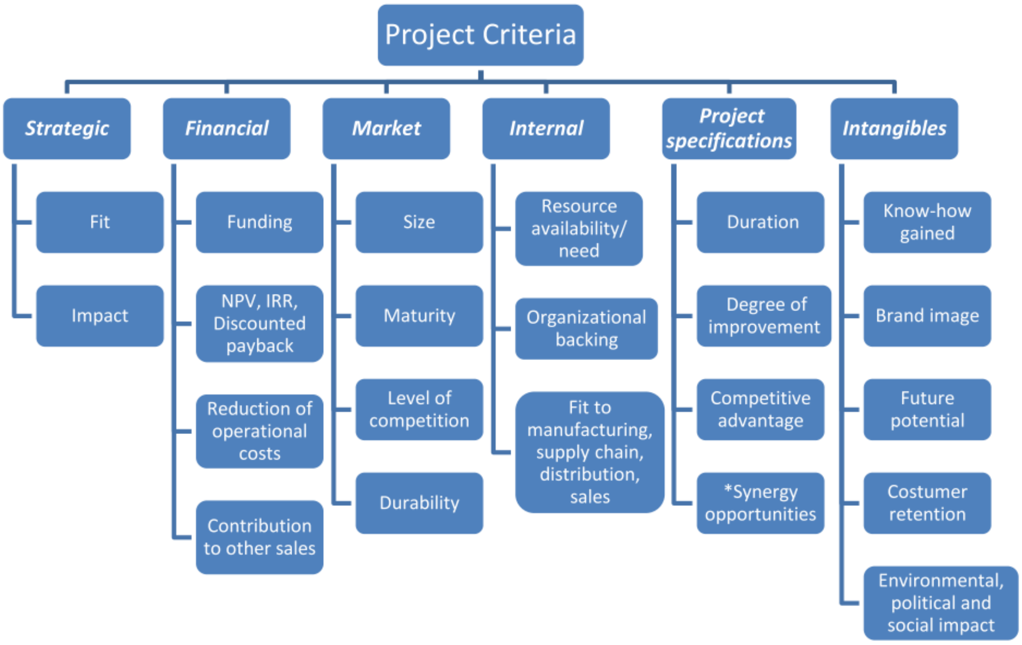


Figure 11. Potential criteria assessing the feasibility (Ribeiro, 2015)

Advantages:

- The flexibility of the tool is one of its most significant benefits. Multiple criteria can be integrated into the scoring model and can be interchanged whenever necessary
- Scoring models are easy to understand and operationalise in corporate culture.
- These models reflect managerial policies in the organisation and can be easily modified.
- The relative importance of the criteria can be considered in a scoring model
- The scoring model allows for sensitivity analysis as compromises between different criteria are readily noticeable.

Disadvantages:

- The concept rating is a relative measure and therefore does not indicate its absolute value. This method does not directly indicate the decision to be made for the go/Kill stage.
- Scoring models are linear, and unfortunately, innovation is nonlinear.
- Often, if there are many criteria, then most of them have small, weighted scores; therefore, they have very little importance on the total score for ranking.

- In the unweighted system, the model assumes that all criteria have an equal "level of importance", which is not true.
- When financial factors such as profitability and net present value are considered, this model gains advantages and disadvantages of earlier profitability models.

3.2.5 Risk

Often risk and uncertainty are terms that are used interchangeably in many different contexts. In many innovations, projects risk is analysed and estimated according to three key parameters. The outcome uncertainty, the degree of control we have over it, and its impact on the project performance (Ilevbare, 2013). The distance between what resources are available versus what resources are necessary is called the outcome uncertainty. These resources may consist of knowledge, skills, competencies, infrastructure and many different factors required for an innovation to succeed, but an organisation may not have them. The wider this gap, the "riskier" is the project (Ilevbare, 2013). On the contrary, estimation of risk and its controllability can be used to mitigate and positively impact outcome uncertainty (Ribeiro, 2015).

Risk is treated as a criterion within a scoring model, checklist, or other mentioned methods to evaluate a concept. Many times, we also associate risk-related parameters with the probability of project success. This is further divided into technical and commercial success factors, which are once again considered within scoring models or criteria used in weighted average methods (Ilevbare, 2013).

3.3 Identified Factor two: Strategy and synergy

The goal of each organisation is to maximise its economic return and sustain it in the long term. To achieve this, the firm needs to create value through innovation through technologies, products, and many other offerings. The purpose of having an organisational strategy is to define how the organisation intends to create this value. Reconception (a phase where a significant resource commitment is required) is said to be the most useful phase of strategic planning in the current context of value creation, early conceptual stages and front-end directly become the best candidates to create a strategy or a roadmap (Mintzberg,1990). In this reference, the term "strategy" stands to explain the formalisation of the fuzzy front end into stages, with well-controlled and monitored key performance indicators, planning and employing the fuzzy front end managers to produce the best possible output in this phase. An

FFE strategy is dedicated to reducing risk and uncertainty quickly and collect relevant know-how in the shortest possible frame of time to reach the organisation's objectives (Hüsig and Kohn, 2003). Research indicates that a strategy's impact is significant if it is integrated within the core business processes where decisions are made, and budgets are allocated. Further, an FFE strategy can support decision-making in complex situations and high uncertainty to create a long term impact (Phaal, Simonse and Ouden, 2008).

Empirical research supports this finding and indicates that a low degree of newness to the firm and a low level of innovativeness for the new product are highly likely to succeed, as seen in figure 12 (Hüsig and Kohn, 2003). This shows the lowest levels of uncertainty are statistically the most successful because there is no risk involved; however, the level of innovation is lower. Perhaps even insufficient, because if it is known to the market, chances are your competitor also knows about it, and it will not be an innovation any more (Jałocha and Wojtanowska, 2019).

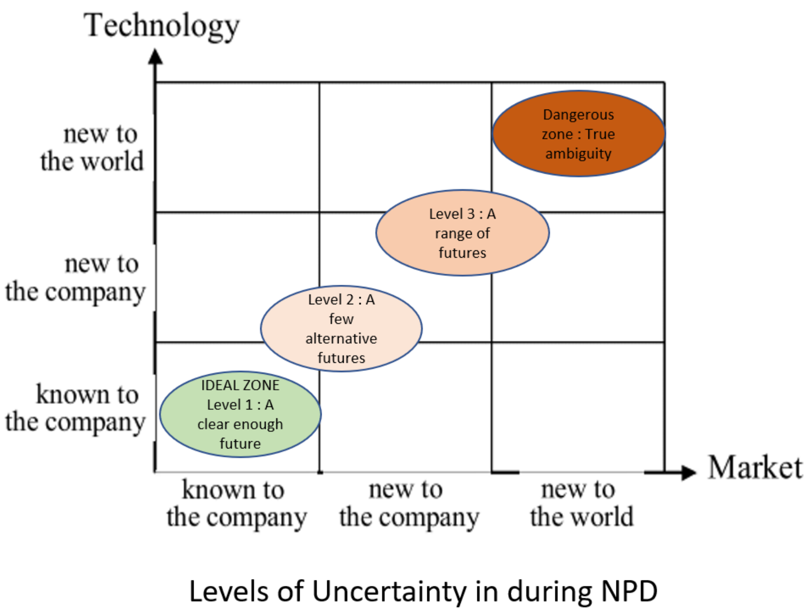


Figure 12. Forms of uncertainty in NPD adapted from Jałocha and Wojtanowska, 2019 and Courtney *et.al* 1997

It is necessary to understand that strategy and synergy do not relate to business strategy or product strategies. Synergy relates those ideas and concepts that resonate with the organisation's product portfolio. Project portfolio management (PPM) is defined as "a set of processes, supported by people and tools to guide the enterprise in selecting the right projects and the right number of projects and maintaining a portfolio of projects that will maximise the enterprise strategic goals, efficient use of resources, stakeholder satisfaction and the bottom line" (Levine,2005, p. 89). PPM is a way to reduce the risk of failure and invest only in the most promising innovation projects, product lines and products to delegate resources towards it.

The innovation project portfolio is a stage that begins before the NPD wherein product strategies and roadmaps are created for short, mid as well as a long-term. Organisations plan specific projects towards specific markets that seem fit to their core competencies. The innovation industry uses many matrices such as risk versus reward, BCG matrix, McKinsey matrix to create such innovation project portfolios. The objective of creating a portfolio is not to determine its business strategy or business model but to have a general vision and answer questions like what this product should do, which market it should address and do we have enough resources to make it succeed. There is plenty of research explaining project portfolio management and innovation portfolio creation (Jałocha and Wojtanowska, 2019). However, innovation project portfolio management is kept out of scope for this research.

During the feasibility assessment and concept selection, it is necessary to check the idea's strategic fit with the firm's existing competencies, products, and technology synergies. Literature also indicates a more market-related perspective and its alignment with company strategy. The selected concepts and ideas must create new market opportunities or serve existing markets without misaligning an organisation's competency (Hüsig and Kohn, 2003). However, it does not mean that solutions that are outside one's domain must not be considered at all. For example, the automotive industry will be constrained to look at automotive solutions and ideas for their projects. They will prefer these solutions because of their core competency, knowledge domain expertise where they feel comfortable implementing such solutions. However, a problem in the automotive industry can be solved by a chemical-based solution, acoustic-based solutions, or something outside the mechanical industry. This does not mean that the concept does not have potential; it simply means that companies are not comfortable working with something they lack knowledge about. Therefore, they are hesitant to take these ideas forward into implementation phases.

TYPE 1	TYPE 2
When solutions of one technical challenge can be applicable to another	When existing solutions, technologies, and materials used in production of one product may benefit the development of another
If some products interact, the technical challenge for one of them can be eliminated by changing another	When problems with one product may actually serve as solutions for another
TYPE 3	TYPE 4

Figure 13. Types of Synergies for solutions (Verbitsky and Casey, 2008)

An analogy to synergy can be, "How many birds can you get with one stone". There are different types of synergies to consider in the selection of ideas. Synergy shows how solutions obtained for one product potentially benefit the other. Figure 13 shows different synergy types that should be considered when we screen ideas and align them to the company's product portfolio (Verbitsky and Casey, 2008).

3.3.1 Strategy and synergy incorporated in concept screening.

Earlier in figure 11, the concept screening criteria begins with "strategy" and is later divided into subcategories such as "fit" and "impact". Strategy and Synergy are incorporated within concept screening methods as an independent criterion against which ideas are assessed.

To further enhance the process, each criterion is sometimes also assigned a level of performance ranging from 1 to 5. To reduce the subjectivity of concept selection, clearly defined definitions for five levels of performance determine their scores. These descriptors of performance act as a support system and reduce some subjective bias during the evaluation. The impact of an idea can be described by its areas of application and can have descriptors of performance, as shown in figure 14.

Level of performance	Areas of Application
5	Idea can be utilized for different markets that you serve or different businesses and new markets that you do not currently serve.
4	Idea can be used in different markets that you currently serve for different products and categories.
3	Idea can be used and replicated for different product categories of the same market
2	Idea can be used for different Products of the same product categories of the same market
1	Idea is focused on the existing market and to make the product slightly more efficient”

Figure 14. Criteria based on areas of application of an idea (Phadnis, 2020)

On the other hand, many project portfolio management matrices such as BCG and McKinsey use a market's profitability versus relative market share to create visual bubble plots during the PPM phase. A criterion can be created based on profitability, as seen in figure 15, and those ideas that get the highest points will automatically be aligned with the project portfolio. Figure 15 shows an example for the criteria of the market with five predefined levels and scores.

Levels	Description
L1	*Highly profitable and growing market*
L2	*Profitable and growing market*
L3	*Highly profitable but stagnated market*
L4	*Profitable but stagnated market*
L5	*Profitable but declining market*
[good]	*Highly profitable but stagnated market*
[neutral]	*Profitable but stagnated market*

Figure 15. An illustration of a descriptor of performance for a Market(Ribeiro, 2015)

3.4 Summary of the section and research gap from the innovation process perspective

Until this point, we have seen the two main factors in the FFE that relate to the success of new products: potential assessment and feasibility and synergy of concepts with product portfolio. However, none of them talk about predicting or forecasting success in all the existing literature and empirical studies performed. We try and create combinations of tools to screen ideas and concepts based on different criteria, as seen above from the most popular methods. Yet, we fail to predict success reliably.

Nevertheless, the most critical issue is the lack of a plan or a roadmap for ideas before a feasibility study. To elaborate on this, today, companies spend a significant amount of time and money explicitly on proving the feasibility of an idea with many financial ratios, calculations, application of audit analysis and many other methods that we have seen above. And yet, companies have launched products and have failed to create the expected outcome that they initially envisaged, or the projects have died during its implementation.

QEA can address this problem by eliminating bad combinations of product stages, market and company stages (objective) by analysing them as a combined system. It can help companies save time, money, and resources to eliminate the need to perform an in-depth feasibility study for failing ideas.

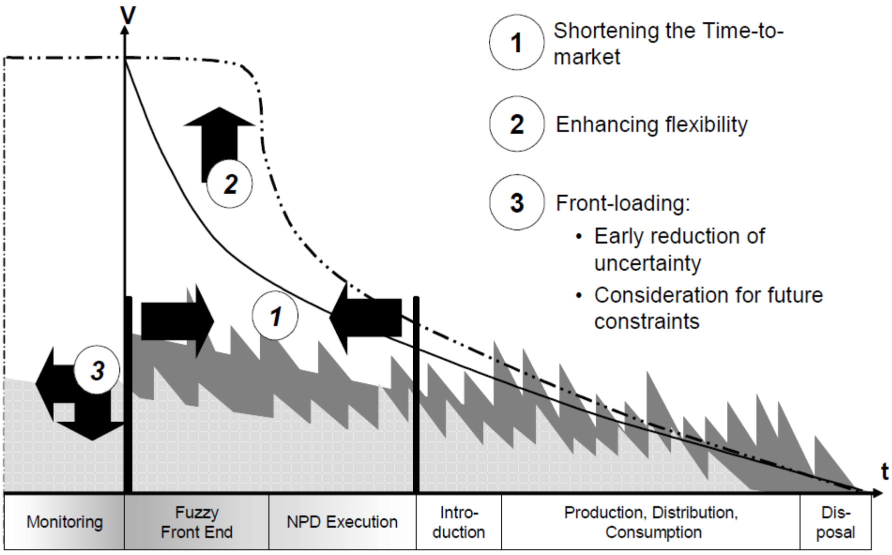


Figure 16. Front end strategies identified by researchers to react to uncertainty challenges (Jetter, 2003)

Researchers identified three main strategies to reduce uncertainty in innovation's funnel, as shown in figure 16 (Jetter, 2003). Reducing time to market is traditionally done by faster cycles of NPD to ensure that customers' requirements and product technologies don't change during development. Engineering activities are sped up, overlapped, and executed in cross-functional teams to improve information transfers and reduce unnecessary corrective actions during product development. Increasing flexibility is achieved through modular product architectures. This concept is again very similar to how many birds can we get with the same stone. Modularity is achieved through flexible design and production technologies and parallel tasks on alternative concepts, and late freezes in design. Another way to achieve flexibility lowering the initial investment and allocating time and money towards uncertain activities such as probing and learning (Jetter, 2003). Finally, frontloading problem-solving activities reduces sequential loads on other teams and tackles the issue of interdependencies by anticipating future constraints at the earliest point in time (Jetter, 2003).

This research goes one step further and complements Jetter’s (2003) finding that improves modularity, frontloading of problem-solving, and shortening time to market. In typical situations, ideas and concepts are selected to go through prototyping and scale-up. Business development activities such as creating a business model, strategy, value propositions are only developed once-solid proof that the concept works in the real world. At this point, it is no longer an idea but a working prototype. Business development teams typically need to wait until the prototype stage to start their work. This means that some parts in the stage-gate process are sequential. The task of business development and creating strategies cannot begin until an idea has been proven to work. The QEA tool could potentially serve as a solution to the above situation by front-loading some business development phase activities before the prototyping phase.

4 Open innovation and strategies

This section will give an overview of open innovation, inbound, outbound, and coupled open innovation processes and their different mechanisms to create value. The section will also identify some of the limitations of open innovation in the fuzzy front end in the context of innovation management and decision-makers that practice open innovation.

Ever since Henry Chesbrough coined the name “open innovation” (OI) in 2003, it became the new normal for the 21st century. Google scholar shows over 6000 citations since the original publication of open innovation was released, along with academia being aligned with the paradigms of open innovation paves the way for research in innovation management by creating specialised issues and journals specifically dedicated towards this topic (Chesbrough, Vanhaverbeke and West, 2014). OI, as it stands, is defined as “a distributed innovation process based on purposively managed knowledge and flows across organisational boundaries, using pecuniary and nonpecuniary mechanisms in line with the organisation’s business model” (Chesbrough and Bogers, 2014 , p. 27). The general abstract and understanding of open innovation is the value created by external knowledge both inside and outside firms’ organisational boundaries.

Today, OI in academia covers a wide range of themes, including strategy, product development, innovation processes, toolkits and users; its limitations are risks and costs, universities, environmental contexts, individual and form organisations, networking, industrial sector and national institutions (Chesbrough, Vanhaverbeke and West, 2014).

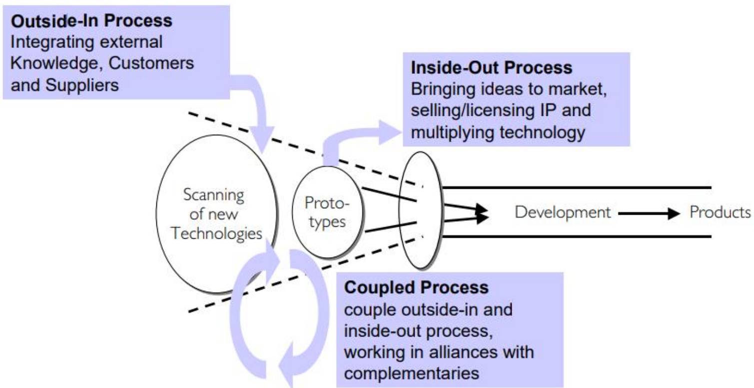


Figure 17. Three archetypes of Open Innovation (Gassmann and Enkel, 2004)

4.1 Inbound open innovation

OI is broadly categorised into three processes, namely, inbound, outbound and coupled open innovation. Inbound OI is defined as the inflow of ideas, knowledge, innovation, technologies through a porous border of an organisation in all stages of the innovation process. Inbound OI is mainly practised for an efficient R and D process by saving time and money by avoiding the wheel's reinvention. Moreover, it is also seen to have a higher degree of novelty and accelerates the ability to breach markets. Inbound open innovation can happen through many different mechanisms (Gassmann and Enkel, 2007).

Figure 18 shows many types of inbound OI activities or mechanisms that could benefit an organisation and accelerate innovation according to the popularity of adoption.

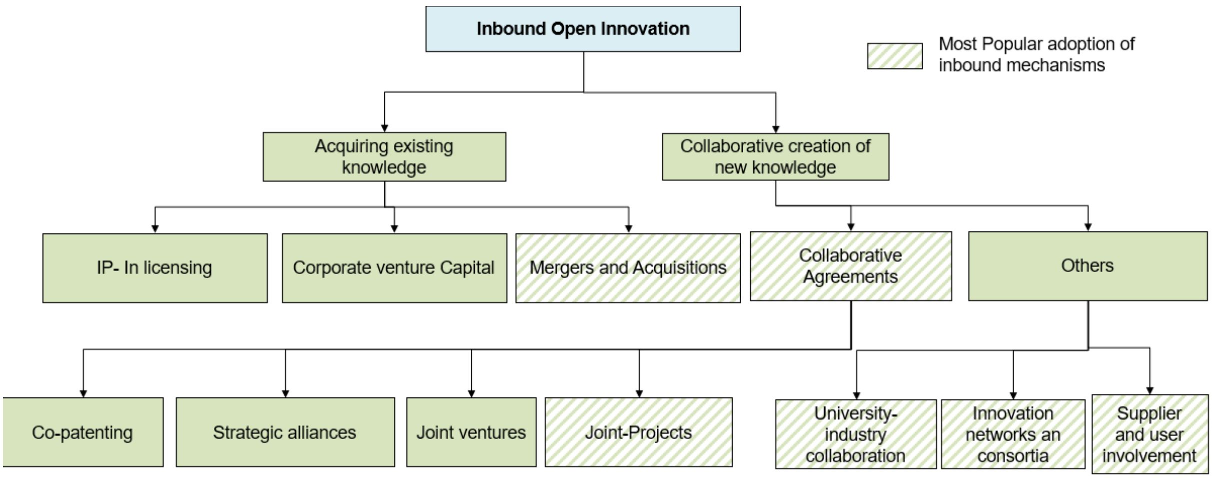


Figure 18. The intensity of adoption of inbound OI activities adopted from Dabrowska *et al.*, 2016

This figure shows that inbound OI has been adopted widely for creating new knowledge through collaborative efforts more than acquiring existing knowledge. The OI-Net project data comprises 51 partners from 35 European countries comprising of more than 500 companies that provide the adoption of open innovation activities in their organisation. The data shows that almost 70% of the companies use OI actively. Within this category, IP in-licensing and crowdsourcing were least intensively adopted out of all the inbound OI mechanisms. Table 6 provides an overview of the inbound OI practice and their understandings (Chesbrough, Vanhaverbeke and West, 2014).

