Product development activities over technology life-cycles in different generations

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Abstract

This study aims to capture changes and priorities in product development activities over technology life-cycles. The product development activities are observed through the targets of *performance maximising*, *cost reduction* and *customisation*. Seven models of technology life-cycles are considered to keep track of technology changes over time by following patterns for product development activities. The empirical part of the study is based on analysing a high-tech infrastructure provider on four technology generations. This study depicts different trends of product development activities over technology life-cycles. Different technology generations can have positive and negative interactions which can be strategically beneficial. The managerial implications of this study include comprehensive insights of concurrent technology generations in the context of technology life-cycles which can be beneficial for companies product development planning.

Key words: Product development, Technology Life-Cycle, cost, customisation, technology generations, growth, maturity, declining technology, embryonic, technology gap, high technology

1 Introduction

In recent years, different new industries have been emerging based on different new technologies. Simultaneously many start-ups have not been successful in offering their technologies to major markets. Also many large companies have disappeared along the appearance of new technologies (Assouroko et al., 2014). Hence, studying the ups and downs of recent technologies especially in the high-tech industry is beneficial for both established companies and start-ups. In this study we begin with understanding the concept of technology life-cycle from the product development perspective. Seven different life-cycles (Khalil, 2000; Little, 1981; Abernathy and Utterback, 1978; Ford and Ryan, 1981; Anderson and Tushman, 1990; Rogers, 2010; Moore, 2002) are discussed to give concrete but wide insight on technologies. Also, the fluctuation of product development activities over technology life-cycles is studied from the literature viewpoint.

An infrastructure manufacturer in high-tech industry is chosen to study the life-cycle of different technology generations: A, B, C and D. By studying different technology generations in a single company, the interactions among the technologies can be analysed, moreover, the product development strategies from one generation to the other can illustrate the evolution of the market and the company's insight. Accordingly, product development activities are studied in the life-cycle of each technology generation and mapped by three different focus areas of product development: *performance maximisation, cost reduction,* and *customisation.*

Previous studies try to draw the structure of technology patterns from various perspectives under the name of technology life-cycle (Albert et al., 2015; Khalil, 2000), while studying technology from the generation perspective. However, there are different technology generations that exist concurrently and their interactions with each other are not studied widely. Additionally, different researchers have tried to formulate technology maturity levels and product development activities, yet they are mostly abstract as for example Abernathy and Utterback (1978), or they are more market based such as Moore (2002). Therefore, this study is based on technology life-cycles and product development activities from the technical viewpoint.

Product development activities have been classified in different ways; according to their degree of newness (Wheelwright and Clark, 1992), or core vs. context impact (Moore, 2002), or as strategic/non-strategic (Hambrick et al., 1982). Hence in this study product development is viewed through insights in *cost reduction, performance maximisation and customisation* which are more aligned with technology life-cycle perspectives. Consequently, as mentioned, determining technologies both from the generation viewpoint and their actual interactions have not been widely studied in the literature, although many researches have discussed concepts such as cannibalisation (Cravens et al., 2002), and other impacts of new technologies on older ones (Chandy and Tellis, 1998). Nevertheless, these have not been studied over technology life-cycles, and the existence of the older technologies have not been seen as a potential trump card for companies to quickly attack the market via new technologies.

In this study, the trend of each focus area of product development activities are analysed. Additionally, the positive and negative interactions of different technology generations in different life-cycle stages are noted, which potentially is the most novel part of the study.

The research questions are formulated as:

RQ1: How product development activities can be mapped over technology life-cycles?

RQ2: How do concurrent technology generations interact with each other over technology life-cycles?

RQ 3 What are the priorities in product development activities over technology life-cycles?