Table 6. Inbound Open Innovation mechanisms (Chesbrough and Brunswicker, 2014)

Inbound practicies	
Consumer and customer co-creation	Involvement of consumers or customers in the generation, evaluation, and testing of novel ideas for products, services, processes, or even business models
Information networking	Networking with other organizations without a formal contractual relationship, e.g., at conferences or events, to access external knowledge
University research grants	Funding of external research projects by researchers and scientists in universities (faculty, PhD students, or postdoctoral fellows) to access external knowledge
Publicly funded R&D consortia	Participation in R&D consortia with other public or private organizations in which R&D activities are fully or partly funded by governmental organizations (e.g., European Commission or National Science Foundation)
Contracting with external R&D service providers	Contracting with external service providers for specialized R&D services, including technology scouting, virtual prototyping, etc.
Idea and start-up competitions	Invitation to entrepreneurial teams and start-ups to submit business ideas via open competitive calls, with collaboration and venture support to winning teams
IP in-licensing	Licensing of external intellectual property rights (e.g., trademarks, patents, etc.) via formal licensing agreements
Supplier innovation awards	Invitation of existing suppliers to participate in innovation and submit innovative ideas
Crowdsourcing	Outsourcing innovation problem solving (including scientific problems) via an open call to external organizations and individuals to submit ideas
Specialized services from OI intermediaries	Contracting services of intermediary organizations specialized in open innovation to act as intermediary between a "searcher"-an organization with an open innovation problem-and "solvers"-a network of organizations and individuals with potential solutions

4.2 Outbound open innovation

Outbound OI is defined as an outflow of idea, knowledge, and innovative technologies through the organisation's porous borders and all stages of the innovation process (Gassmann and Enkel, 2007). This category allows for the commercialisation of knowledge assets inside the firm’s organisation and opening it to the outside world. However, it is not about opening up the process aimlessly but with a specific objective realised within a company's strategic fit. Outbound OI can help organisations enter new markets, create new additional products and services, set new standards, gain external knowledge, enhance their reputation, and strengthen its networks (Chesbrough, Vanhaverbeke and West, 2014). Figure 19 shows the outbound governance mechanisms that can drive innovation.

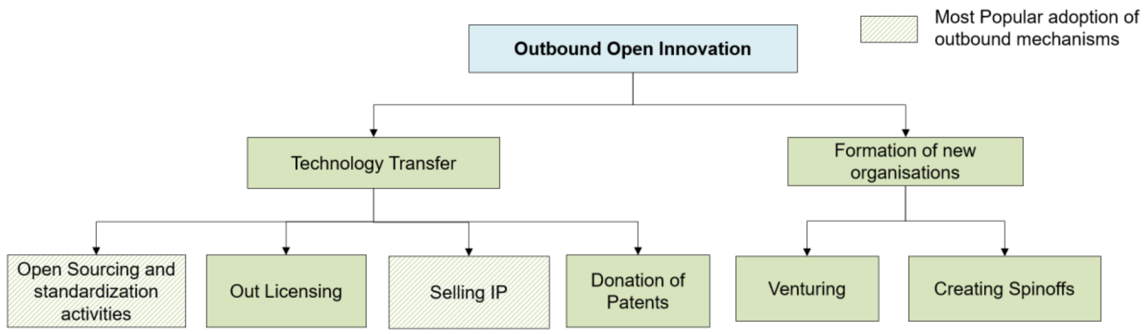


Figure 19. The intensity of adoption of outbound OI activities adopted from Dabrowska *et al.*, 2016

The figure above shows standardisation activities as an outbound mechanism was widely adopted, whereas IP out-licensing and donation of IP (free revealing) to external parties were the least adopted. Table 7 below shows outbound open innovation mechanisms and their overview of activities performed.

Table 7. Outbound Open Innovation mechanisms (Chesbrough and Brunswicker, 2014)

Outbound Practices	
Joint venture activities with external Partners	Strategic and Financial investment in independent ventures
Selling of market-ready products	Sale of market-ready novel product idea to a third party for sale to its customers
Participation in public standardization	Participation in standardization activities via formal standardization agencies (e.g., ISO) or informal standardization consortia (e.g., OASIS)
Corporate business incubation and venturing	Corporate incubators or accelerators developing potentially profitable ideas and offering supportive environments for entrepreneurs inside the organization to identify novel paths to market
IP out-licensing and patient selling	Licensing of internal IP to external organizations via licensing agreements or selling via single payment
Donations to commons or nonprofits	Donations to commons or nonprofits (e.g., open-source communities) to support external R&D
Spinoffs	Investment in new ventures founded by firm's employees outside organizational boundaries

Lastly, coupled OI is the combination of inbound and outbound methods, where knowledge from external parties enters the firm's boundaries and exits the firm's boundaries. Coupled OI creates value from both sides of the innovation process. The categorisations of open innovation were put into a matrix framework with respect to its monetary and nonmonetary considerations by Chesbrough and Brunswicker, 2014. Figure 20 shows the categorisation of various open innovation mechanisms based on the direction of open innovation and financial flows. They were divided into four distinct parts, namely, acquiring, selling, sourcing, and revealing. The matrix below shows different practices mapped according to this pecuniary framework:

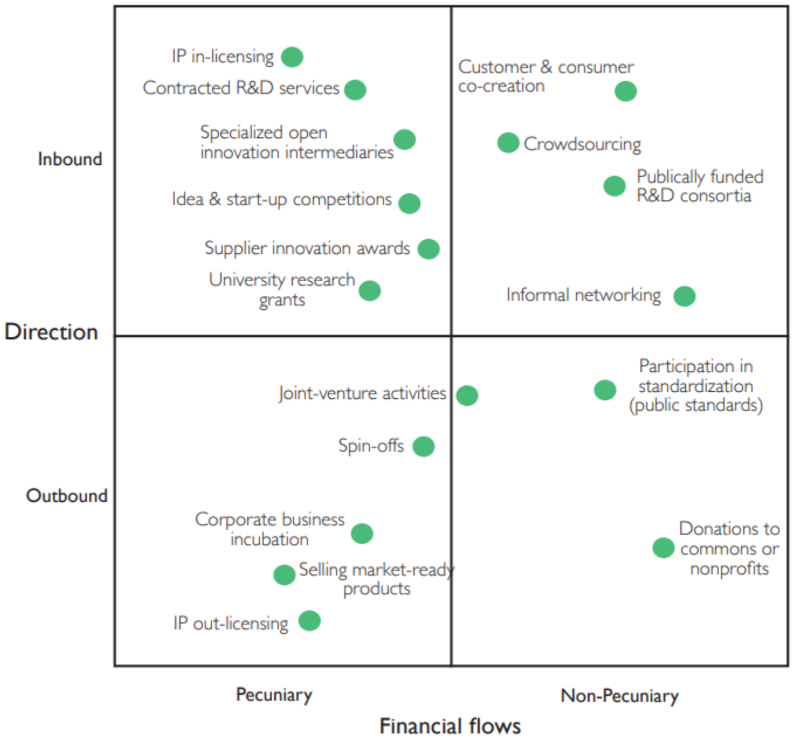


Figure 20. The framework of Inbound and Outbound OI by Chesbrough and Brunswicker (2014)

Acquiring: Quadrant one, pecuniary inbound innovation: is responsible for the acquisition of new knowledge from external partners through mechanisms such as IP in licensing, idea and start-up competitions, supplier innovation awards, university research grants and contracted R&D services

Selling: quadrant two, pecuniary outbound innovation relates to organisations' mechanisms to commercialise their knowledge and bring it to external markets. This may include IP out-licensing, selling market-ready products, corporate business incubations, and creating spin-offs and joint venture activities.

Sourcing: quadrant three, nonpecuniary inbound innovation wherein the company explores and searches for external ideas and knowledge to exhilarate internal R&D.

Revealing: quadrant four, nonpecuniary outbound innovation wherein the company shares its internal knowledge with external partners for free without expecting a monetary return (Chesbrough and Brunswicker, 2014).

4.3 Known challenges of open innovation

On the one hand, open innovation has seen its fair share of success in the industry but is not limited to its many challenges that are also spoken of in literature. Considering the fuzzy front end, the literature states that the pre-invention phase of innovation is one of the most critical phases having the ability to create a significant impact on the whole innovation process that influences design and total cost of innovation (Likar *et al.*, 2014). Moreover, it is also said to have the lowest implementation costs with the least amount of available information.

The existing literature on OI in the FFE attempts to resolve problems in the problem identification phase, generate the appropriate perception for circumstance and deal with insufficient data and information. In all three phases, the OI attribute of co-creation and usage of external and internal competencies is visible. It represents an extreme form of open innovation and enables employees' proactive involvement and external experts to create concrete solutions (Likar *et al.*, 2014). Researchers suggested using the e-supported mass identification of problems and solutions (e-MIPS) method in the problem identification phase, which breaks down a problem into some problems with more precise goals. Later the ideation phase, different methods are used by teams to come up with ideas. Lastly, a criteria-based selection process(where internal and external stakeholders are involved) allows for filtering ideas to bring out the best implementation ideas (Likar *et al.*, 2014).

Additionally, countless research papers identify challenges in the FFE to make the initial stage of innovation more structured and manage it effectively. It highlights several disadvantages such as uncontrolled spill overs, loss of control, increased organisational complexity, managerial costs (Hopkins et al., 2013; Huang et al., 2009; Praest and Mortensen, 2011; Trott and Hartmann, 2009; Vrande et al., 2009). A multidimensional perspective on OI in the front end is provided identifying challenges such as miscommunication of ideas, inappropriate management, general project management issues, many inter-organisational, intangible elements, elements related to IPR and its management and other organisation related factors such as challenges of implementing OI within an organisation and the appropriate degree of openness needed to optimise the “innovation process” (Chesbrough and Brunswicker, 2014; Satu, 2014; Manzini, Lazzarotti and Pellegrini, 2017).

4.4 Summary of the section and research gap from OI perspective

This research addresses one of the major problems with open innovation that has been scarcely explored. It is one of the most critical issues despite the countless research and knowledge on OI. Researchers present theoretical bases but lacked practical methodologies or tools to put them into practice. The main problem with open innovation is that there are so many potential ways of incorporating open innovation for new product development and accelerating innovation (Enkel, Gassmann and Chesbrough, 2009). However, how is a decision-maker supposed to know which one would be the best possible strategy for his product? How do we know which strategy would work for his company? This research addresses a problem that has plagued OI and other innovation methodologies as well, which specific mechanisms/strategy should be used for a particular product.

One might think this is almost impossible, as there can be so many different types of products. All strategies might be applicable in one way or another, given the right circumstances. For such a method to exist, it must be highly generalizable to be universal, applicable to all different types of products, companies, and markets. Additionally, this tool must be reliable, easy to use and implement within the stage-gate process and somehow accelerate speed to market by eliminating the time needed for unnecessary feasibility studies. Lastly, this tool must be robust and should provide a guided roadmap of what a company should do to make a specific product successful for a specific market.

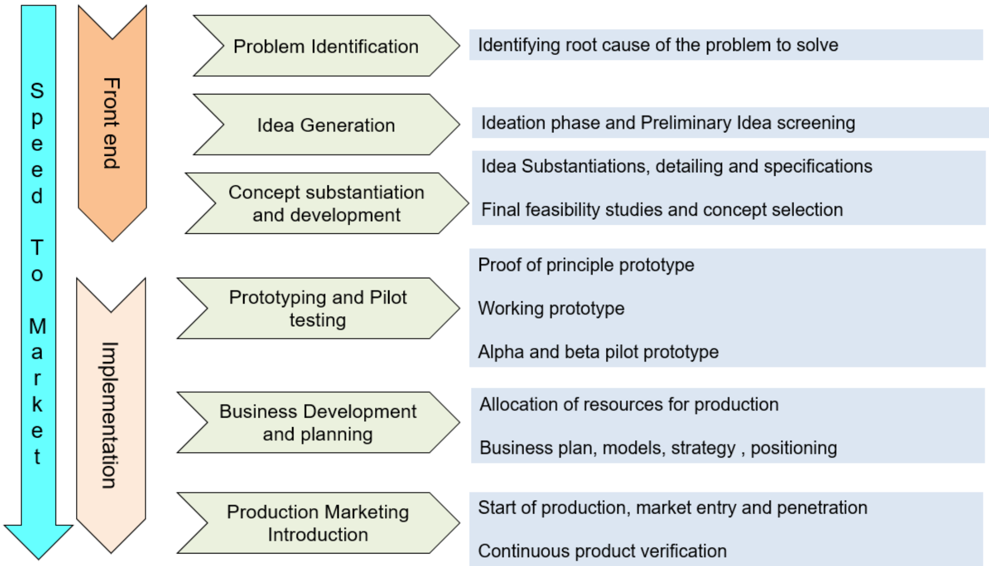


Figure 21. Traditional sequential NPD process

Figure 21 above represents the traditional innovation process where activities occur sequentially, resulting in a longer speed to market. Mainly the business development activities start after the prototyping. This makes sense because the uncertainty is too high at the concept stages; if it does not clear the technical feasibility test, there is no point in the business development phase. However, "front-loading" some business development activities, even though it is preliminary, provide a direction to the company and allows them to see what needs to be done in the upcoming timelines (Jetter, 2003).

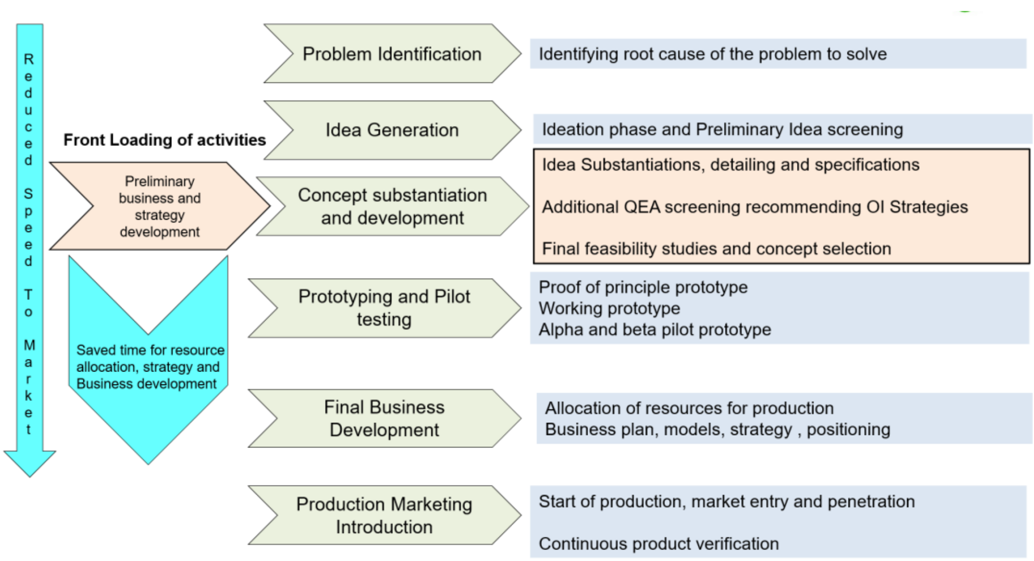


Figure 22. Proposed parallel NPD process incorporating QEA

Figure 22 shows the new proposed NPD process where activities of business development and planning are parallelized. Parallel activities add QEA integrated OI that provides an extra layer of screening to ideas. Quantum economic analysis integrated with the open innovation strategy can provide us with a universal method that can allow us to recommend a specific OI mechanism or a set of mechanisms. As an implication, it could allow decision-makers to make changes, plan ahead of time, delegate necessary resources, create or dissolve organisational structures parallelly while conducting a feasibility study, thereby reducing the time and money required during NPD.

5 Quantum economic analysis

5.1 Why is the analysis "Quantum"?

This section represents a core part of the thesis and explains what Quantum economic analysis is, its history and its theoretical base. It was initially known as a business cube referred to in Vissarion Sibiryakov, a TRIZspecialist from Russia in 2002. Later in 2003, American economists and active investors developed this method, Katzman, Schneider and Topichisvilli and named as Quantum economic analysis. Lastly, in 2012 the business cube method became part of strategic management and was called the business cube meta-strategy (Khlebnikova, Alperovich and Yatsnya, 2012). Therefore, QEA is known by many names such as business cube, idea audit, meta-strategy. The authors of this tool developed it initially to devise brand development strategies (Topchishvili, Katsman and Schneider, 2003). This method helps to identify modifications needed to the company to maximise the probability of business success. Let us understand it from an analogy.

As shown in figure 23, a business system is a delivery mechanism for providing specific products, goods or services to customers. The primary function of the business system is to scale value to customers (Kuryan, 2017). However, the business system comprises many different interrelated and dependent elements that need to interact to create success. It contains factors such as organisation, market, products, and value propositions from competitors. Out of all these elements, within our business scope, we can influence and impact our products and our organisation. Supersystem elements (those that exist outside of what we control) such as the market can be difficult to influence directly as many other competitors challenge it.

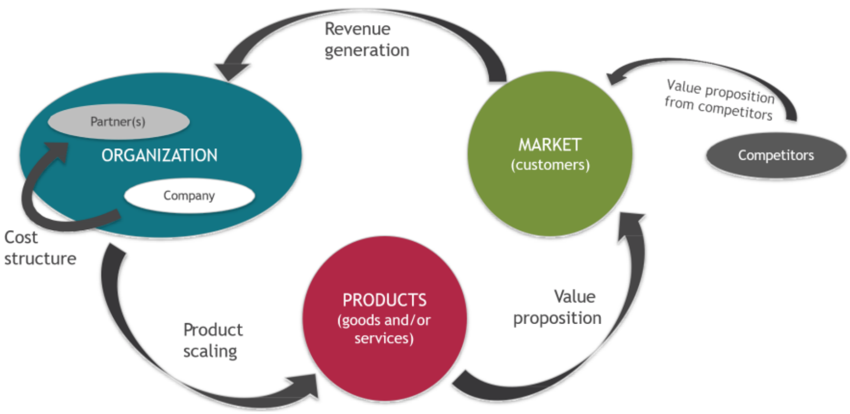


Figure 23. Representation of the business system (Kuryan, 2017)

Since we are considering a business system, the concepts of dynamic systems apply to business as well. “Homeostasis” is a property of a system in which variables are regulated so that internal conditions remained stable and relatively constant. This homeostasis condition must be achieved even within a business system. According to Ashby, (1958, p. 83) “in a business system, homeostasis refers to a company’s ability to maintain its state of equilibrium by counteracting internal and external turbulences through absorption of contextual variety”. The QEA cube addresses this problem and identifies 13 such stable combinations based on evolutionary S-curves between product stages, company stages and market stages.

The name “Quantum economic analysis” was adopted from quantum physics, where the state of a particle can be described as a combination of a quantum number. A particle is allowed to stay in a stable condition only at certain permitted energy levels and cannot enter the forbidden energy states. Similarly, in a business system, a project may fall into one of the permitted states; just like there are forbidden energy states for particles, certain evolutionary combinations are forbidden for business. Moreover, for a particle to move from one energy level to another, it must absorb energy. Similarly, a business must absorb the investment to transition from one state to another. Suppose a business finds itself in a forbidden position in terms of evolutionary levels of the market, product and the company stage. In that case, it will fail, and state targeted actions would be required to put this business in a permitted state and increase its chances of success (Topchishvili, Katsman and Schneider, 2003).

QEA originated from an extensive empirical study conducted by the International Institute of technical and economic rationale (MITEO) that considers hundreds of case studies and data samples. Recently, QEA has been used for new product development in the best TRIZ based consulting companies worldwide. It has been incorporated as a standard in the TRIZ assisted stage-gate process. Abramov, 2017 states that although TRIZ solutions can create the wow effect that their clients have never seen, often the companies and clients are unable to implement the solutions and take them forward towards commercialisation. Therefore, as an additional step of screening better concepts, QEA-based screening is incorporated along with traditional criteria-based screening methods in the early stages of the project (Abramov, 2017). The figure below shows the TRIZ assisted stage-gate process integrated with QEA

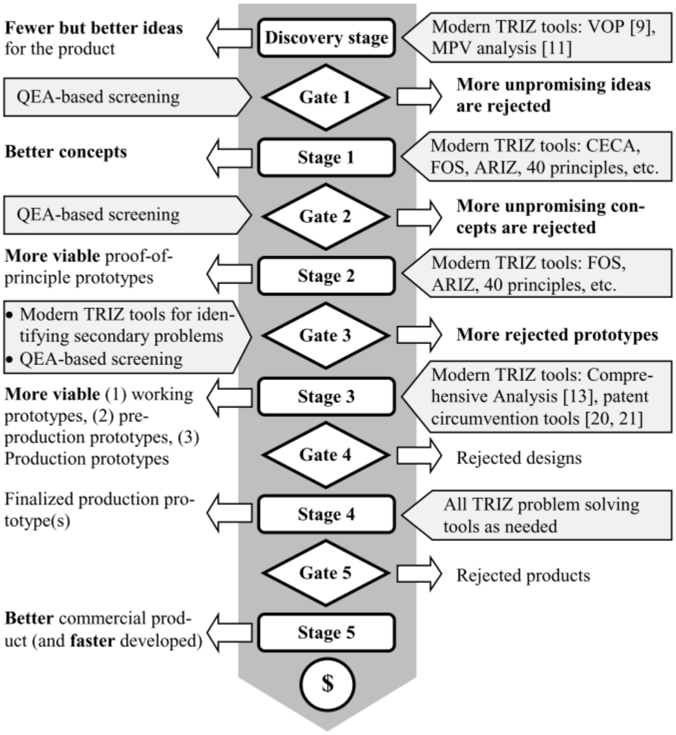


Figure 24. Modern TRIZ assisted stage-gate process (Abramov, 2017)

Additionally, researchers validated QEA extensively to determine its success rate. 143 TRIZ-consulting projects were analysed from 1997 to 2017, with more than 400 feasible solutions delivered to the companies and were tested with the QEA method. As a result, the researchers found a striking 88% success rate where QEA accurately predicted the commercialised solutions and those that the companies did not implement. The solutions that did not make it inside the success rate were also elaborated upon; it was found that the companies' managers were dismissed or the department responsible for NPD was resolved (Abramov, Markosov and Medvedev, 2018). The study concludes that QEA is accurate enough to be utilised in projects for screening.

5.2 Foundation of QEA: Evolutionary S-Curves

In the 21st century, every Business Administration degree will teach students and learners about the S-shaped curve. Originally born in the 19th century by performing experiments in microbiology where researchers placed a colony of bacteria on a petri dish and observed the number of bacteria grow over time. They noticed that was the number of bacteria remains the same in the birth phase, then at a certain point, it starts growing slowly in the beginning and grows exponentially later. The growth rate then slows down eventually as there is no food available for the bacteria, and they start eating each other, leading to death. This story has been heard, repeated and published in countless journals. It was observed by many researchers later that all systems, whether it be artificial or biological, evolve in the natural life cycle following the characteristics of an S-shaped curve (Modis, 2003).

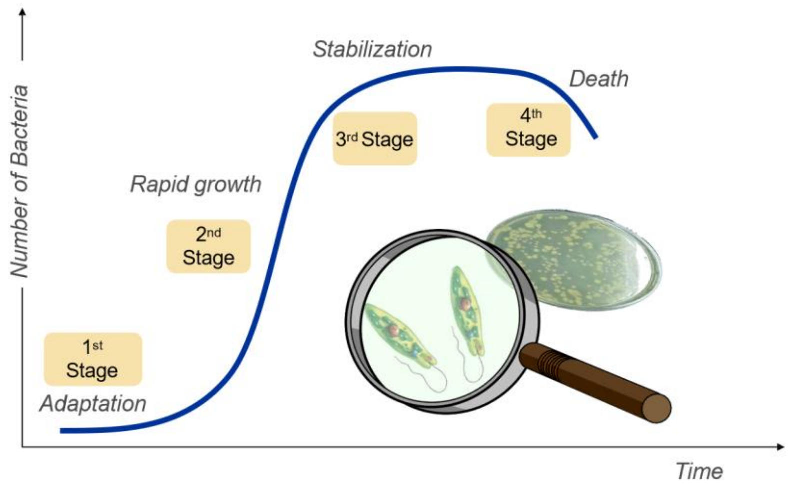


Figure 25. The S-shaped curve for bacteria in 1900s (adopted from Modis,2003)

The S-shaped curve demonstrates a law of natural growth. It has already been proven using mathematical functions by physicists, biologists and industry scholars researching the life cycle of new product development. S-curves are universal and can be used to explain almost any phenomena in the world, as explained by a well-known physicist and leading researcher in the S-curve application (Modis, 2003). Today S-curves are used for technology forecasting and prediction for decision making about investments, strategic planning for long-term forecasts for a product, markets and companies (Dmitry and Guio Roland, 2012). S-curves have been identified in the innovation industry to describe the origin and evolution of radical innovations, incremental innovations, market formations, discontinuous innovations, management styles, and consumer behaviours (Garcia and Calantone, 2002).

Figure 26. Representing technology/marketing S curve phenomenon(Garcia and Calantone, 2002)

For example, figure 26 shows the description of radical innovation as characterised by Foster, 1986. It was stated that radical innovations are those that begin a new S-curve, replacing the old technology. According to Foster, at the beginning of an early research and development program, knowledge bases need to be established. The new product is as good as a prototype with many functionality limitations. Uncertainty in the birth phase is relatively high until the knowledge is acquired. Once the gaps in the knowledge are filled, the pace of the progress and the growth rate increases substantially until a point where the technology itself reaches physical limits, and the performance improvement is minor. The effort required to improve a parameter compared to its return is exponential until a new technology takes over and starts a new S-curve (Garcia and Calantone, 2002).

However, the S-curve application in the industry is flawed due to its poor understandings and interpretations. Practitioners can end up with unreliable and inadequate results most of the time due to the wrong application of the S-curve (Dmitry and Guio Roland, 2012). The problem is that industry experts know about S-curves but do not know how to use them or how do we map our product on the S-curve, limiting its usability and practical applications severely throughout the innovation domain.

In fact, many studies do not even consider the product stage to affect the success of innovation. For example, a highly popular empirical study seen in section 3, conducted to analyse the variables in the fuzzy front end that influence innovation's success, does not account for the stage of the product, technology, and life cycle of the system. Their interaction and influence in the FFE is clearly stated as a limitation in the study and remains unaccounted for (Hüsig and Kohn, 2003). Those studies that do consider the S-curves are often done independently and remain at a theoretical level rather than a practical method that can be used by innovation managers. Therefore, understanding S-curves has become a “good-to-know” skill rather than a standard practice.

Therefore, the next section will explain evolutionary S-curves established for products, companies and market. Each stage of the S-curve for each of the categories has some specific characteristics and traits that have been analysed over the years and proven in practice that innovation managers can identify and use this knowledge to their benefit to create strategic plans and reduce the risk of failure.

5.3 QEA business cube and characteristics

This section elaborates on QEA and describes each stage's S-curve characteristics for the product, market, and company. As we already know from previous sections, there are “Allowed/stable/successful” states and “not allowed/unstable/unsuccessful states” in QEA. Figure 27 shows the QEA business cube wherein the market, company and product are put on three different axes creating a three-dimensional graph. Each axis can have a specific number of stages. This creates a QEA business cube of 60 cells, out of which only 13 are stable or successful (marked by dark grey cells). This indicates that the chances of success are about 21.6 %. If companies continue to create products blindly, we have a very low chance of ending up in the successful combinations (Topchishvili, Katsman and Schneider, 2003;Abramov, 2017).

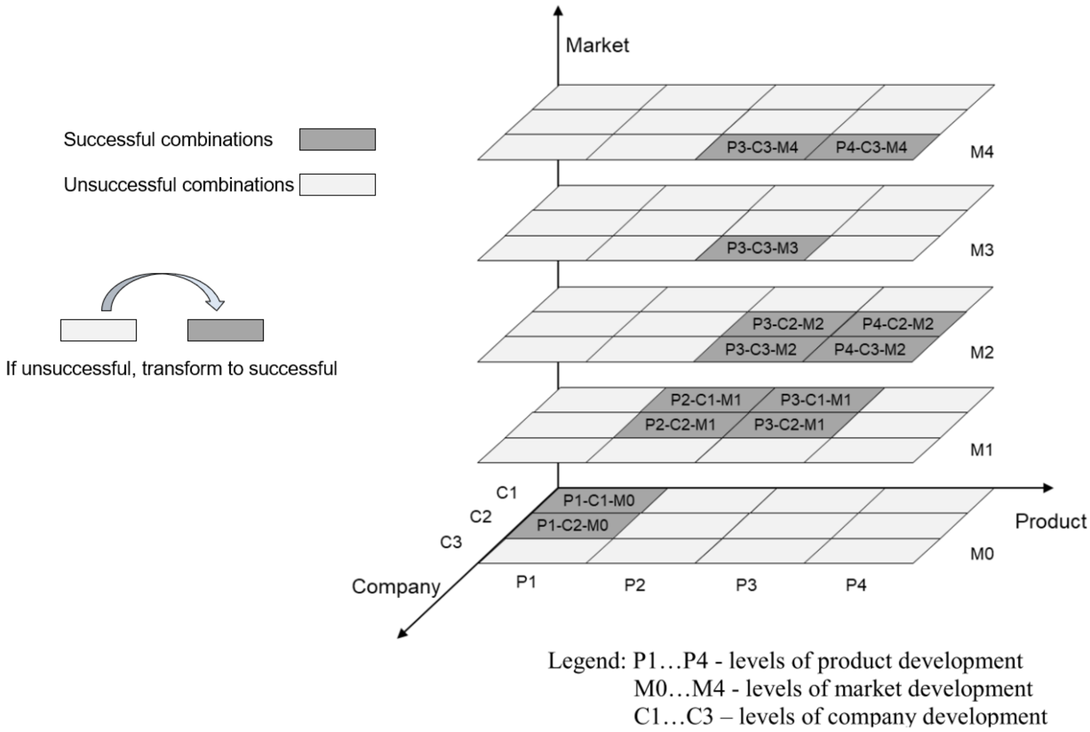


Figure 27. QEA business cube stable states (Abramov, Markosov and Medvedev, 2018)

There are four levels of product stages ranging from P1 to P4, three levels of the company ranging from C1 to C3 and five levels of the market from M0 to M4. The authors of QEA state that "QEA does not predict success, but it can help cut-off those projects that are in the wrong state, allowing investors and decision-makers to focus investments, therefore fewer but better options to maximise success instead of having a deadlock" (Topchishvili, Katsman and Schneider, 2003, p. 43). As seen in figure 27, the allowed set of combinations are P1-C1-M0; P1-C2-M0; P2-C1-M1; P2-C2-M1; P3-C1-M1; P3-C2-M1; P3-C2-M2; P3-C3-M2; P3-C3-M3; P3-C3-M4; P4-C2-M2; P4-C3-M2; P4-C3-M4.

Table 8 shows the QEA characteristics based on the products' stage, companies' stages based on access to capital, and markets stages of determining one of the above combinations. Each stage of each category has well-defined qualitative indicators that fit any product into the QEA business cube.

Table 8. QEA characteristics based on levels of development (Topchishvili, Katsman and Schneider, 2003; Abramov, 2017)

Level of development	Development Level Characteristics		
	Product (P)	Company (C)	Market (M)
0	N/A	N/A	Very few consumers - early adopters only
1	Product level of development is determined as in regular TRIZ S-curve analysis, e.g. as described by Litvin and Lyubomirskiy [10]	Company can access up to $3,000,000 in capital	New consumers appear, but they keep using previous product as well
2		Company can access from $10,000,000 to $100,000,000 in capital	Mass consumer is switching to the new product, completely abandoning previous
3		Company can access over $100,000,000 in capital	All potential consumers are already using new product
4		N/A	Consumers are leaving the market and switching to a newer product

5.4 Determination of developmental stage for products

In the 20th century, the S-curve studies also showed that engineering systems' technical parameters also follow the same pattern along the curve. For example, in the evolution of cars, parameters such as fuel efficiency, safety, steering controllability, and speed can be studied using S-curves. In 1975, Altshuller, the creator of TRIZ, discovered that products and technologies do not evolve randomly and are predictable. They were known as patterns of evolution and today are recognised as Trends of Engineering Systems Evolution (TESE). Modern TRIZ possesses the most comprehensive understanding of the evolution of engineering systems that help us determine our product's stage and recommend a successful product strategy necessary to evolve the product (Lyubomirskiy *et al.*, 2014).

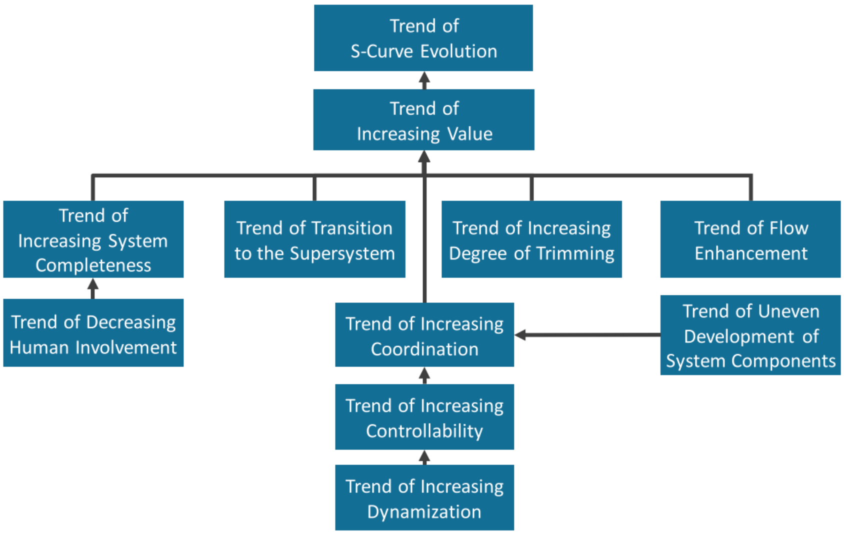


Figure 28. Trends of Engineering Systems Evolution in Modern TRIZ (Lyubomirskiy *et al.*, 2014)

Pragmatic S-curve analysis has identified different indicators, including some based on technological evolution and the market, to provide specific guidelines and aid innovation managers in focusing their R&D efforts and driving good decisions in the innovation process. This section will provide an overview of the trend of increasing value according to the modern TRIZ methods. An S-curve is built not for an entire product but for each main parameter of value of the product. Consumers tend to buy products and make purchase decisions on such parameters such as fuel efficiency, speed, attractiveness, comfort et cetera. In modern age of innovation, Main parameters of Value (MPV) are those parameters that are important and unsatisfied on the market that drive the purchase decision of a consumer. Ideally, each MPV should have its S-curve and later must be integrated to determine the stage of the product (Lyubomirskiy *et al.*, 2014). However, during this research, we use regular TRIZ based S-curve analysis based on the operation principle of the technology of the product.

At a general level, one of the trends, the "trend of increasing value", says that as engineering systems evolve, their value tends to increase over time, not linearly but along the S-curve. The figure below shows a value engineering perspective towards the trend of S-curves wherein functionality divided by cost is shown as an equation invented by Larry Miles, creator of value engineering in 1947.

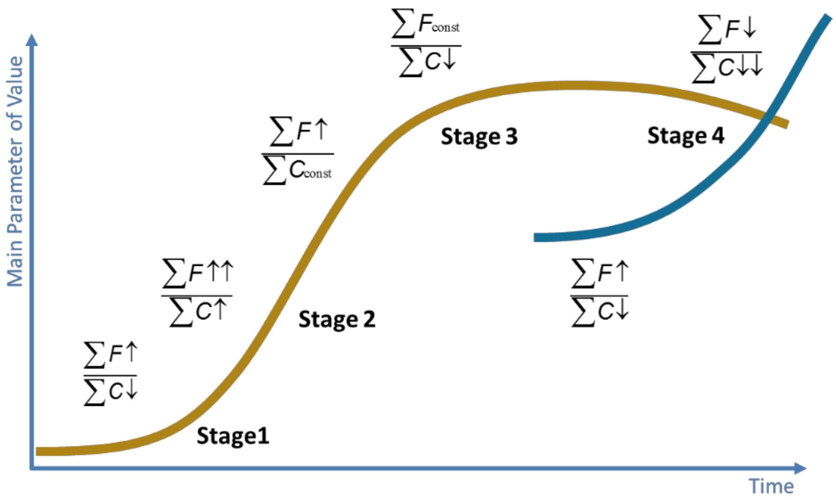


Figure 29. Trend of increasing value (Lyubomirskiy et al., 2014)

Figure 30 shows different stages of the S-curve and functionality and cost factors changing as products evolve. At stage I(infancy) the system is still a prototype and is not very functional. This type of system is not on the market and the only way to increase their value is to improve its functionality and to decrease its costs just enough so that it can enter the market. At the second stage, the product is on the market. To increase its value, we can either improve the functionality while keeping costs constant or increase costs provided the functionality grows proportionally. There will be a point where the product gains incremental functionality at the expense of significant efforts. This means that the product has reached stage III, where the only way to increase its value is cost reduction (assuming the same market).

Lastly, at the death phase, there would be a point where product must be created with inferior functionality but much cheaper. It implies functionality must drop along with heavy cost reduction so it may still make money (Lyubomirskiy *et al.*, 2014). General understanding of functionality over cost gives R&D managers a roadmap of “what not to do” at a particular stage. For an example, from the figure above it is quite clear that if the engineering system is a stage III, we must not focus on functionality but must delegate our efforts towards reducing cost.

Christensen’s commoditisation of the product also supports this theory. Figure 30 shows how every new product turns into a commodity over time.

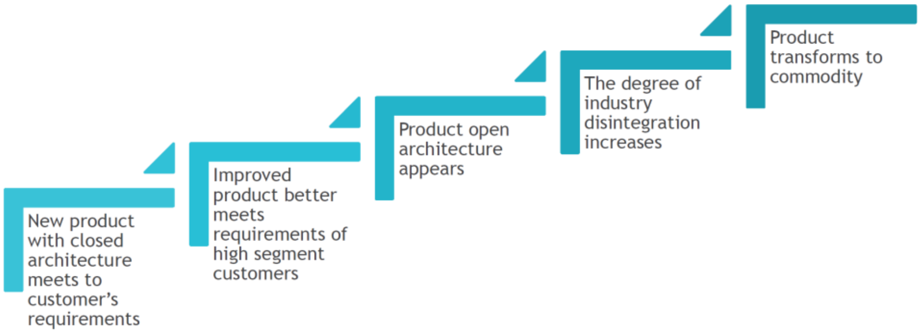


Figure 30. Commoditization of a product during its life cycle (Christensen, 2003)

Christensen's theory complements the above graph where stage I and II are directed towards increasing functionality; however, stage III is specifically focused on cost reduction while keeping functionality constant. At this stage, products become commoditised and are omnipresent in the market (Christensen, 2003).

According to Christensen, 2003 at stage I and II, a new product with a closed architecture is born to meet customer requirements. He explains that it often carries bare minimal functionality for lead users or early adopters that are interested in the product. Slowly, as the product improves and creates value, it gets targeted towards the leading, niche segments of customers. At late stage II, the product architecture opens up so manufacturers and other OEMs can design their offerings specifically for your product creating a fashion house of hundreds of product variants. Lastly, at stage III, the degree of disintegration increases where many different manufacturers position their product differently in different segments at different prices that transform the product into a commodity over time (Christensen, 2003).

5.4.1 Stage I Products: Infancy

Stage I products are typically prototyping and in the lab. These products have not reached production and deliver their function with minimal performance for the very first time. Components are not refined, and there are many iterations and variants experimented on before entering production. The easiest way to recognise a stage I system is that it is absent on the market.

Qualitative indicators of stage I products:

1. Presence on the market: The product is not on the market, is still in lab phases and has not begun production. This is an undoubted case of stage I products.
2. Adaptation of components from other systems: This product needs to adapt components from other engineering systems. Due to a lack of resources, this product will adapt existing already developed components from other areas to fulfil this gap instead of developing everything all by itself.
3. Integration of elements with supersystem: the engineering system uses elements in its infrastructure around it.
4. Lack of financial resources: there is very little money for further development of this product.

Recommendation for stage I products:

1. Selecting the variant of the product that fits the existing infrastructure will succeed.
2. Eliminate bottlenecks and critical factors that stop the product from entering the market. The key idea is it is unnecessary to eliminate all disadvantages of the system but only focused on those points that stop it from entering production. Compromises are acceptable if functionality is delivered at a minimally acceptable level for consumers.
3. The hybridisation of systems: merging the system with the current leading systems is recommended. For example, Hybrid cars combined internal combustion engines and electric motors.
4. Significant modifications: at this stage, it is still possible to fundamentally change the product or operation principle. Consider the physical, technological limits and analyse whether they need to be changed before entering the market (Lyubomirskiy *et al.*, 2014).

5.4.2 Stage II Products: Rapid growth

At stage two, the products MPV's grow at a fast rate. Companies want to hold the product at stage two to generate revenues. More importantly, there is plenty of scope and resources to improve its functionality because it is far from its physical limits. The cost of the product increases with each iteration while the functionality also increases. Specialised components are developed for the product instead of the "adapted" component at an earlier stage.

Qualitative indicators of stage II products:

1. The product is in Mass production (on the market), an increase in production volume is visible, and MPV grows rapidly.
2. The product consumes very specialised resources, components, parts built for it.
3. Many variations of the product appear with different designs and applications for the same product. It acquires many additional functions (those that are delivered to a supersystem other than its target).
4. Engineering system acquires functions close to its main function. For example, gas stations selling only gas now sell additional functions like washings, repairs, maintenance etc.
5. At the end of stage two, the number of variants drop because optimisation of the engineering system starts reaching its limitations.
6. Supersystem (everything the product interacts with) starts to adjust to your product.

Recommendation for stage II products:

1. Optimisation and refinement work for this stage.
2. Expanding the fields of application of the product to other areas, i.e. new markets, is recommended.
3. Minimise the existing disadvantages in the product, improve the efficiency of operation.
4. Adapt the product to utilise specially adapted resources of the super system.
5. Adding new components is as successful as removing components from the product (Lyubomirskiy *et al.*, 2014).

5.4.3 Stage III Products: Maturity

Improving the product's features requires an exponential amount of effort and cost with little to no actual improvement. Physical limitations are reached for the improvement of technology or MPV’s. Many limitations such as economic, user-based, supersystem legal, phycological limits cause stagnation of sales and very slow growth of MPV’s.

Qualitative indicators of stage III products:

1. The product becomes a commodity and is in mass production.
2. The product consumes highly specialised resources and has many variants.

3. The product variations mainly differ in aesthetics and design-based differences and not on technology.
4. The infrastructure around the product includes many components that were just designed for your product. Accessories for your product are prominently visible.
5. Additional functions are added to the product that have nothing to do with the product's main function.