2 Objectives and Methodology

The aim of the study is to capture product development activities over technology life-cycles (TLC) and investigate the changes of product development activities by the level of technology maturity. The first step is introducing TLC, as there are different TLCs discussed in previous studies. The TLCs introduce various patterns of technologies over their life time. Initially, seven different TLCs were selected, those that are more related to product development area. In chapter 3.1 these TLCs and their essence are briefly discussed to form basis for mapping the product development activities. Additionally, different stages of TLC's are considered by cross analysing their criteria. The stages of the discussed seven TLCs are merged to ease data collection and analysis, and to increase the accuracy of the results. This way the milestones from TLCs still support the different stages. Product development over TLC from the perspective of competitive impact and degree of newness are discussed in chapter 3.2. Product development activities are studied by three focus areas: *performance maximisation, cost reduction,* and *customisation*.

The empirical part of the study is based on analysing a high-tech infrastructure provider and their data on four technology generations (A, B, C and D). The company has been one of the leaders in its own industry from the very beginning of the industry appearance since 1990s, with over 12 billion Euro net sales in 2015. The company operates in business-to-business markets, even though the current company name was also linked to related consumer products in the near past. The qualitative data was collected by nine semi-structured interviews (Merton et al., 1990) with R&D managers who have been working for different technology generations, and by the means of four group meetings with high-level R&D directors whom have been influential in strategic decisions and are aware of market and technology fluctuations in the industry. Also, some company confidential material such as reports and presentations have been used to support the analysis. The Interviews were conducted informally, in a qualitative manner to allow the interviewees to explain and clarify the cases and topics as entities. All the interviews were transcribed for the purpose of the analysis. The data contained detailed information about the different technology generations, their differences, and all meaningful events, occurrences and developments along the technology life-cycle. This includes the particular development focus areas at different times, and the underlying motivations behind made decisions. The proportional shares of product development activities belonging to the three focus areas were also assessed based on available numerical data and related documentation, exact data however cannot be revealed. The results of these assessments and the relating analysis have been confirmed by the interviewees. The data is as accurate as the company documents can provide and as how far the interviewees can possibly recall. Number of informants providing similar information, can also be seen to support the accuracy of the data.

The high-tech industry seems a proper case industry for analysing *product development activities* further *based on technology life-cycles* due to the industry pace. Additionally, the case company has been active from the very beginning of the industry's emergence; it has been one of the leaders in the industry so they have the information from the past to the present day. Moreover, as they have been one of the most effective companies in their industry, their product development could be seen as one of the most thoughtful ones as they have made meaningful moves throughout the life-cycles. The research process of this study is presented in Figure 1. Literature review on TLCs and product development formed the basis for the interviews. The case company was selected based on the opportunity to have an access to an internationally well-known company whose technology has undergone several generations and was therefore a suitable object for research.

[Please insert figure 1 here]

Section four presents the results of the empirical study. Due to the confidentiality of the strategic information, different portions of product development activities are presented in percentages which, however, should not unnecessarily weaken the creditability of the study. This study is qualitative in nature and aims to understand studied phenomena. This means clarifying the meaning and significance of the analysed phenomenon. The samples utilised by qualitative research are typically discretionary to the researcher. Research objects may not be high in numbers, but are studied thoroughly, emphasising the quality of input material. The size of the sample must however be adequate enough for the type of analysis and interpretations (Patton, 2002; Siggelkow, 2007).

3 Literature Review

3.1 TLC orientation

When a company is implementing any technologies, platforms, or even new products based on new technologies, it is important that they recognise if the technology is growing or disappearing, or if there are any trade-offs with regards the technology´s future (McCarthy, 2003; Burgelman et al., 2004; Gao et al., 2013). Also, there is a strong bond between product life-cycle and technology life-cycle. Product life-cycle can be seen as fluctuations of market (Klepper, 1997) or sales (Cox, 1967) during the products' existence in the market area. The Product life-cycle management area takes care of single products or groups of similar products (Saaksvuori and Immonen, 2008). Product life-cycle management have lots of strategic interaction with the business strategy of a company (Anderson and Zeithaml, 1984) and even product portfolio management (Tolonen et al., 2015). As a result, product life-cycle management theories are helpful for technical and business forecasting (Rink and Swan, 1979). In essence, product life-cycle can be seen as more detailed than technology life-cycle, while technology life-cycle studies can provide influential data for product life-cycle management, Although the definitions in the area are sometimes blurry and not concrete enough (Pinquié et al., 2015). Even Cooper (1983) indicates normative modes for proper product development with seven stages which is similar to the product life-cycle and technology life-cycle, and is in line with product life-cycle management concepts as well.

Technology life-cycle is in some sense a pattern of technology performance over time (Albert et al., 2015, Khalil, 2000). Ideally a company has a different mixture of product development as both “defender of the current technology” and “attacker of the new technology” (O’Reilly and Tushman, 2013; Wheelwright and Clark, 1992). Although the inertia of staying in the market with the current profitable technology is a powerful incentive for managers (Asthana, 1995), the managers should design the technology and product development portfolio in a way that it guarantees not only short term success but also long term victory for the company (Burgelman et al, 2004; Albert et al, 2015). Therefore companies must evaluate the future situation of each technology and the respective probabilities of success (McCarthy, 2003).

There are different technology life-cycles with different stages for various aspects (e.g. Ford and Ryan, 1981; Abernathy and Utterback, 1978; Anderson and Tushman, 1990; Little, 1981;; Erickson et al., 1990; Achilladelis, 1993; Achilladelis et al., 1990; Watts and Porter, 1997; Khalil, 2000; Linden and Fenn, 2003; Rogers, 2010; Moore and Adamson, 2011, Routley et al., 2013). In this study seven different technology life-cycles form the basis of the product development structure (Table1). Each of the seven TLCs investigate technology maturity from various perspectives to ease the evaluation of product development activities based on technology maturity. These Technology life-cycles are selected due to their relevance to product development area. In addition, there are much more defined TLCs which can be found, similar to the mentioned ones but are out of the scope of this study.

The most generic technology life-cycle belongs to Khalil (2000) although the model originated from Fisher and Pry (1971) who aimed to introduce a technology forecasting method. The TLC by Khalil (2000) is based on technology performance patterns and contains four stages: embryonic, growth, maturity, and aging. Even though Khalil’s model is one of the most utilised technology life-cycle models, some studies criticise it due to insufficiency of performance parameters to illustrate economical and technical tendencies (e.g. Murmann and Frenken, 2006; Gao et al., 2013; Ernst, 1997; Lee and Nakisenovic, 1989; Asthana, 1995).

The second model, one by Little (1981) seems to resemble Khalil’s TLC, tough the ordinates of the model are integration and competitive impact. Little’s model is based on different studies on strategic innovation and business planning (e.g. Albert et al., 2015; Gao et al., 2013; Reinders, 2006 and Erickson et al., 1990). The model by Little (1981) concludes the technology transformation into four stages: embryonic, pacing technology, key technology and basic technology. Little’s model and derivative studies (Reinders, 2006 and Erickson et al., 1990; Shahmarichatghieh, 2015) describe the characteristics of technology in each part of technology life-cycle and suggest strategies accordingly.

The third studied technology life-cycle is a model by Abernathy and Utterback (1978). The model tries to observe innovative activities’ trend over time. Abernathy and Utterback (1978) define three different areas in technology life-cycle; in the beginning companies try to provide new technology with the best performance and application to fulfil the needs of new adopters and convince conservatives to buy the technology, also referred to as “performance maximising”. Then, producing more derivatives and variations gain better market share because the competitors are trying hard (sales maximising). Subsequently, standardisation, modularisation and other techniques can provide acceptable market for the technology in the latter part of the TLC (cost minimising). As the model encompasses many aspects, different studies have modified and utilised it for various industrial purposes since (Boudreau and Lakhani, 2015; De Massis et al., 2015)