Recommendation for stage III products:

1. The most important recommendation at the near and medium-term is cost reduction and deep trimming in products. It is necessary to throw out components to reduce cost; this can be achieved using radical trimming or delegating your product's functions to the supersystem.
2. It is recommended to develop service components for a product. Those that provide recurring revenue to the company and need maintenance from time to time.
3. Aesthetic changes are recommended to focus on a design and appearance of the product.
4. Jumping to a new S-curve, for that specific MPV is recommended action in the long term. Contradictions need to be resolved to overcome the limits and move to a new S-curve (Lyubomirskiy *et al.*, 2014).

5.4.4 Stage IV products: Decline

At this stage, the product becomes old and does not have enough resources to grow. Production volume drops dramatically coupled with declining revenues. This stage becomes inevitable when younger systems at stage III do not integrate with the product or another stage II product or system pushes your product out of the market. At this stage, your product's functionality is no longer necessary because its function is performed by something else within its vicinity already.

Qualitative indicators for stage IV:

1. Presence on the market: the product cannot survive on the market but may sell in isolated niches. This is the only stage where the MPV goes down.
2. The product loses its utilitarian purpose and turns into means of entertainment, attraction, decoration or toys.
3. Product functions only in the niche market that it has established.

4. The product becomes integrated into other supersystem elements by default.

Recommendations for stage IV:

1. transform the product into cheap disposable products or luxury products at this stage.
2. Switch to new markets and niches where the product can be competitive.
3. Cost reduction and deep trimming, along with aesthetic improvements, should continue similar to stage III.
4. Switching the operation principle, integrating alternative systems to make a jump to the new S-curve is recommended.

5.4.5 Summary of pragmatic S-curve analysis

The trends of engineering systems evolution have originated by studying thousands of patents by extracting common principles and trends irrespective of the company’s domain. If a company knows the MPV’s of its product, S-curve analysis helps us identify the S-curve position and support decision-making for innovation managers. They help us decide the correct path that we must take for our product. Moreover, S-curve analysis can also be used for benchmarking. We can identify our system's future development potential and estimate where it will be in the next few years.

The main use of pragmatic S-curve analysis is to stop managers from making the wrong decisions at the wrong stage. For an example, if we try to improve functionality of a stage III system, it will fail inevitably. Simply because cost reduction while keeping functionality constant is a main recommendation. Moreover, it is also important to know that if a company does not follow these recommendations, some other competitors will. The market will keep evolving towards growing MPV’s and it is up to the organisation to make use of this knowledge and to capitalise on it at the right moment. Figure 31 shows the key indicators that can quickly tell us about an engineering system's position on the S-curve.

	Stage 1	Transitional stage	Stage 2	Stage 3	Stage 4
Presence on the market	no	niche	mass production	mass production	niche
MPV behavior	doesn't grow	grow	grow	doesn't grow	goes down

Figure 31. Major indicators for the stage of a product (Lyubomirskiy *et al.*, 2014)

5.5 Determination of developmental stage of companies

In simple words, the category is consisting of three main stages, namely, C1, C2 and C3. The authors of QEA found a relationship between the management styles, decision-making, innovation processes within the company with access to capital. In the research phase, different industries and companies were analysed. Those companies that had a similar culture, organisational goals, risks, management styles were grouped. Based on its access to capital, we can separate three distinct stages of companies based on their access to capital. The main characteristic that separated companies behaviour and stage of development was their access to capital. Therefore, a company at the C1 stage means that a company can access up to $ 3 million in the capital, a company at the C2 stage and access between 10 million to $100 million in capital whereas, a C3 company can access more than a hundred million dollars in capital. This revolutionary pattern applies to companies independent of the domain (Topchishvili, Katsman and Schneider, 2003). Let us look at some individual characteristics of each of the company stages:

5.5.1 Company at Stage I -(C1)

Objective of the company: At the first stage, the company is a typical start-up, sometimes also known as a “garage” company that can access somewhere between several hundred thousand up to $ 3 million in the capital. The main objective of this company is to develop a new product. At this stage, companies mainly focus on developing their product to develop a working prototype and pitch to investors. In this stage, start-ups try to establish personal contact with the investor or representatives of investment institutions because the product is more in a prototype phase and requires more funding to go into mass manufacturing and commercialisation. For stage, companies can work with stage I, II or III products very well.

Style of decision-making: At this stage, decision-making is dynamic, and decisions are made on the spot. Typically, the decisions are new each time as companies lack experience. However, this allows companies to have freedom of choice where many potential decisions are possible. The work style of these companies is similar to that of an entrepreneur where an individual ability (usually the founder or the idea creator) demonstrates leadership to guide the innovation culture of the team

Trigger mechanism for employees: In this stage, employees of the company mostly are founders themselves, who either take part in the invention or the ideas that they wish to commercialise. Employees in this company are willing to solve the problems by themselves and are independent yet enthusiastic about their product. There are not very disciplined but are willing to take bold and dynamic proactive decisions at early stages to help their product succeed. Table 9 highlights stage I companies' characteristics (Topchishvili, Katsman and Schneider, 2003; Zlotin and Zusman, 2001).

Table 9. Characteristics of Stage I Companies (Zlotin and Zusman, 2001,p. 90)

Feature	Description
Goals of the organization	Develop the business; create a market.
Public relations	Business holds no interest to investors. Customers are unaware of the product/service provided by the organization.
Factors stimulating business development	Personal motivations of those involved in the business.
Factors impeding business development	Lack of resources; no market in place.
Main contradiction	Product/service is potentially very useful, but the public fails to recognize this.
Organization size	Fewer than fifty people.
Management system	***Charismatic*** , based on personal enthusiasm.
Organization structure	Informal; concentrated around the leader, or having several centers each with its own leader.
Organization leader	Informal leader, usually the author/inventor of the product or service; creative, highly respected by organization personnel.
Organization personnel	Creative and enterprising people looking for a unique opportunity.
Main requirements of personnel	Personal reliability, enthusiasm, persistence.
Area of professional knowledge	Not very important; in the process of being established.
Attitude toward personnel initiative	Encouraged in all aspects throughout the business.
Attitude toward mistakes by personnel	Usually not critical; easily corrected; no punishment.
Rules and behavior	In the process of being established; informal, based on precedents.
Rewards	Practically no financial reward, only personal satisfaction in knowing that something of value is being developed.
Prestige	According to creative accomplishments in business and in the organization.
Morale and environment	Good. Benevolent relationships and creative competition.
Attitude toward organization personnel	Informal communication, friendship, cooperation.
Attitude toward external business environment	Attempting to attract people to the business and to join the organization.
Discipline	Voluntary; people are dedicated to the business; no enforcement needed.
Reaction to difficulties, stresses	Consolidation and displacement or removal of unsuitable personnel.
Flow of information	Free, informal, effective.
Language	Simple, without special terminology, able to attract people (popular).
Area where creativity is required	To develop the product/service and the entire business.
Ideas, innovations	Many new important ideas; ideas are easy to implement.

5.5.2 Company at Stage II -(C2)

Objective of the company: At this stage, the companies go public to the stock market to attract investors and increase market value. Stage II companies can access from $ 10 million to $100 million in capital. Companies focus on developing technologies of mass production for their first product and begin development for additional products that would be created based on the first one. They focus on creating an efficient infrastructure and scalable production, quality control processes, sales and customer support systems. Different departments begin to emerge within the company, and hierarchal structures start to be established.

Style of decision-making and management: In this phase, there is clear responsibility and role provided to an individual. There may also be a change in management as the creator and the founder of the company is no longer leading the decision-making (change in leadership) but gets replaced by the authority of professional managers. Corporate culture begins to develop, and decisions are “occasionally” dynamic and on the spot. The corporate culture reflects the style of decision-making, making it independent of an individual's decision. There is a clear division of responsibilities, wherein the organisation incorporates a specific structure, internal relationships and value system. The organisation's size increases with additional people, departments, staff and support services are developed as a part of a restructuring and establishing corporate culture.

Trigger mechanism for employees: the trigger mechanism begins to change into a materialistic part since roles are clearly defined in an organisational structure. Innovations and ideas are more incremental and mediocre from the employees. There is more focus on developing the manufacturing process, services, and products. Table 10 provides some key indicators and characteristics of companies at stage II (Topchishvili, Katsman and Schneider, 2003; Zlotin and Zusman, 2001).

Table 10. Characteristics of Stage II Companies (Zlotin and Zusman, 2001,p. 90)

Feature	Description
Goals of the organization	Develop the business; increase and develop the market and the organization itself.
Public relations	Investors are interested in the business. Customers are interested in the product/service provided by the organization.
Factors stimulating business development	Investors are interested in the business. Customers are interested in the product/service provided by the organization
Factors impeding business development	Unable to quickly utilize resources; much time spent searching for new ideas using Trial-and-Error.
Main contradiction	Structuring the organization helps to develop the business but moves the organization toward Stage 3.
Organization size	50 - 1000 employees and growing.
Management system	***Economic*** with some ***charismatic*** and ***administrative*** elements.
Organization structure	Simple formal, with hierarchical and horizontal links.
Organization leader	Formal leader with professional background, good communication skills, respected by organization personnel.
Organization personnel	People from Stage 1, along with professionals and auxiliary personnel.
Main requirements of personnel	Educated professional; having controlled initiative.
Area of professional knowledge	Directed, dynamic, in-depth
Attitude toward personnel initiative	Encouraged only within the scope of the assignment
Attitude toward mistakes by personnel	No punishment for mistakes resulting from good intentions. Inaction is not appreciated.
Rules and behavior	In the process of formalization yet easy to understand and accept; directed toward business and the prosperity of the organization.
Rewards	Continued personal satisfaction plus adequate salary or other material reward according to accomplishments.
Prestige	According to accomplishments
Morale and environment	Normal. Good cooperation and honest competition.
Attitude toward organization personnel	Informal communication. Establishment of seniority system once organization hierarchy is built.
Attitude toward external business environment	Selection of those best suited for the organization.
Discipline	Combination of dedication and some enforcement.
Reaction to difficulties, stresses	Consolidation and active defense; activation of creative approach (as in Stage 1).
Flow of information	Well-organized, effective within the organization, limited with respect to external organizations and competitors.
Language	Popular plus specific.
Area where creativity is required	To develop the product/service, manufacturing process, other applications.
Ideas, innovations	Few important ideas; many mediocre ideas; development of important Stage 1 ideas. Implementing these ideas is more difficult, but there are more resources to achieve this.

5.5.3 Company at Stage III -(C3)

Objective of the Company: a stage III company, if it remains as a private entity, tries to maximise the profits from existing sales and protect its market from competitors of tomorrow. These companies can access more than $ 100 Million in capital. If the company has gone public, it tries to maximise market expectations, thus increasing its share price. The company tries to maintain its stability and survivability rather than developing a business. Business and sales start to stagnate, where employees work for their self-survival rather than for the business. In this phase, corporate culture has already been well established within the organisation. These companies work well with a stage II or a stage III product but cannot work with revolutionary stage I products.

Style of decision-making and management: the decision-making is no longer proactive and dynamic but reactive and slow given the tremendous complexity of processes established within the company. This happens due to the rise of a new corporate culture where bureaucracy obstacles begin to grow and appear. The interaction between management becomes complicated, and communication takes place only through official documents that are time-consuming. In the beginning, documentation and structuring allow for business growth; however, it causes an increase in disorder. The absence of dynamic, proactive behaviour and decision-making coupled with the low enthusiasm towards the business creates an unimpressive bureaucratic corporate culture. Companies become slow to react to market change. The management becomes fragmented within the company, which deals with independent goals and targets rather than proactive steps towards the bigger picture.

Trigger for employees: The level of professionalism now becomes less critical, hiring of less qualified workers becomes a norm with a minimal scope of innovation or creativity. The staff is no longer motivated to improve the business but to ensure survivability in the market and protect their position and reputation built for investors. Employees typically need materialistic reward factors to promote them and many extra privileges such as vacations, cars, insurance et cetera. The progress of the company in general start slowing down. Table 11 shows companies' key characteristics at stage III (Topchishvili, Katsman and Schneider, 2003; Zlotin and Zusman, 2001).

Table 11. Characteristics of Stage III Companies (Zlotin and Zusman, 2001,p. 90)

Feature	Description
Goals of the organization	Continue to develop the business; increase and develop the market.
Public relations	Investors are interested in the business. Customers are interested in the product/service provided by the organization.
Factors stimulating business development	Personal motivations of organization personnel; public demand.
Factors impeding business development	The inherent resources in the product/service under development and/or market demand are exhausted.
Main contradiction	The organization must be dynamic to provide long-term prosperity, but this requires great effort and expense.
Organization size	Practically unlimited.
Management system	Economic with some charismatic and administrative elements.
Organization structure	Complementary simple formal and informal elements; directed toward organizational prosperity. Includes independent departments, horizontal and hierarchical links.
Organization leader	Formal leader with professional background, good communication skills, respected by organization personnel.
Organization personnel	People carefully selected, educated and trained to work for the organization.
Main requirements of personnel	Professionals who reflect the corporate "culture."
Area of professional knowledge	Wide in scope, dynamic; in-depth as needed.
Attitude toward personnel initiative	Any initiative not harmful for the business is welcome.
Attitude toward mistakes by personnel	No punishment for mistakes resulting from good intentions. Inaction is not appreciated.
Rules and behavior	Combination of informal and formal, directed toward the prosperity of the organization.
Rewards	Personal satisfaction plus adequate salary or other material reward according to accomplishments
Prestige	According to accomplishments and to the prosperity of the organization as a whole.
Morale and environment	Good. Fruitful cooperation and honest competition.
Attitude toward organization personnel	Informal communication together with a system of seniority.
Attitude toward external business environment	Selection of those best suited; cooperation with those who want to contribute.
Discipline	Combination of dedication and some enforcement.
Reaction to difficulties, stresses	Consolidation and active defense, activation of creative approach (as in Stage 1).
Flow of information	Well-organized, effective within the organization, limited with respect to external organizations and competitors.
Language	Popular plus specific.
Area where creativity is required	Improvement, looking for new applications, diversification.
Ideas, innovations	Many mediocre ideas, development of important ideas from Stage 1. Active search for a new perspective and high-level ideas.

5.6 Determination of developmental stage of markets

Plenty of research was found on the developmental stages of a market. The most unified and coherent evolution of the market was stated in a book written by Geoffrey Moore called Crossing the Chasm, third edition marketing and selling disruptive products to mainstream customers, 2014. Within the QEA method, this category is the only one that consists of a total of five stages instead of four, ranging from M0 to M4. The evolutionary classification of markets is divided into many subgroups and could be integrated under one class: consumers and their behaviour. The market was further classified into targets, stages of development of companies trading on the market, stages of technical development of products sold in the market, and buyers' psychology (Topchishvili, Katsman and Schneider, 2003; Moore, 2014).

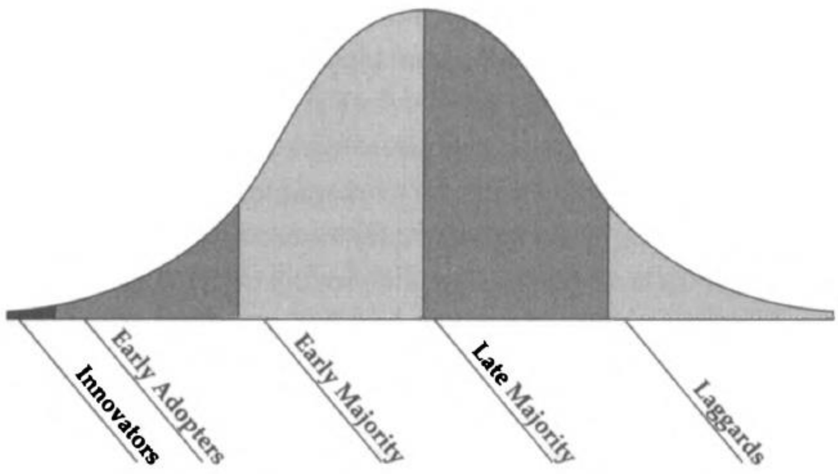


Figure 32. Technology adoption Lifecycle (Moore, 2014)

The technology adoption life-cycle represents the market and can be distinctly divided into five separate stages. They consist of innovators, early adopters, early majority, late majority and laggards. Moreover, each stage represented above consists of different groups of customers with unique psychographics that influence the development and the dynamics of the market. The S-curve shown below shows the different types of customers appearing at different developmental stages. At stage I, we have “followers/early adopters”; stage II consists of “pragmatists/progressives”; stage III consists of “sceptics”; and lastly, stage IV consists of “conservatives”. In the following chapter, we will look at each of the market stages, and they are corresponding consumer psychographics in detail.

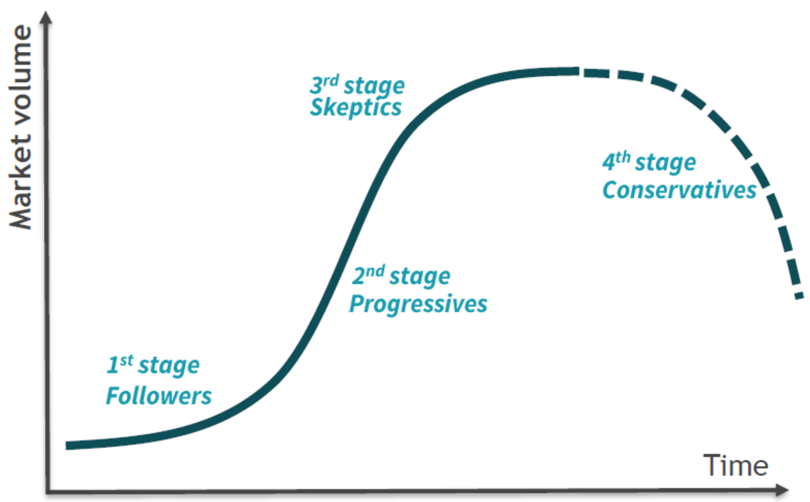


Figure 33. Customer types at different development level of markets(Moore, 2014)

5.6.1 Market at Stage 0- (M0)
Key characteristic: Very few or no consumers, early adopters only

At this stage 0 of the market, there are no consumers who pay to use this new offering. We could say that there is no market at this stage because the main objective of companies is to check the concept in real life before launching it commercially. This market's sole purpose is to gather feedback and improve the product based on the user's recommendations. This phase aims to draw future consumers' attention to the emergence and existence of a new class of products.

Primarily, some enthusiasts want to try an innovation as a hobby. Therefore, products sold in zero level markets are primarily meant for enthusiasts, reviewers, product testers and experiments. Companies need to listen to these recommendations and improve upon them to gain their trust and confidence and show that they will address their needs. These users are also known as "followers", those groups of people who make products fashionable and famous (potentially increasing product attractiveness). Moreover, this allows companies to create an initial market pull. When this company launches the new, improved product based on stage 0, the people who are enthusiasts, reviewers become the first buyers and spread information about the product using word of mouth. "Lead users" are generally the ones that will be interested in the products at this stage. Companies must approach them and involve them during product development for continuous feedback and improvements for the early stages of innovation.

5.6.2 Market at Stage I- Followers (M1)
Key characteristic: New consumers appear, but they keep using the previous product as well.

At stage I and early stage II, the development of the market heavily depends on two factors. Firstly, the value proposition or offering solves a vital problem that was unsatisfied on the market. It addresses an unmet need that the competition did not address before. Secondly, consumers by the product due to the sense of exclusivity offered to them along with the product. Consumers at this stage want to be more "progressive" than others, almost as if a forward-thinking vision of the company is sold to the customer. At this stage, any imperfections of the product will be forgiven as long as it adequately performs its main function. This type of product is usually launched in a niche or the premium segment. Consumers do not hesitate to pay more for the exclusivity to get their hands on this new technology, features, and premium experience before anyone else.

Additionally, there are already enough buyers who pay for a product but have not left the previous market entirely. In other words, the mass majority of people still use the old product. The market is currently in a phase where it picks up traction and turns out to be a successful product for the company. A product in this market is nowhere near its physical limit of improvement and can have many different iterations year after year with better versions launched by the company.

This “early majority or early-stage II” phase consists of customers, also called pragmatists. This type of consumer is hard to win but is very loyal to the company and the product once they get accustomed to the offering. On the one hand, there is an increase in sales volume, which is excellent for the company’s growth. Simultaneously, the product's cost begins to decrease as new competitors bring similar offerings at a competitive price. Companies must win these pragmatist buyers and their trust because they become the most reliable customers in the long term. Retaining customers and protecting this market becomes the long-term strategy for companies. This type of customers also like to see competitive products and generally buy proven market leaders only. They are known to reasonably price sensitive but are not limited or hesitant to pay towards premium services. The buying psychology of pragmatists also includes the company they buy from, quality of the product, the infrastructure of supporting products, system interfaces and reliability of the service they will get from this company. Pragmatists also communicate with other pragmatists; they communicate with other people in their domain or industry. This also brings the word-of-mouth marketing strategy into play, where relationships and references can make a giant quantum leap in sales volume for stage I markets. Lastly, companies need to be patient to win these customers through marketing, constant communication, building relationships, and visibility (Moore, 2014; Topchishvili, Katsman and Schneider, 2003).

5.6.3 Market at Stage II- Progressives/pragmatists (M2)

Key characteristic: Mass consumer is switching to a new product, completely abandoning the previous one.

In this stage, the segment still consists of pragmatists. However, the primary indicator of the stage is where the mass consumer starts using the new product while altogether abandoning the old one. All the previous recommendations for stage I markets still apply to stage II. A classic example of this case can be the mobile phone. When iPhones debuted in 2008, many pragmatists appeared; however, most still kept using the old button-based phones. Until 2010, the market was at an early stage II, but consumers wholly abandoned the previous generation of handsets for the new fully touchscreen technology versions between 2010 and 2012. Another indicator of the stage is where consumers start using the product to perform many functions and more tasks. At this stage, consumers develop a sense of habit to use the product daily and do not compromise on functionality and performance anymore. In this phase, the product grows into an international fashion house where many different variants, designs, features appear for different segments. Additionally, consumers no longer value novelty aspects of the product, but this does not mean that new functionality is not appreciated. Consumers would like to have diverse functionality to expand their tasks (Topchishvili, Katsman and Schneider, 2003; Moore, 2014).

5.6.4 Market at Stage III- Skeptics (M3)

Key characteristic: All potential consumers are already using the new product.

At the third stage of the market, all consumers have already switched to the new product. An analogy to the situation would be where the number of buyers could represent the country's population. The mobile phone in the year 2021 would be an example of stage III markets. It is almost impossible to find a group of customers that does not use a mobile device. Another example could be the Internet, where everybody uses it. At this stage, the psychology of buying the product is the discomfort of its absence. One cannot live without it as it has already been accustomed and oriented towards human habits, fulfils all requirements and does not create any “novelty” anymore. This type of product has become a part of human life and causes distress and discomfort if it is absent.

Additionally, the market tries to prevent the emergence of other competing markets to find new niches at this stage. Although one cannot predict the duration of time for which product will be at stage III, it may last for decades or centuries. Similarly, with markets, it may last for an unknown period. The consumers in this market are also called sceptics because they believe that any disruptive innovation for the product will rarely fulfil their needs and requirements and will come with consequences. Sceptics believe that there is nothing to be done or no problem to be solved anymore for the product, as it works just fine.

This may be a bad thing for the company in terms of stagnating sales. However, it is necessary to reduce sceptics' influence by working on new disruptive technologies and changing their perspective for new products. Stage III does not mean that there will be no sales for the company; it is just that these consumers are satisfied in terms of all aspects and do not think that they need any other added functionality than what they currently have. They believe that most innovations in this segment are incremental, and most radical innovations are unnecessary and do not satisfy a need. Moreover, the market is heavily saturated by many different products which perform similar functionality. Therefore, the customer's freedom of choice is quite high, although the novelty aspects are mainly in the product's looks and aesthetic design. Therefore, the consumer would usually be attracted to the best "value for money" offering and may switch to other competitors based on cost. This is one reason why cost reduction becomes one of the best strategies at stage III for products.

5.6.5 Market at Stage IV- Conservatives (M4)

Key characteristic: Consumers are leaving the market and are switching to the newer or next-generation product.

It is important to note that a stage IV market can sometimes be entered by stage II company. Mainly because stage III companies are now not interested as profits and sales stagnate; however, stage II companies may target niche markets for the same product and may continue to profit in new markets. At this stage, consumers are potentially leaving the market and are switching to a next-generation product or a new disruptive technology. It was also seen in studies where the market tries to slow down the outflow of consumers to find sustainable niche segments to slow down the progress of growing competitive markets. Conservatives are seen at mid to late-stage III and early-stage IV phases where consumers believe in the philosophy of "as long as it works for me, it is fine". These type of consumers want the basic functionality of the product. They tend to invest in these products only at the end of technology lifecycles with mature products and low costs. In this phase, products are as good as commodities and are driven by heavy cost reduction from the competition.

In some cases, conservatives also fear high technology and buy products with bundles and preassembled packages such as heavy discounts and freebies. If we were to summarise the consumer psychographics in one line, it would be low cost-moderate functionality-convenience. These consumers also do not look for a product that can do everything but more of a product that performs one function, such as using the speaker to listen to music without being “smart”.

These consumers often put companies in a dilemma where low-end and low-cost markets are not profitable; therefore, innovations are not focused on these consumers. This affects the relationship with buyers and may cause consumers never to buy this company’s products. Companies can deal with the situation by providing a “whole/complete solution” specific to this market or can reduce costs through low overhead distribution channels. Companies' focus must be on convenience related features rather than performance and new feature sets (Topchishvili, Katsman and Schneider, 2003; Moore, 2014).

5.7 Summary of the section

QEA provides a framework that is universal and generalisable for all business systems. Moreover, it is dynamic, which means it can adapt as time progresses. We already know that all business systems must go through the S-curve stage from infancy to maturity, whether it be a product, company or market. However, we can use this information to devise strategies ahead of time and reap the ability to predict the next synergetic state of QEA to take actionable measures using open innovation strategies. One of the reasons why OI was not integrated with QEA is because academia lacked a common time-based dynamic framework that could explain universal phenomena. Businesses can be very different from each other, with different product strategies and markets. Therefore it was necessary to find common ground based on which we could recommend OI strategies to answer the research questions.

Each combination in QEA describes a specific state of the business. Moreover, if this state falls within the unsuccessful combinations, it does not necessarily mean that the company will fail to commercialise the product. According to expert one, the correct interpretation is that more time, money, and resources would be required to commercialise the product compared to a successful combination.

Lastly, the product part of QEA comes from TRIZ based S-curve analysis, meaning product-related recommendations for each stage are already applicable for R&D departments, and innovation heads are known to work extracted based on patterns. This research merely adds a partial part of the business world in terms of open innovation mechanisms. It integrates open innovation with the technological and engineering domain of TRIZ, attempting to create a synergy of two of the best methods in the innovation industry.

6 Methodology

This chapter elaborates on the research design, research approach, sampling and data collection strategy and research strategy used in the thesis. Additionally, the researcher also explains the retrospective analysis method for analysing the secondary data. Lastly, some measures taken by the researcher to mitigate the risk of validity and subjectivity in the research are mentioned.

6.1 Research design

The research design provides a systematic outline of the research, its logic and reflects the researcher's thinking process to ensure validity, reliability, and replicability of his work. The research design also facilitates the methodical choices, approaches and strategies used during the research. There are several types of research designs, namely, “exploratory”, “descriptive”, “explanatory”, and “evaluative research” (Saunders, Lewis and Thornhill, 2016). These research designs are dependent on the type of research question and the objective of the research.

In this thesis, we use the exploratory research design used to discover or explore new insights about a given topic. According to Saunders, 2016, research questions for this design are likely, to begin with a ‘what’ or a ‘how’. The exploratory research design is well-suited for this thesis as we intend to explore the appropriate set of open innovation strategies applicable to different premises of a business system. The assumption made for this research is that only some specific open innovation strategies are applicable in certain situations. We try to identify the “conditions” under which the OI strategies are most suited through this research.

Additionally, OI and QEA have never been integrated in academia or in the real world, making the study exploratory. This type of research typically can be flexible and adaptable to change wherein, the direction of the research can be dependent upon the research findings. Exploratory research may include literature search, interviewing experts, conducting an in-depth individual interview or analysing data to uncover new insights in the topic (Saunders, Lewis and Thornhill, 2016).

A critical literature review is essential irrespective of the category of the research design. It consists of four major types, namely integrative, theoretical, methodical, and systematic review. Given the research background and the research questions, the literature review is selected as a theoretical review. The theoretical review is “a body of theory that has accumulated in regard to an issue, concept, theory or phenomena” (Saunders, Lewis and

Thornhill, 2016, p. 74). The theoretical review's objective is to establish the fact that current theories, methods or tools are insufficient to explain new emerging problems (Saunders, Lewis and Thornhill, 2016). In this thesis, we identify several methods used to assess the feasibility of idea screening and their advantages and disadvantages. Lastly, several justifications suggest that the current methods are insufficient given the current circumstances of the innovation process.

6.2 Research approach

The purpose of the literature review also serves to guide the researcher in selecting the appropriate research approach. The three main types of research approaches used in scientific studies are deductive, inductive, and abductive. Deductive approaches are typically used to verify a theory and test the hypothesis related to an existing theory. Inductive approaches are used to build new theories or modify existing theories to improve them by exploring patterns, themes and create a new conceptual framework. Abductive research is also used for theory generation or modification of existing theory but includes verifying and testing the new conceptual framework (Saunders, Lewis and Thornhill, 2016).

An inductive approach is mainly used when researchers need to define the context, situation or conditions under which an event occurs. In this thesis, we use an inductive theory development approach wherein we attempt to modify an existing tool, QEA and use it to improve OI's efficacy by defining a set of conditions for OI strategies. The above statement justifies the author’s choice of research approach precisely (Saunders, Lewis and Thornhill, 2016).

6.3 Research strategy

A research strategy is a connection between the philosophy and the choice of methods used to analyse data. It is essentially a plan of action to answer the proposed research questions (Denzin and Lincoln 2011). It must be aligned with the research approach and the type of research. According to Bryman 2012, there are two main research strategies for scientific research: quantitative and qualitative research. Quantitative research is associated with numeric data and uses highly structured data collection techniques. Often, it is used with the deductive approach to test a theory. Quantitative analysis is used to establish the relationship between variables typically through an experimental design.

On the other hand, qualitative research is associated with words, audio, video and other non-numeric data. It is strongly associated with an interpretive philosophy as results are primarily dependent upon the researcher's subjectivity to conclude. Qualitative research uses an inductive theory approach directed towards providing a better and richer understanding of the topic. It is often emergent and consists of research strategies such as action research, case study research, ethnography, grounded theory and the rate of research (Saunders, Lewis and Thornhill, 2016).

In this thesis, we utilise a qualitative research method as the subject of interest is new, unexplored and other existing literature in this area is relatively scarce (Morse, 1991). Therefore, qualitative research is justified to be utilised in the current scope. Additionally, we also utilise an expert's interview as a supportive measure to the new framework developed and validate research findings (Saunders, Lewis and Thornhill, 2016).

Out of the many research strategies employed for the methodical qualitative choice, we decide to use case study research. A case study is defined as "an in-depth enquiry into a topic or phenomena within its real-life setting" (Yin 2014, p. 187). Case study research is known to create new insights from intensive analysis of real-life cases that generate new theories and is highly dependent on the research philosophy of interpretivism. A case study strategy can also include studying multiple cases mainly to see whether the research findings can be replicated across all of them. This is also known as literal replication (Yin 2014). It is also necessary to carefully select the cases chosen for the analysis to prove literal application wherein similar patterns or themes can be extracted (Saunders, Lewis and Thornhill, 2016).

This research selects case studies carefully based on criteria to achieve literal replication wherein patterns extracted from the data can be generalised and abstracted to all existing business systems. The explanation of the selection of cases will be provided in the next section.

6.4 Sampling and data collection

As mentioned earlier, this research follows an exploratory design and an inductive approach to theory development. It utilises a qualitative research method and a case study research strategy to analyse and extract patterns and later present its findings.

There are two main types of sampling techniques, namely, probability and non-probability sampling. This research uses a nonprobability sampling technique since we do not have a well-defined sampling frame. Therefore, in this situation, the samples or the case studies must be selected with some subjective judgment. For nonprobability sampling-based methods, the sample size is not known and can vary depending upon situations. There are no well-defined rules, and the sample size depends on relevance to the research, the research question and the researcher. Data can be collected until no new research findings emerge. In this case, the sample size is twenty case studies considering the time based limitations and the adequacy of research findings in the masters thesis stage. However, the researcher can add cases later as long as the research yields new results.

Purposive sampling is a non-probability sampling method that is often used for case study research strategy is wherein we select a small sample most relevant to the research (Neuman 2005). The twenty case studies selected are based on purposive sampling (judgemental sampling). The researcher uses his judgement to select the best possible cases that will answer the proposed research question. Typically, purposive samples are not considered statistically representative as selected samples can be highly subjective. However, in this case, the researcher also uses Heterogeneous or maximum variation sampling to provide a wide enough variation of characteristics in the cases selected to increase the research findings' generalisability. Using this method, the selected sample can also become representative of the population. According to Patton, 2002 the lower sample size does not negate the strength of the research. In such cases, the selection is based on sample selection criteria established by the researcher.

In this thesis, the twenty case studies are selected primarily on the richness of information, availability of data in sources from the works of Chesborough (2003) and McGrath (2013) , and secondary data from an international research project, INSPIRE, funded by the European Commission under the Horizon 2020 programme, aimed to understand and support open innovation in Europe’s SMEs. The INSPIRE project has collected more than 100 case studies of businesses from all over Europe using qualitative analysis to assess the SMEs open innovation strategies, challenges, and impacts. The platform is open to the public with full access to case studies.

To consider maximum variation sample, the researcher selected case studies for different sized companies ranging from start-ups to small and medium-scale enterprises and large-scale enterprises covering a wide range of domains. Only those case studies that had enough information to establish clear timelines of the company's state such as time of establishment, funding received for scale-up activities, source of the funding, clear information of the launch of the product, internal strategic decisions made, open innovation strategy/mechanism and indicators of commercial success for the product have been selected. This ensures adequate data from the case study to draw logical conclusions during the analysis. An additional source of information called Crunchbase was utilised to extract additional information about the selected cases. Crunchbase is one of the world's largest platforms that monitors private and public companies worldwide, keeping track of their investments, funding received period of funding, number of employees, size of the company and type of investment received by a specific company. This database is a reliable and accurate source of information and is publicly available worldwide.

6.5 Validity and reliability

The quality of the research depends on its validity and its reliability. Reliability is defined as the extent of research consistency to be replicated or repeatable by using the same research design and the research procedures. The research is reliable if another researcher conducts the same analysis and achieves the same findings as to the original research. On the other hand, validity is defined as precision in analysing data, methods and tools used during the research process (Saunders, Lewis and Thornhill, 2016).

Additionally, the choice of using a retrospective design is said to pose severe threats to the validity of the research. First, the inaccuracy caused due to an imperfect recall of the interviewee. As a result, the researcher fails to establish a correct timeline of events. Secondly, the spoiler effect wherein the researcher may skew the results in his direction imparts subjective bias due to the case's known results (Street and Ward, 2013). Both conditions are considered, and preventive measures have been taken to ensure the validity of the research.

The problem of inaccuracies of the interviewee is accounted for the INSPIRE project collected information in 2016 (archival data now) from owners of the companies themselves. Partners of the project conducted interviews through recordings which were then transcribed and analysed.

Later, based on the interviews, case studies were written and published after being validated by experts. Other cases selected from well-known books and publications written by industry experts claim to have investigated the possibility of inaccuracy during data collection and accounted for the same.

To tackle the problem of introducing a subjective bias, the researcher validated the cases, their outcomes, the timelines established jointly with an expert from the domain to ensure objectivity throughout the analysis. Moreover, some more data sources were used to verify the established timelines by collecting news articles and information from official company webpages to support the analysis.

Secondly, to ensure this research's reliability, the researcher takes all precautions regarding the data collection mechanism, sources of cases selected and clearly explains the step-by-step procedure used to establish the timeline of events and draw conclusions from them. The researcher makes use of two experts in the domain for different purposes.

The quality of the analysis is ensured in a two-step method. Firstly, applying QEA correctly to the cases and secondly, drawing conclusions and inferences from the cases. Expert 1 provides the knowledge for correctly applying the QEA method to a case study. It ensures that the results of QEA are not false due to the wrong application of the tool. Expert 2, on the other hand, analyses the case studies independently to verify the outcomes of the research. Lastly, he also supports the researcher by facilitating the analysis through constant critical feedback.

6.5.1 Introduction to experts in their role in the thesis

This short section will introduce the two experts and their contribution to this research.

Expert 1 -Gen-TRIZ LLC

Gen-TRIZ is one of the world’s largest TRIZ consulting companies that performs end-to-end projects for clients ranging from Fortune 500 companies to start-ups using their innovative methodology TRIZ for 30 years.

Expert 1- Dr Abramov is one of the foremost and widely recognised members of the TRIZ community with more than 25 years of TRIZ consulting experience and more than a hundred projects completed with various clients working alongside GEN3/Gen-TRIZ. He is as involved with the industry as he is with academia with several publications in peer-reviewed journals. Dr Abramov holds a PhD in radio engineering and a TRIZ Master in the TRIZ methods. Currently, he is the Chief technological officer of Gen-TRIZ, a company that has implemented the QEA tool explicitly in projects.

His contribution to this thesis was to guide the researcher regarding the implementation of QEA during the data analysis phase, managerial implications and limitations of QEA, its efficacy in real NPD projects and his personal experience of actively using the tool.

Expert 2 -TRIZ Asia

TRIZ Asia is a consulting company that utilises the innovative methodology of TRIZ and is a strategic partner of Gen-TRIZ since 2016. TRIZ Asia provides technical consulting capabilities to its clients, many of them being fortune 500 and is one of the leading providers of end-to-end projects operating in India.

Expert 2: Mr Phadnis has over 30 years of experience in consulting, manufacturing, new product development, and innovation with some of the world's leading companies. He is a postgraduate in patent law, quality management, a level 3 certified TRIZ professional and a Six Sigma master black belt. He has been applying QEA and TRIZ methods within innovation projects. Additionally, he has developed comprehensive frameworks for institutionalising innovation in organizations, including assessment and audit methods for building the complete infrastructure for systematic innovation deployments in organizations. Currently, he is the Chief technological officer for TRIZ Asia.

Expert two contributes to this research monumentally to ensure its validity and reliability. Data has been analysed independently by the expert to verify the outcomes of the research. It includes establishing correct timelines for the case studies analysed, applying the QEA tool to identify the combination before and after commercialization and extracting the emergent patterns from the given data. Each case selected for the analysis was verified to ensure minimal errors, reduce subjective bias and negate the ‘spoiler effect’ of research. Lastly, expert two acts as a facilitator and guides the researcher through constant critical feedback. Table 12 gives an overview of the respective experts and their contribution to this thesis.

Table 12. List of experts and their respective contributions

List of experts	Name of the company	Experts position in the company	Contribution to the study
Expert 1	Gen-TRIZ	Chief Technological Officer	Application of QEA, analysis of cases, validity, limitations, the efficacy of QEA and personal experience
Expert 2	TRIZ-Asia	Chief Technological Officer	Validity, reliability, joint analysis of case studies, interpretation of results, validation of findings

6.6 Data analysis

In this research, the author uses a complex, longitudinal case study design called a retrospective study. A retrospective study typically includes first-person accounts, interviews, and data collected after an event for activity has occurred. The outcome of the events is known. In this type of research design, we establish a timeline of events and evaluate which variables have changed over a period of time. The timeline is reconstructed after events have occurred (Street and Ward, 2013).

The three most important factors in retrospective cases are:

- Data is collected after events have occurred.
- The researcher has access to first-person account or archival data of the account.
- The final outcomes (that were presumably influenced by variables under the study)

Retrospective case designs are efficient as all the data collected is available at once to the researcher. This type of research design is used in three instances: extreme case, multiple recurrences, and multiple organisations. In this study, we use multiple organisations type case design to analyse a similar innovation process of multiple companies by establishing a timeline of events and investigating the change variables throughout the time (Street and Ward, 2013). This design is well-suited given the current research background, as it is appropriate for research questions that investigate how organisations respond to an internal or external stimulus. In this research, the author utilizes the archival data from the INSPIRE project and

popular books to detect the changes made by a specific open innovation mechanism on QEA combinations before and after commercialization.
The researcher demonstrates two case studies (a successful and an unsuccessful case) systematically showing the timeline of events, how it was established, and the process by which the conclusions of the study were drawn. The exact process has replicated for the remaining cases.

The logic of the analysis at a macro level is shown below. Our goal is to establish the most appropriate open innovation strategy used for a specific QEA combination. The QEA screening tool provides the condition or situation of a business system at an instant of time (which the researcher needs to assess and establish) before the new product was commercialised. Using the collected data, we investigate which open innovation strategies were utilised (change variable). This also allows us to detect which of the three elements (product stage, company stage or market state) within the QEA method were impacted by this change. Lastly, we map the new QEA condition after the commercialisation of the new product.

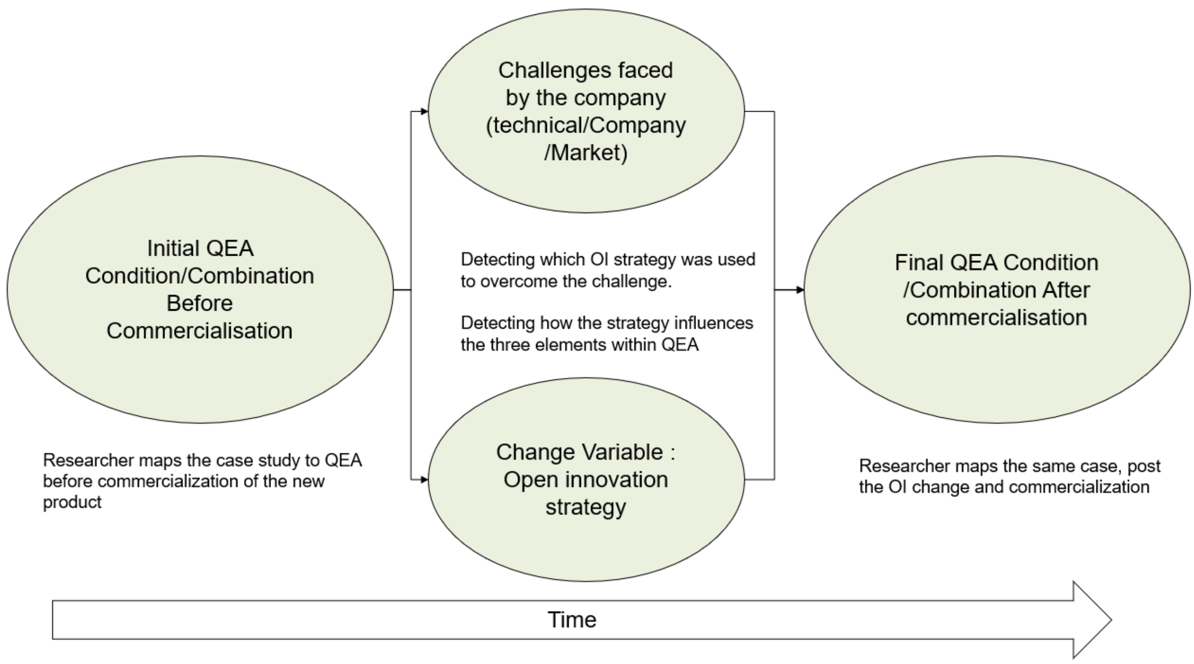


Figure 34. Macro-level roadmap for Data analysis in a retrospective case design

We analyse two cases in detail to provide a more holistic overview and a clear representation of establishing timelines, steps taken by the researcher to conclude and how the QEA combinations were impacted. The remaining case studies can be found in Table 14.

6.6.1 Case Study: Kodak digital camera

Background: Kodak case study is popular among many sources globally as one of the biggest failures and is well-known in the innovation community. This is an example of a failed case study about Kodak's digital camera technology invented in 1975. Kodak did not commercialise the technology ten years after its competitors. Later, the company filed for bankruptcy in 2012. However, Kodak did commercialise the technology in 1991, even though they were late. They stopped manufacturing film-based cameras in 2004 completely and yet, even after commercialising the digital camera technology, they failed. Let's analyse this case study using the QEA business cube step-by-step.

Step by Step procedure used to map the cases to their QEA combination:

Case study source: "The end of competitive advantage" Rita Gunther McGrath, 2013 (well-known expert in innovation industry), Forbes magazines and Harvard business review articles (Chunka, 2012).

New Product/technology: The Eastman Kodak Company invented digital camera technology in 1975. Steve Sasson and an electrical engineer developed the technology.

Mapping the initial QEA condition (at a particular instant of time) according to this information:

Step 1: Map the Stage of company (C):

Kodak, as a company in 1975, was a market leader in film-based camera technology with revenues of more than $ 3.5 billion. According to the criteria explained in section 5.5, a C3 company can typically access capital of more than $ 100 million for company stages. This is typically reflected in the revenues of the company (John, 1995). Therefore, Kodak is placed in the C3 position.

Step 2: Map the Stage of product/technology (P):

According to indicators for product or technology stage based on TRIZ-based S-curve analysis explained in section 5.4, if the product or technology is completely new in the world, and is not present on the market, then the product is said to be stage I(infancy). Note, we do not conduct S-curve analysis for a company's new product. We assess the technology of the product in the world and place it on the S-curve.

Step 3: Map the stage of the market (M):

Since the digital camera technology in 1975 was not commercialised, it did not have any customers according to market stage indicators explained in section 5.6. If there are no customers and the technology is completely new then the market is at M0 stage. There are early adopters of the technology and tech enthusiast that are willing to buy the product.

Therefore, the initial QEA combination is P1-C3-M0. This condition fails according to the QEA method, and steps must be taken to modify and change this combination into a successful one.

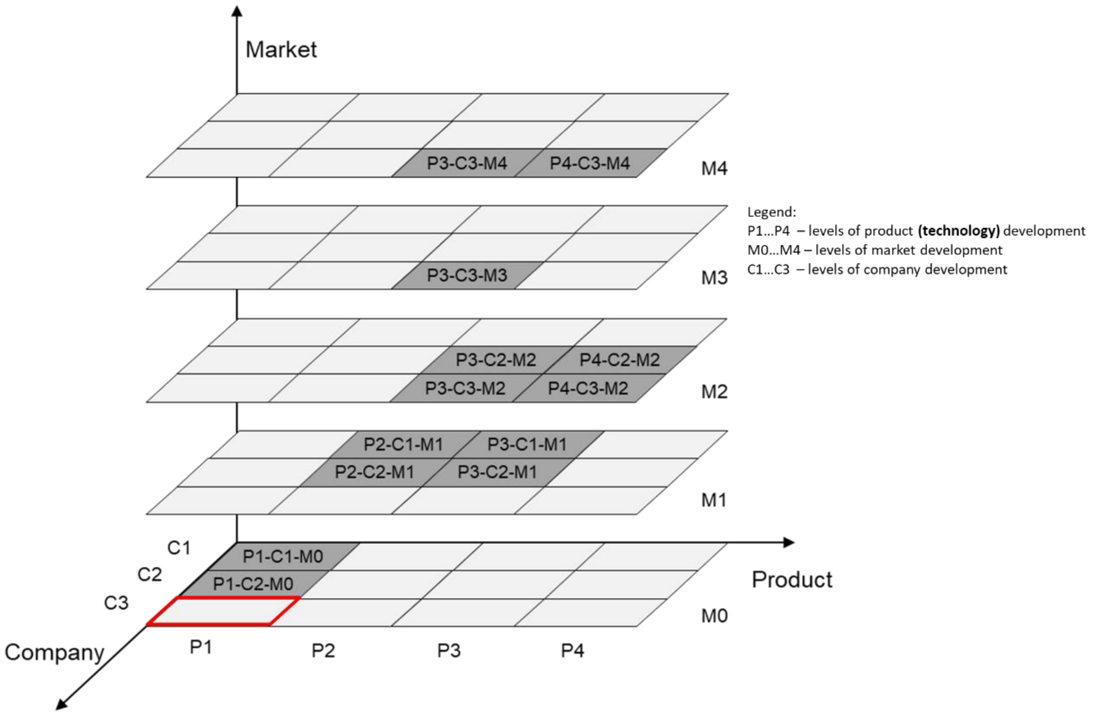


Figure 35. Kodak's initial QEA combination, P1-C3-M0

Step four: Identify the challenges faced by the company based on data.

Product-related challenges: In this case, the challenge was mainly technical or product-related as the prototype was bulky and oversized. It also had many other technical disadvantages that had to be resolved before reaching the market. Therefore, Kodak in ideal conditions, could have applied the TRIZ based recommendations for stage I products i.e elimination of critical bottlenecks that keep the engineering system of the market and focusing on the main champion parameter of the technology while keeping other parameters to a minimally acceptable level. However, they chose to ignore the recommendation and did not take pro-active measures to commercialise the technology.

Company related challenges: Many different reliable sources indicate that Kodak company's management reacted to digital photography as “that’s cute-but don’t tell anyone about it” (Chunka, 2012). This statement indicates that Kodak’s management enjoyed current market share over tomorrow’s threat. Additionally, it was plagued with bureaucracies, the inability to listen to employees, and turning a blind eye to technology's next generation. Interestingly, QEA recognised this combination correctly and accurately states that C3 stage that the company's agility has become poor, and the management is reactive rather than proactive. According to QEA, to be successful, it is necessary to move from C3 to either C2 or C1 stage. This means that Kodak had applied the characteristics of a C2 or C1 stage company to be successful at that moment. This correlates with business management logic wherein agility of the company and decision-making is far more dynamic in smaller companies than large giants.

Step five: Investigate the current condition of QEA to predict the next nearest successful combination.

For Kodak: the nearest successful combination according to the QEA method would be shifting from P1-C3-M0 to P2-C2-M1 or P2-C1-M1. Any combination with C3 will not work because the product was at stage I and needs to be commercialised first (i.e. P2), and it cannot jump directly to stage 3.

Step 6: Identify the open innovation strategy used in the case.

In this case, no strategy was used because the product was never commercialised therefore, there was no change in the QEA combination.

Step 7: Identify the elements in the QEA combination that get influenced by the strategy.

In this case, since no strategy was used and the product was not commercialised, none of the QEA method elements was impacted. The elements in QEA refer to changes in the product stage, changes in the company stage and changes in the market stage.

Step 8: Analyse the results of the case after the product or technology was commercialised.

Kodak finally commercialise the technology in the year 1991 and stop the sales for traditional film-based cameras in 2004. However, after the technology was commercialised in this situation, we analyse the QEA condition once again.

Product stage: At this stage, when the technology was commercialised, time had passed, and the product had already reached P2 stage as other manufacturers like Fuji film commercialise the digital camera technology in 1988. This means that the product has moved to stage II.

Company stage: Kodak is still at C3 based on the companies financial report (John, 1995).

Market stage: The market between 1990 and 1993 had moved from being an early adopter to the M1 stage, where new consumers were appearing, but they were using the old film technology as well. We know this information other digital camera making companies like Fuji film have reported significant growth from their digital camera.

Therefore, the new QEA combination is P2-C3-M1 which is yet again unsuccessful according to QEA.

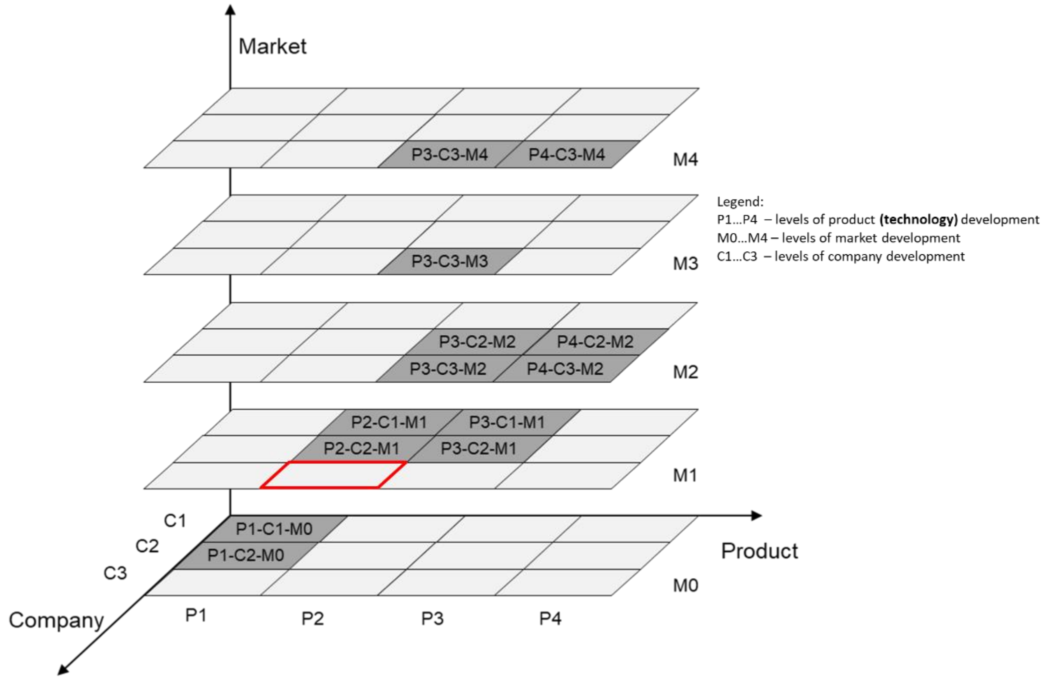


Figure 36. Kodaks Final QEA combination in 1991, P2-C3-M1

Conclusions: In the case of Kodak, both of their combinations involved either a C3-P1 combination or a C3-P2 combination. The problem being C3. Kodak still had tight control over the department for the new technology, which means that bureaucracies, slow agility, reactive progress, and dynamic decision-making were still present due to the company's large size. If only, Kodak created an isolated subsidiary, a spin-off, a new brand, a joint venture (these (partially extracted result, from other replicated cases) which is not controlled under Kodak's management maybe it would have succeeded. This was an example of a failed case. Let's look at another example of Fujifilm, which is a continuation of this case.

6.6.2 Case study: Fuji-film cameras

Background: Fuji film was one of the first companies to commercialise the digital camera in 1988. At that point, it was not a multinational giant but more of a successful SME. They were early innovators in electronic digital camera's and recognised that digital photography would be the next big thing in camera technology.

let us analyse the case step-by-step using the same process as mentioned above:

Mapping the initial QEA condition (at a particular instant of time) according to this information:

Step 1: Map the Stage of company (C): Fuji film was a stage II company. We know this information from their annual report from the year 1990. According to stage II companies, they can access capital between $ 10 million-$ 100 million.

Step 2: Map the Stage of product/technology (P): Fuji film launched its first digital camera in the market, overcoming the technology barriers and limitations in 1989, according to their website.

Step 3: Map the stage of the market (M): The market, however, was M0 wherein we only have early adopters and almost no consumers as market acceptance is low, and consumers need to be informed about the new change of technology.

Step four: Identify the challenges faced by the company based on data

Market-related: The main challenge that Fuji film had to deal with was the market. It was necessary to reach wider audiences, sales channels and distribution logistics that Fuji film did not have. Consumers had to be informed and educated on the benefits of the new technology. It was necessary to advertise the unmet needs that were satisfied using the new camera and create a comfortable environment concerning the new product's usability.

Step five: Investigate the current condition of QEA to predict the next nearest successful combination.

Given the current amount of information, the QEA combination at the state is P2-C2-M0, which itself is an unsuccessful combination. This means that if a business system were to stay in this combination for a long, it would inevitably fail. The nearest successful combination for Fuji film is P2-C2-M1. Therefore, QEA is suggesting shifting M0 to M1 by making some strategic changes to the organisation. Moreover, according to TRIZ based S-curve analysis, the recommendations for stage II are applicable. Some of them are expanding the application areas for the product, optimisations and refinement while minimising existing disadvantages. An increase in the product's cost at this stage is acceptable, provided the functionality also increases.

Step 6: Identify the open innovation strategy used in the case

Fuji film created partnerships and collaborations with existing distribution channels all over the world to reach wider audiences. They tied up with another leading manufacturer Nikon which co-developed the camera with them, the market leader in camera housing and use this partnership for additional market reach.

Step 7: Identify the elements in the QEA combination that get influenced by the strategy.

In this case, we see that to shift from M0 to M1, partnerships and collaborations are made with industry partners that deliver similar functionality as a company's product.

Step 7: Analyse the results of the case after the product was commercialised.

Creating collaborations, partnerships and codeveloping the digital camera with Nikon allowed them to push the market to the M1 stage. Therefore, their final QEA combination is P2-C2-M1.

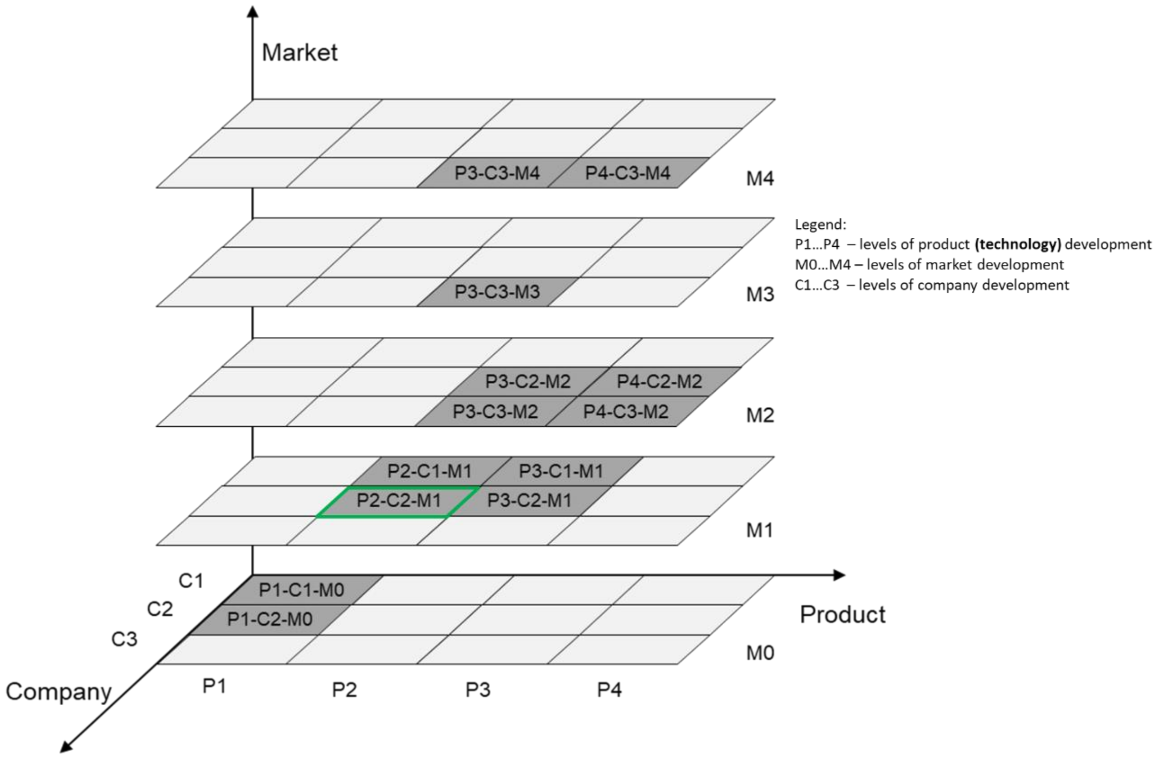


Figure 37. Fuji film new QEA combination, P2-C2-M1 using collaborative innovation.

Conclusions: Firstly, we see that Fujifilm commercialised the product following the S-curve recommendation for Stage 1 products. Moreover, we see open innovation practised in terms of partnerships and co-development of a project that seem to have influenced few elements of the QEA cube, namely, the Market. Now we have a clear representation of a “before state” an “After state” and the “change variable”. Similarly, the researcher analyses all cases by considering the available facts and data to investigate emergent patterns and themes that could be used to build a new framework to answer the research question.

6.7 Extraction of patterns and themes from data

To answer our research question of which open innovation strategy is most appropriate for a specific scenario, the researcher detects an emergent pattern of the same open innovation mechanism used that influences an element in the QEA. The conclusions and results are not drawn from a single case but are verified based on the frequency of an open innovation mechanism seen in all 20 cases. For example, to move from C3 to either C2 or C1 conditions, companies employ an open innovation mechanism of creating a spin-off company, isolated subsidiary, joint venture or a separate business unit that operates autonomously under the company (extract from results chapter 7).

Table 14 shows an overview of all the cases analysed using QEA in the before state, the after state and the open innovation mechanism deployed. Additionally, the table also shows whether the QEA combination is within the allowed set. It started with a case study column, wherein we see the company's name and its location. Next, the product or technology to be commercialised is stated. We then map the initial QEA combination (before commercialisation). Based on data, we fill in the open innovation strategies or mechanisms used by the company. Post which, we assess the QEA fit (successful or unsuccessful) according to the thirteen combinations mentioned in section 5. Lastly, we assess the impact of the open innovation strategy on QEA or which elements are influenced. For example, university collaboration as an OI strategy influences products' S-curve position to shift from P1 to P2.

Case Study and country	Product /technology	Initial QEA condition	Change variable: OI strategies/mechanisms used	Final QEA condition	QEA Cube fit	Influenced QEA element by OI mechanism
Kodak, USA	Digital camera	P1-C3-M0	NA	P2-C3-M1	No	NA
Fujifilm (Japan)	Digital camera	P2-C2-M0	Partnership, collaborations, and co-development with Nikon	P2-C2-M1	Yes	Market: M0 to M1
Saule Technology, Poland	New process for perovskite solar cell	P1-C2-M0	Publicly funded RandD consortia, university research grants, Joint Public projects. Collaboration with large energy companies	P2-C2-M1	Yes	Product: P1to P2 Market – M0 to M1
Wilibox(LigoWave) USA	Software technology for OTA updates and remote operations	P2-C1-M0	Joint venture with competitor Deliberant. Joint venture with Teltonika	P2-C2-M1	Yes	Company: C1to C2 Market M0-M1
Selvita Poland	Drug development service business of selling the IP for drugs	P1-C2-M0	Collaboration with universities and researchers. Partnerships with medium and large-scale medical enterprises, IP licensing and selling	P2-C2-M1	Yes	Product: P1 to P2 Market – M0 to M1
Timbeter, Estonia	Technology of image recognition for timber measurement	P2-C1-M0	Collaboration with forestry industry and government and other forestry companies	P2-C1-M1	Yes	Market – M0 to M1

Flomon technologies, Czech Republic	Technology for network monitoring using ML an AI	P1-C1-M0	Collaboration with an industry leader Ixia and university research collaboration grants	P2-C2-M1	Yes	Product: P1 to P2 Market: M0 to M1
HealBe Corp, USA	Smart health band that tracks calorie intake	P1-C1-M0	Crowdfunding (Indigogo), a joint collaboration with Universities research, collaborations with other companies	P2-C2-M1	Yes	Product- P1 to P2 Market- M0-M1
Bose Ltd, USA	Earphones that let you sleep better Sleep buds.	P3-C3-M0	Acquisition of Hush technologies(start-up), crowdfunding	P2-C2-M1	Yes	Company-C3 to C2 Product- P3 to P2 Market-M0 to M1
Saulės Vėjo Aruodai, Lithuania	Collect and Reflect double-sided Blinds that saves energy	P1-C1-M0	Collaboration with the local blind manufacturer, IP-Licensing	P2-C1-M1	Yes	Product- P1 to P2 Market-M0 to M1
Intel, USA	New technology development for chip and architectures	P1-C3-M0	University research collaborations, Contracted R and D services, Spinoffs, venture capitalism for start-ups, Autonomous subsidiaries inside Intel	P2-C1-M1	Yes	Company-C3 to C1 Product- P1 to P2 Market- M0 to M1
Oatley, Sweden	Enzyme technology to convert solid oats to liquid	P2-C1-M0	Collaborations with direct food chains and grocery, Funding from Public and private sectors	P2-C2-M1	Yes	Company-C1 to C2 Market- M0 to M1
Baltled, Lithuania	LED lighting solutions company	P2-C1-M1	Strategic alliance, a joint partnership with Japanese company	P3-C2-M2	Yes	Company-C1 to C2 Product- P2 to P3 Market-M1 to M2

Instax, Japan	Instax Instant Camera (Fujifilm)	P3-C3-M4	A strategic business unit of Fuji film (like a daughter company)	P2-C2-M1	Yes	Company-C3 to C2 Product- P3 to P2 Market- M0 to M1
Elinta, Lithuania	3d Foot scanner for orthopaedic applications	P1-C1-M0	Joint collaboration with Baltic ortho service and public-funded Rand D. Collaboration with Delacam(relatively large company)	P2-C2-M1	Yes	Company-C1 to C2 Product – P1 to P2 Market- M0 to M1
Sewio Networks, Czech Republic	UWB technology for precision location tracking Indoors	P2-C1-M0	Partnership with Open collaboration programme Delawave , Funding from Venture capital Y-soft	P2-C1-M1	Yes	Market-M0 to M1
Deeper UAB, Lithuania	Portable Sonar technology for Angling	P2-C1-M0	University collaboration, crowdfunding and collaboration with Amazon, Walmart and sports selling manufacturers	P3-C3-M2	Yes	Product- P2 to P3 Market- M0 to M2
Airbus-Infactory Solutions, Germany	A sensor that performs quality inspections of composites automatically	P1-C3-M0	Spinoff company from Airbus, isolated subsidiary with independent operations	P2-C2-M1	Yes	Company-C3 to C2 Market- M0 to M1
Anyces, France	Bluetooth technology allowing communication between with other objects	P2-C1-M1	Collaborations with large companies in communications technology	P3-C1-M2	No	Product- P2 to P3 Market -M1 to M2

Uber, USA	Fully driverless autonomous vehicle technology	P1-C3-M0	Contracted RandD services, Venture capitalism, sold off division, equity stake in Aurora(start-up, separate company)	P1-C2-M0	Yes	Company C3 to C2

Table 13. Overview of Cases analysed with their change variable.

7 Results

In this section, we summarise the results of the analysis and the emergent trends that answer our research questions. The trends can be divided into three main parts, product-related trends, company-related trends and market-related trends. Within each part, we can either have an ascending (moving from 1 to 4) or descending order (moving from 4 to 1) of the QEA combination. In some trends, it is also important to notice the company's size as it seems to affect the choice of open innovation mechanism. Let us break down the findings into three parts to understand them better.

7.1 Research finding 1: Product-related trends.

The first significant finding applies explicitly to start-ups and small companies wherein new technologies that are not on the market (P1 stage) are being developed. In the case of Saule technologies, Selvita, Flomon technologies, Elinta, HealBe, (refer to table 13), these companies had their products on P1; however, they are typically small companies of either C1 or a C2 stage. From the cases mentioned earlier, it was seen that if the company size is small, that is, a start-up or a C1 stage, they try and use existing resources to gain funding and use it to develop the product until at least a prototype phase. There are a few special mentions in the cases mentioned above, such as Saule technologies and Selvita. This is because the public funding that these companies received was more than $ 10 million, which is a C2 criterion. In the case of Saule technologies, the funding was used to develop the manufacturing process for scaleup activities. For Selvita, funding was used to accelerate drug development and hire more university scientists.

Interestingly, venture capitalist investments and funding were absent in the above cases. From a business logic perspective, if the technology or the product is not proven on at least a prototype scale (physical lab-scale working stage), no industry partners or venture capitalists are interested in investing their capital. To reach the prototype stage, the company still needs funding. Therefore, small companies, mainly start-ups, rely on existing infrastructure to gather funding and develop products to a point where they can be ready to scale up and enter the market.

To shift from P1 to P2 small companies and start-ups use the cheapest available resources from existing infrastructures like joint development projects with universities, collaboration with other university researchers, university research grants, publicly funded R and D and sometimes contracted R&D services. However, the problem of funding seems to disappear for large giant companies(C3) stage. For example, Larger companies like Intel's case (refer table 13) use university research collaborations as one of the main strategies to accelerate R&D and bring products to market. This conclusion is logically true from the business perspective as larger companies already have the capital and funding needed to develop technologies. Therefore, they do not rely on publicly funded R and D or university research grants but still need competencies for getting new products and technologies to the market.

This finding indicates that to shift from P1 to P2, the primary need for all three types of companies is acquiring knowledge partners' competence, i.e. university research. On the other hand, large companies can buy intellectual property (IP) or acquires the company that owns the IP. For example, in case of Bose Ltd, a manufacturer of premium audio products, acquired a small start-up called Hush technologies in the year 2017. Hush technology developed and commercialised a product that helps user sleep better. Upon deeper analysis, it was seen that Hush technologies were granted a patent on an improved sleep masking technology in March 2017. Bose acquired the company just after the patent was granted (in august 2017). Later, Bose came up with a new product called sleep-buds that play masking sounds that help the user sleep better. Therefore, it is very likely that Bose acquired the company because of the patent that the start-up company-owned. Also, C2 and C1 stage companies are too small and lack the capital needed to acquire another company, and only large C3 companies can afford it. Once the product reaches stage II(P2), it will start growing and ascending to stage III and IV according to S-curves naturally. The regular TRIZ based S-curve analysis recommendations apply to the product from stage II onwards.

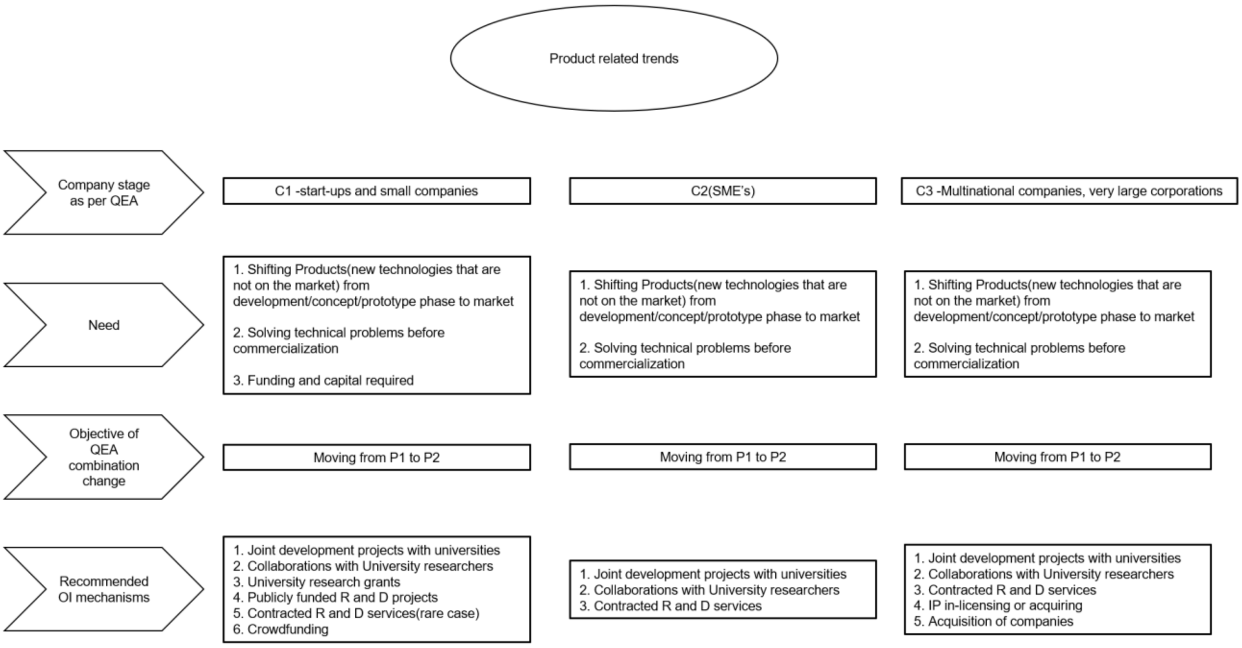


Figure 38. Shifting from P1 to P2 in QEA

Generalised recommendation for this condition: Find existing knowledge partners and use the OI mechanisms mentioned in figure 38. Suppose it is a small company and does not have the funds or capital to develop the product, use existing pubic-related infrastructure to gain funding and recruit knowledge partners. Larger companies can use OI strategies like joint development of products, contracted research and development services, IP acquisition, in-licensing or acquiring the company (provided it has the knowledge needed to push P1 to P2).

7.2 Research finding 2: Market-related trends

Once the product gets to the P2 stage, companies must win the market. This is mainly because the combination for start-ups that is P2-C1-M0 fails according to QEA, and the only way to make it succeed is to push the M0 to M1(P2-C2-M1). In many of the cases analysed, it was seen that start-ups made collaborations and partnerships with companies that were leading in the market segment and deliver the same function as their product. Moreover, it was also noticed that C1 companies that need to push the market to the M1 stage partner up and collaborate with companies that have access to broader markets, have existing sales and distribution channels, and lend their manufacturing facilities. Once again, this makes sense from a business perspective as funding is still limited and brand development strategies are still being formulated. Therefore small companies try to use existing players that have enough market visibility to expand their sales.

It was also noticed that partnerships were made with leading companies in the market segment (naturally, they will have higher visibility in the consumer's eyes) and delivered a similar functionality as the start-up’s product, for example, in Flomon technologies(refer to table 13), a software technology created for network traffic monitoring and anomaly detection using machine learning and artificial intelligence partnered with Ixia. This large company had wider audiences and on existing cybersecurity-related business. Another example can be from BaltLed, a manufacturer of lighting solutions partnering up with one of the Japanese leaders to expand their market. In some cases, like Sewio networks, it was also seen companies would try an attempt to receive venture capitalist funding from a VC who already owns a manufacturing facility and is willing to lend it to the start-up. Sewio networks was funded by a VC called Y-soft that provided manufacturing facilities, distribution channels and logistics. Similarly, Oatley (refer to table 13) received funding from public and private investor that already owned manufacturing facilities, distribution and sales networks. Oatley could leverage this competency and reach the market faster. However, it was also noticed that venture capitalists are typically interested in finding the product only at the P2 stage. Notice the Sewio networks and Oatley case, both technologies were at the P2 stage. At the P1 stages, VC finds it hard to believe and is not convinced to fund the venture. When the technology reaches a proven in practise stage, then the VC becomes interested in funding the start-up.

Crowdfunding was also seen as a trend in 2 to 3 cases where early adopters were reached through platforms like Indigogo. For example, cases Healbe, Deeper UAB and Bose used crowdfunding to gain early backers and adopters for their product. It is also one ways to estimate the demand and market size for an unknown market for new products.

C1 and C2 stage companies also used IP licensing and selling to reach the market as it allows them to grow without a manufacturing a physical product. Therefore, they simply sell the know-how and distribution rights to other partners and out-source manufacturing. For example, in Case Seltiva and Saulės Vėjo Aruodai, IP licensing and selling is used as a main business strategy instead of physically manufacturing the product themselves. Recently, Saule technology is also looking for partners to license their technology and know-how to reach wider markets without manufacturing the product themselves.

C3 company practically do not worry about access to the market because they are large enough and globally present to manufacture products themselves. However, some large companies do not want to risk their capital for a radically new product when entering new niches and unknown markets. Therefore, they may choose crowdfunding as one open innovation mechanism to solve this problem. This was seen in the case study Bose Ltd sleep buds(refer to table 13). The reason behind crowdfunding was not the capital but to assess the market demand and the market size to plan accordingly. The original sleep buds failed not due to a business issue but because of a technical battery glitch; thus, the product was withdrawn from the market. However, the second generation of sleep buds is a commercial success resolving all technical issues and is well received by target audiences.

Figure 39 summarises market-related findings wherein only a handful of OI mechanisms are used according to QEA.

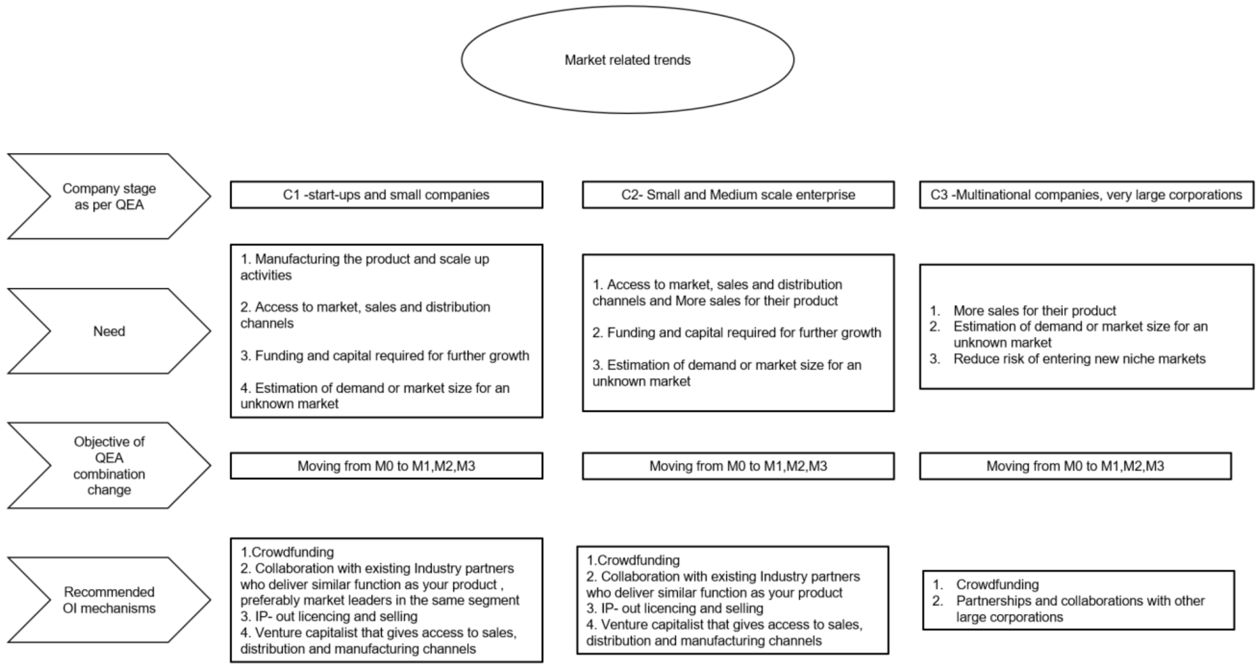


Figure 39. Shifting from M0 to M1, M2, M3 condition

Generalised recommendation for this condition: For C1 companies, identify and collaborate with market leaders in the segment or VC, those that already possess the reach, visibility, distribution channels, have a wide segment of customers and potentially could lend manufacturing facilities for the product. Identify partners who deliver similar functionality as your new product. Conversely, explore the possibility of IP out-licensing and selling it to external distributors who deliver similar functions as your product instead of manufacturing it yourself. Crowdfunding is also a recommended option to estimate the market size for an unknown market and to gain early adopters for the product.

7.3 Research finding 3: Company related trends.

In this section, a special trend for C3 companies, namely large giants and MNC corporations, was observed. We already know that according to QEA, the C3 company stage does not play well with the P1 and P2 stage of products. The reasons for this have already been stated in the literature review. Some of them are bureaucracy, loss of agility, processes involved complexity of the organisation, et cetera. However, this does not mean that large MNC corporations cannot produce radically new technologies. Special measures are taken to ensure that dynamism and flexibility are maintained within the company using organisational strategies.

Organisations like Bose Ltd acquired a small start-up hush technology (C1 stage company) and internally gave control to the department outside of the MNCs typical management. Sources say that hush technology operated separately (strategic business unit) within Bose to develop the sleep buds. Moreover, according to Chesbrough, Intel(refer to table 13) also uses a similar strategy within its organisation with autonomous departments (like C1 companies) that are flexible and detached from regular Intel management (Chesbrough, 2003). Additionally, companies like in the case study of Airbus created a spin-off called in factory solutions. However, it operated under a different CEO, product team and management isolated from Airbus. Expert 1 added that companies such as Apple follow a similar organisational structure to ensure agility in NPD. Creation of such strategic business units or departments isolated from the company minimizes bureaucracies and provides flexibility to research and development teams to operate better.

Therefore, if a C3 company attempts to develop a P1 or P2 product, an example could be Kodak with its digital camera, it would inevitably fail due to management reasons. Conversely, preventive measures such as acquisitions, creating joint ventures, spin-offs, daughter companies, autonomous departments, and subsidiaries resolve the contradiction , where a company is at a C3 state and yet has a C2 or a C1 company's characteristics.

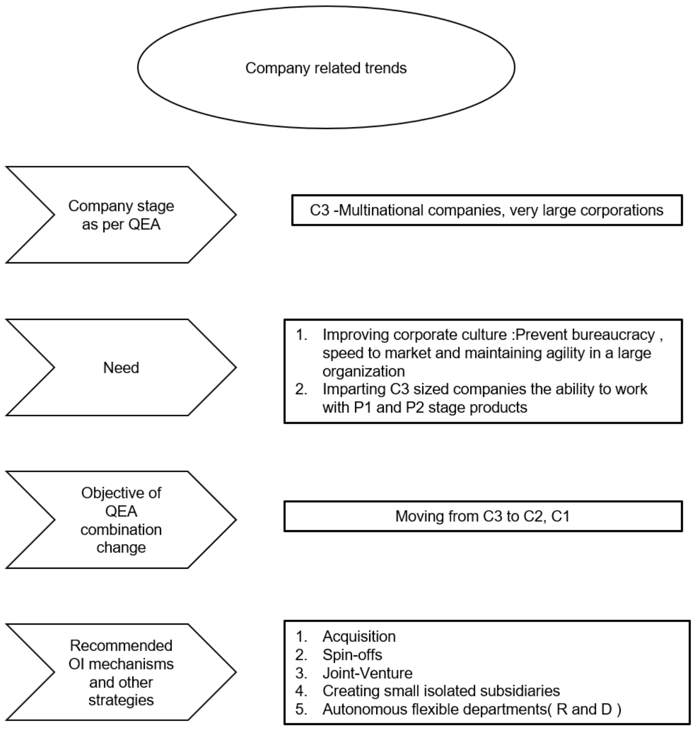


Figure 40. Shifting from C3 to C2, C1 condition

Generalised recommendation for this condition: If the company is in a C3 state, then attempt to use the recommended OI strategies and other mechanisms mentioned in figure 40 to impart characteristics of a C1 or a C2 organisation to increase the probability of commercial success. This move adds dynamic proactive decision making (refer to section 5.5.1 and 5.5.2) and minimises the traditional bureaucracies in management that accumulates over a period of time in firms.

Although the findings have been represented in three separate parts, their implications and practical use are simultaneous. Meaning, sometimes it is necessary to shift multiple parameters either ascending or descending simultaneously to gain the best possible recommendations. For example, it is possible that a company's current state is P2-C3-M0 which is an unsuccessful combination and needs to shift C3 to C2 and M0 to M1 simultaneously, to be commercially successful by QEA logic to end up in P2-C2-M1. Nevertheless, these recommendations are practical and universally applicable for any company, product and market.

8 Discussions

This research attempts to recommend OI strategies using Quantum economic analysis for any given product, market and company. The researcher analyses several case studies to identify the impact of an OI mechanism on QEA before and after the new product commercialization. The research findings include three main patterns: shifting of products from P1 to P2, shifting the market from M0 to M1, and shifting the company stage from C3 to C1. A set of suitable OI strategies have been elaborated in chapter 7 for the conditions mentioned above. This research provides a practical tool for decision-makers that can be used during NPD not only for idea screening purposes, but also providing suitable open innovation strategies applicable for a business.

Firstly, in section 2, Grupp and Schubert (2010), Patel and Pavitt (1995) stated that a catch-all indicator of commercial success could not exist. However, the QEA tool with its 13 combinations provides such an indicator. It also covers all three entities of the definition of successful innovation: product, market, and company (Taylor, 2017). It goes a step further by considering the synergies between these three entities and provides a simple yet important indicator of commercial success using the S-curve position. This allows QEA to be generalised and be applicable to any given product for any given company.

In chapter 2, we review many idea screening tools used in NPD to assess concepts' commercial potential (Cooper, Edgett and Kleinschmidt, 2001; Meredith and Mantel, 2009). While these tools are effective in NPD, they fail to capture any information regarding S-curves and how it impacts NPD's commercial success. In contrast, the modified QEA tool integrated with OI provides additional information to provide new insights into product development strategy and business strategy. For example, if a product is at the P3 stages, decision-makers immediately know that all ideas and concepts related to increasing the functionality at the expense of increased cost must be rejected. Additionally, TRIZ based S-curves provide a clear recommendation of cost reduction and development of service components for the main product (Lyubomirskiy *et al.*, 2014). Simultaneously, OI strategies will allow decision-makers to plan for future business development activities, though they are preliminary, accelerating speed to market.

The QEA-OI screening tool is not built to replace any of the traditional tools but instead provides an additional output to support other idea screening tools (Cooper, 2002). The tool provides innovation and business-related output unlike any of the other idea screening tools. The QEA-OI tool used in conjunction with the traditional idea screening tools would provide the traditional feasibility assessment perspective and business-related perspectives simultaneously in the fuzzy front end. This allows decision-makers to make better informed decisions for selecting and developing strategies for new products in the short, mid and long term. This step can also reduce the failure rates of innovation lower than current situations (Castellion and Markham, 2013).

We also review some characteristics for a good idea selection model: realism, capability, flexibility, ease of use, cost, and ease of computerisation (Meredith and Mantel, 2009). QEA tool integrated with OI fits well into all of the criteria defined by Meredith and Mantel. QEA reflects realism-based companies' access to capital in just three distinct stages, C1, C2 and C3. It reflects flexibility and robustness due to a handful of successful combinations possible for any product type. QEA is relatively easy to use and implement. Lastly, it considers multiple factors at once under the same roof, ranging from technical perspective , managerial perspectives, and consumer behaviour-related perspectives elaborated in chapter 5.4 onwards (Topchishvili, Katsman and Schneider, 2003).

In chapter 3, we review the main strategies used to reduce the uncertainty during NPD. Wherein, frontloading of activities or making activities parallel helps increase speed to market by considering future constraints (Jetter, 2003). This research complements Jetter's findings by frontloading business development activities. The QEA-OI tool helps make the preliminary business development activities parallel throughout the innovation process. We consider many future considerations (assess where the next successful QEA combination will be) and business challenges to recommend a suitable open innovation strategy. Business development activities like identifying partners, university collaborations, IP licensing and selling, acquisitions and other OI related mechanisms can begin at the idea screening phase itself, instead of waiting for prototyping and piloting phases, thereby increasing speed to market.

Lastly, the QEA screening tool was unknowingly validated by testing it out on cases during the analysis phase. According to the cases analysed, the researcher found a 100% success rate of QEA after commercialization products. On the contrary, when expert one experimentally validated QEA in his research, the success rate was 88% (Abramov, Markosov and Medvedev, 2018). In this thesis, the QEA success rate is likely to be an extreme case or an overestimation of the result. Research ethics are considered in this situation wherein the author checks for statistical evidence whether the results of QEA in his study and another researcher are comparable.

The researcher performed a 2-sample proportionality test and stated the null hypothesis as "the author's QEA success rate is equal to the success rate of another researcher with no statistical difference". The resulting P-value was 0.165. The P-value indicates that the author and another researcher's success rate are statistically speaking, similar to each other with a 95% confidence levels. However, this finding may not be conclusive as the sample size is less than 50 cases in both groups of data analysed. Moreover, other methods for verifying reliability are suited to this study due to its qualitative nature. Therefore, it is necessary to test the QEA method on a broader dataset to prove its reliability further.

9 Conclusions

In this section, we review the research topic results and reiterate the research questions that have been answered through the study. Lastly, we stayed some limitations and topics for future research.

This thesis's objective was to create a new method that acts as a preliminary step towards a full-fledged feasibility study that takes heavy resources from the company. This would allow the company to reject concepts and ideas early and save time, money, human resources for unpromising ideas.

This research started by exploring the answers to the two research questions mentioned below:

RQ1: How can QEA and Open innovation be integrated?

RQ2: How can we identify the most appropriate set of Open innovation strategies for any given business system using QEA?

In section 3.2, we reviewed several concept selection and feasibility methods (Factor 1) used in the NPD process stating their advantages and disadvantages. To answer research question one, the researcher developed a new tool based on OI patterns extracted from case studies and map them according to shifting QEA combinations. Moreover, QEA is also represented to be integrated into the stage-gate process, that allows for frontloading of activities and reducing risk.

Integrating QEA and OI to create a new tool does not replace the traditional concept selection methods. However, it supports it by acting as a preliminary step before conducting a detailed analysis and feasibility study. Moreover, this research provides a practical hands-on tool that is easy to implement, provides adequate output and makes strategic decision making easier by frontloading many of the activities performed at the end of the stage-gate process.

As shown in figure 41, we use QEA screening for each concept and note the specific combination. If it is within the successful fit of the QEA, proceed with technical benchmarking and traditional feasibility checks to end up in the sweet spot. If the idea or concept falls within the unsuccessful region of the QEA, use OI strategies to convert this combination to a successful one and proceed with technical benchmarking and traditional feasibility studies. In both cases, we get an early recommendation of what needs to be done and more importantly, what should be avoided. By using the method, we attempt to be roughly right rather than completely wrong.

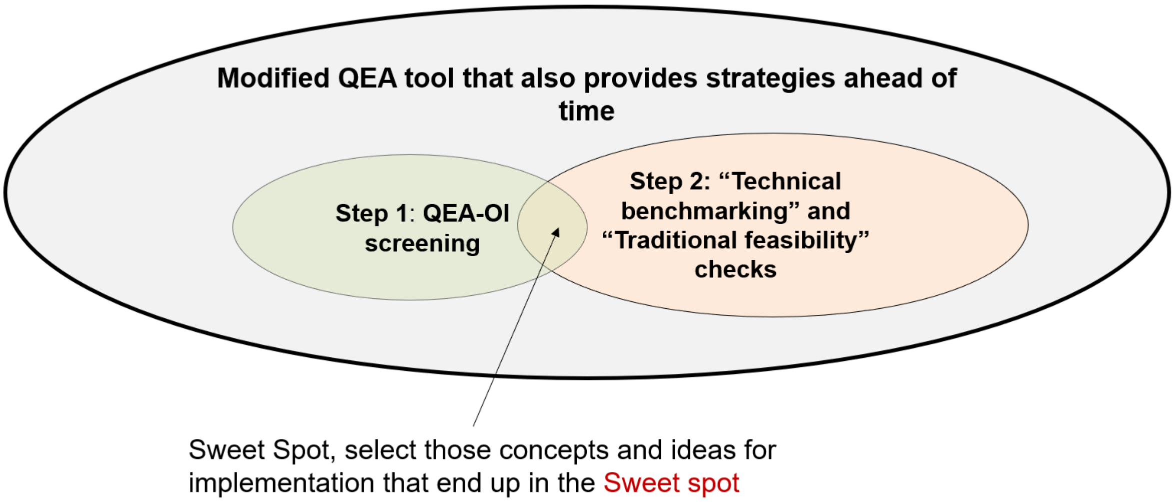


Figure 41. Integrating QEA-OI screening with the stage-gate process.

The algorithm for the modified QEA-OI tool is shown in figure 42. The flowchart below illustrates a roadmap integrating the proposed method in real projects involving NPD. The key takeaway from this flowchart is that, if it is impossible to shift an unsuccessful combination to a successful one, drop the concept or idea and reject the QEA losers. This way, we can save time and resources without pursuing unpromising directions at the early stages. We have successfully answered research question one, where QEA and OI have been integrated into the stage-gate process to improve the efficacy of innovation and business-related success.

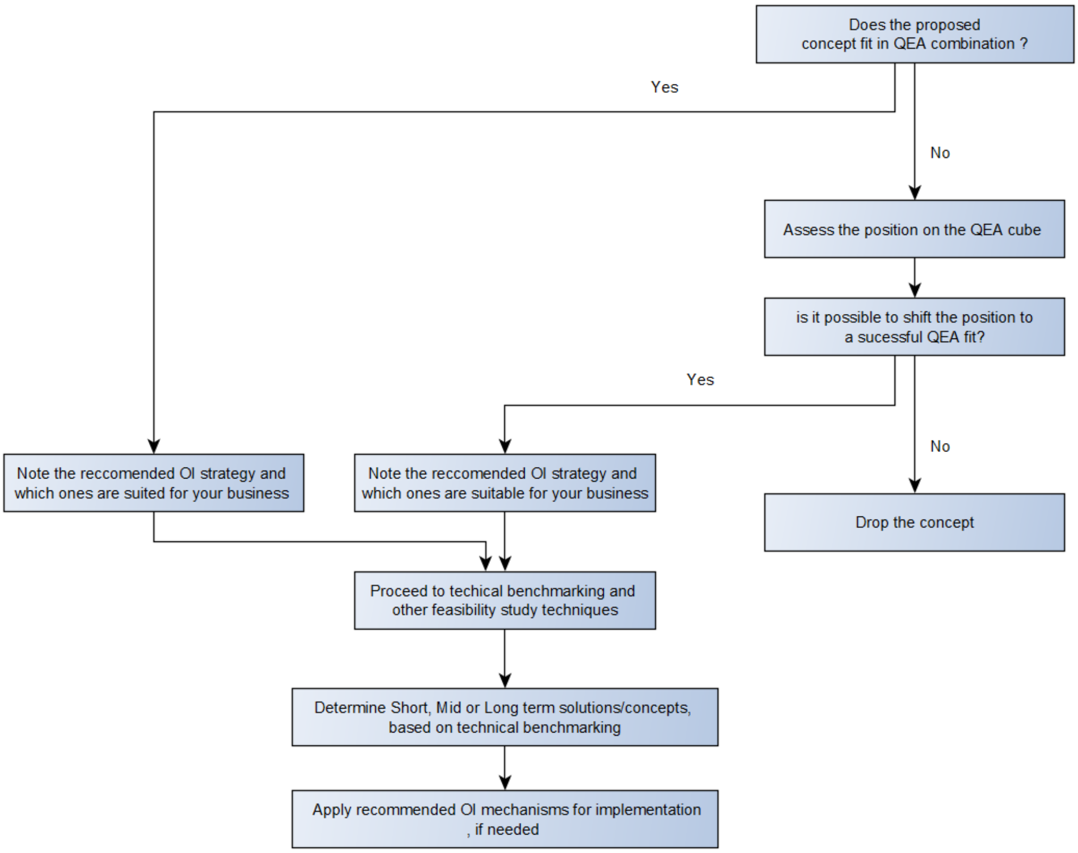


Figure 42. Algorithm for QEA-OI implementation in real projects

To answer research question two, we now know that QEA provides the "when" (under which condition a specific OI strategy can be used)of the research and corresponding OI strategy resulting from the patterns in the case studies presents the "what" (OI strategy used) of the research. According to QEA, it was also shown that not all OI strategies and mechanisms are applicable in all conditions. Therefore, the researcher successfully answer research question two to provide a roadmap of suitable and most appropriate OI strategies that can be used for any given business system using the QEA screening tool.

9.1 Theoretical contribution

The major contribution of this research is towards the implications of the S-curve theory. Heijer, 2010 conducts an in-depth analysis of the managerial usefulness of S-curves. He concludes by saying that some of the practical implications of the S-curve theory are absent. Heijer argues that determining the exact position of the S-curve is a time-consuming and complicated process. Additionally, there is no well-defined process for positioning system on the S-curve and does not provide any useful tools to managers (Heijer, 2010). Secondly, he argues that which specific technology will take over an existing technology S-curve cannot be predicted. Lastly, he argues by saying that the predictive value of the S-curve is not sufficient. Therefore, he concludes that the managerial usefulness of using S-curves is next to none (Heijer, 2010).

In contrast to Heijers work, modern TRIZ has established a systematic procedure to determine the S-curve position using qualitative indicators (elaborated in section 5) from the market and the product (Lyubomirskiy *et al.*, 2014). Moreover, TRIZ also addresses predicting and forecasting the technology reliably through the Trends of Engineering Systems Evolution (Lyubomirskiy *et al.*, 2014). Lastly, to address the problem of multiple S-curves within an S-curve, recently TRIZ implemented the Pragmatic or Integral S-curve analysis approach that considers each parameter of the system to integrate and position it on the curve (Lyubomirskiy *et al.*, 2014). It already provides product-related strategies for each stage and recommends improvements proving its managerial usefulness.

However, the recommendations that TRIZ provides lacks any company related, market-related and open innovation-related strategies. This research fills in the gap by expanding the TRIZ body of knowledge in other territories, such as business strategy and open innovation. This, in turn, increases the S-curve theory's managerial usefulness and widens its application by expanding it to managers and decision-makers. Additionally, it also expands the TRIZ body of knowledge to business and management applications, an emerging area in academia recently (Souchkov, 2007; Litvin, 2011; Teplov, 2014; Vicente-Gomila and Gomila, 2015).

Furthermore, Open innovation and TRIZ recently been an area of interest for researchers all over the world. Recent research has tried to integrate open innovation and TRIZ. Some studies include linking inventive principles to SMEs using open innovation models, solving problems of adoption of OI using TRIZ, comparisons between approaches of TRIZ and OI and integrating TRIZ approaches to out-bound OI via reverse function-oriented search (Bianchi *et al.*, 2010; Hanifi *et al.*, 2016; Otavă and Brad, 2020). However, the number of studies is extremely low, and none of them provides a new method or a tool that combines both methods effectively.

The QEA-OI tool is perhaps the first tool that successfully integrates them by providing the strength of TRIZ through S-curve analysis and strength of open innovation through its strategies that can help firms innovate better. Moreover, a combination of methods also may allow TRIZ to gain more visibility in the world and increase its popularity to inculcate systematic innovation for research and development teams.

Husig and Kohn’s (2003) empirical study states that “the influence of the types of innovation, industry-specific differences, stage of product/industry/technology life cycle, and market dynamics are contextual factors that have been set constant or ignored in most of the studies. How do these interact and influence the fuzzy front end activities and affect the success of new products is unanswered” (Hüsig and Kohn, 2003,p. 13). This research directly addresses the limitation in the above study by providing the characteristics of different product stages, market stages and company stages and their potential impact on the fuzzy front end. QEA explains the dynamics of different S-curve stages of product, markets and companies. The product covers factors like technology lifecycles; the company covers elements such as the firm's age and structures; lastly, the market covers different consumer behaviour aspects (Topchishvili, Katsman and Schneider, 2003).

9.2 Managerial implications

This section discusses the industrial use of QEA screening, who should use the tool and justifications for using it. We include knowledge contributions expert one regarding the tool’s applicability, industrial use case, target audiences and justifications for using QEA.

Industrial use of QEA based screening:

Expert one has extensive experience with the QEA method since 2010. However, this method was recently implemented in their company Gen-TRIZ has been standardised their innovation processes. So far, it has been officially implemented in seven full-blown projects with clients.

In many consulting projects, brilliant solutions were delivered to the client; however, they were never implemented. The solutions were technically feasible, commercially viable and up to a point where clients could develop them further and commercialise them with relatively less effort. This situation seems to have inspired expert one to identify why brilliant ideas and concepts, even though technically feasible, were not implemented by the client. In 2010, he came across the QEA method through the original book called “the science to win in investments, management and marketing” written by Topchishvili, Katsman and Schneider, 2003. Wherein, The book claimed to have identified certain combinations or conditions that succeed more than others. The book answered many questions that expert one had in his mind about NPD failures despite delivering brilliant solutions to the client. The book explained several phenomena occurring in the business side of innovation that lead to the failure of even the best technologically superior products using several case studies.

However, to believe in the method and use it in real projects, he needed to test it himself. Therefore, in 2017 expert 1 conducts an experimental design to validate the company's QEA method internally. The experiment's objective was to validate the method by assessing the solutions were “successful” according to QEA and checking the result in the real world by tracking the situation of the solutions delivered to the client. The result was a staggering 88% accuracy achieved in the experimental test. This convinced expert one that something unique about the method could be utilised to deliver value for their clients (Abramov, Markosov and Medvedev, 2018).

Since then, QEA has been used in the stage-gate process after the idea generation phase to screen concepts. However, it is used in combination with traditional criteria-based benchmarking and does not substitute it. It is now a new TRIZ tool implemented as a standardised procedure since 2018. Concerning other companies that use QEA, currently, there are not many. Expert one says it may be because TRIZ itself is not a very popular tool globally; therefore, QEA is scarcely known in the innovation industry.

So far, many of Gen-TRIZ clients have asked for the explanation and logic of QEA and are interested in using the method for their innovation projects and NPD because they believe that it’s a quick and immediate way to assess ideas. Some also confirmed that it brings a unique element to traditional screening processes. QEA has been used in industries such as nuclear, filtration, fertiliser, power plants, preservative manufacturing and others.

Who should use QEA screening?

According to expert one, QEA is very easy to apply as a method and is quick; however, it requires knowledge of basic knowledge of TRIZ, specifically for determining the product's developmental stage. However, it can be applied by an individual with basic TRIZ training. In an ideal scenario, it should be used by Head of Innovation teams, key decision-makers, and Operation Heads and those that are involved in the stage-gate process, as it attempts to guide a strategic decision in terms of business, product development and technological direction.

Why should an individual use QEA?

According to expert one, one of the critical reasons to use this method is S-curves. QEA is based on S-curves. The expert quotes, “S-curve is a universal trend that manifests itself, not just in engineering systems but also in business systems. Ignorance of the S-curve would most likely end up in a business failure. Therefore, companies need to analyse it, research it and figure out how it works in the business world.”

Moreover, he also agrees that S-curves are comprehended as a phenomenon in the business world and innovation management but not used practically. However, TRIZ has been the methodology that tries to use this phenomenon and knowledge and puts it in practice to benefit from it and prevent failures. It allows companies to avoid the wrong strategic path that they may end up using traditional methods.

How do we interpret the successful and unsuccessful combinations in QEA?

According to expert one, it is wrong to understand that if a concept falls within an unsuccessful combination of the QEA, it would be unsuccessful. He claims that success is still possible with an unsuccessful combination; however, it would take more efforts, money, time and resources to commercialise it. Therefore, the right understanding would be that unsuccessful and successful combinations in QEA allow us to distinguish between short-term, mid-term, and long-term concepts. The farther the combination from and allowed a successful set, the more time and resources it may take to commercialise the idea.

Open Innovation and QEA

Expert one and two agree that there is a clear research gap between TRIZ tools and the world of business management, innovation management or, in this case, open innovation. Expert two also states that in the current condition of QEA, it does not give any strategic directions to the decision-maker apart from product or technology related recommendations. QEA needs more managerial usefulness, praticalality and strategies of what to do in a particular situation. This research successfully delivers just that.

This research is unique, as it attempts to merge two different domains in the innovation industry, namely TRIZ and innovation management. Such attempts have been made before on a managerial and theoretical level. However, this is the first time that S-curves have been integrated with a popular approach like open innovation. Especially when speed to market, shorter NPD cycles and reducing the risk in the fuzzy front end is an absolute necessity for efficient resource management for the company. This research aims to target two different audiences. First, TRIZ consultants and professionals using the TRIZ method in projects wherein the research can provide additional value by recommending OI strategies that help in business growth and commercialisation. Secondly, for open innovation practitioners that have been in a dilemma of selecting the most appropriate OI strategy for their business. It provides the best of both worlds and attempts to create a larger community of TRIZ-OI innovation professionals through a practice-based hands-on tool.

9.3 Limitations and future scope of work

Data related limitations: In this research, data availability was one of the most important factors to establish results and findings. This research only considers a few open innovation mechanisms and strategies as mentioned in the cases. Moreover, the dataset analysed was limited to 20 case studies which were restricted by research timelines. It is recommended to test the modified QEA tool on at least 50 case studies or more for better generalisability. Some of the case studies sources were extracted from Chesbrough's (2003), and McGrath (2014) works. The data collected by Chesbrough may date as early as 1995; by the time the book was published, there may have been changes to the respective cases covered in the original books. Lastly, the original works of QEA were published in the Russian language and were translated (using DeepL translator) to English using one of the best online translating tools. Despite using good translation software, there could be a possibility of lost information during translation, which may alter the context's meaning and present a flaw in results.

Research related limitations: In this research, we apply a complex research design of a retrospective case analysis which requires the researcher to establish a well-defined timeline of events for a selected case. Though the researcher attempts to establish the appropriate timeline through available data, use of multiple sources and databases, there is a possibility of incomplete data or information that was missed out that could influence the study results.

Additionally, an abductive research approach may also be possible wherein research may conduct an experimental analysis to test the tool using cases for unknown outcomes. Empirical validation of this research could prove vital in its reliability, validity and accuracy of the proposed method in the long run.

QEA method related limitation: the developmental stage of products are assessed by regular Triz based S-curve analysis due to lack of data and information. Pragmatic or integral S-curve analysis was not utilised due to its data-hungry nature on estimating the product's main parameters of value. Currently, well-defined guidelines and a step-by-step algorithm for deploying QEA, searching for adjacent markets with the same product, or using an existing manufacturing technology to produce multiple products are absent. These limitations make it an excellent topic for future research.

Currently, QEA is limited to product, market and company-related factors. However, given the 21st century, one major factor that is not accounted for within this method is business models. Given the variety of business models and business model innovation driving new products' commercial success, it could make an interesting future scope, wherein QEA could recommend strategies and appropriate business models for a given combination. Integration of business models with QEA could be pioneering research and perhaps could also be computerised. This method could become a decision support system that could be automated and provides the appropriate business models, product strategies, and business strategies based on user input.

Additionally, since the QEA method claims to predict commercial success based on S-curves, validating QEA empirically to prove its influence on failure rates of innovation with and without QEA would make an interesting future topic. Empirical validation and deductive studies have tremendous scope for this method to be conducted within different organisations, different types of organisational structures with different products. Perhaps, cultural differences within organisations based on geographical location may impact the QEA cube as well. The immediate short-term research scope could be to test the findings of this research on extensive data-rich real case studies and predict the open innovation strategies used by companies. Lastly, this research may pave the way for improving the managerial usefulness of the S-curve theory and their practical applicability through new tools, methods and processes to accelerate the industry towards systematic innovation.

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