The fourth TLC model comes from Ford and Ryan (1981) who consider the TLC from the viewpoint of *original manufacturer*, therefore each stage evaluation tries to find opportunities and pros and cons of selling, licencing, or other technological strategies from technology owner’s perspective. As the model gives useful insight on technology situation against competitiveness and strategic conflicts, other researchers have been working to complete and apply the model in different strategic areas (Thudiom, 2015; Krcmar, 2015). Ford and Ryan’s TLC model starts with the first technology development idea, followed by technology application; hence it is the time that technology could be applied in product development and companies encounter the product cost issue. Moreover, the possible applications could become clearer and the uncertainties reduced compared with previous stages. The third stage of the model, application launch matches with “performance maximising” stage of Abernathy and Utterback (1978) while the following application growth stage corresponds with “sales maximisation of Abernathy and Utterback’s model. Finally, the technology reaches maturity and becomes degraded (Ford and Ryan, 1981).

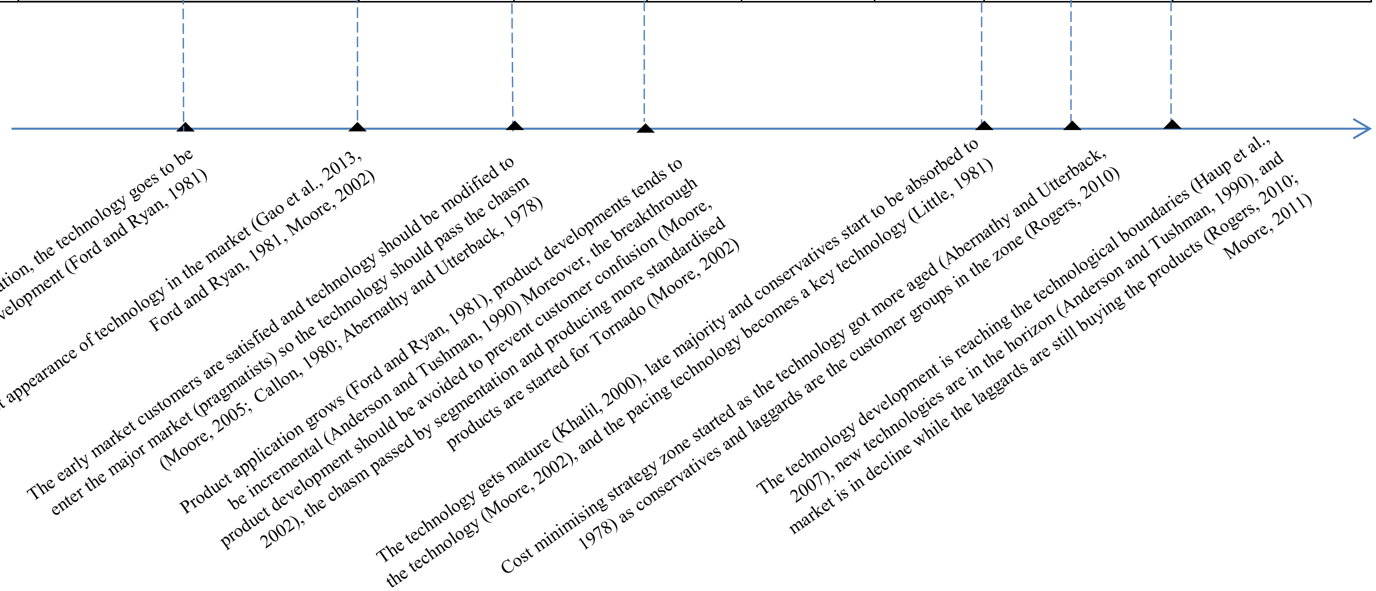
The fifth model by Anderson and Tushman (1990) built a technology cycle based on *sociocultural* factors from product design and creation perspective. The technology cycle starts with technology discontinuity when the developers compete against each other, work with the new born technology to find solutions to substitute older technologies and fight against market inertia to use the current technologies. By the time that the players find a dominant design, the technology and development activities tend to incline towards incremental changes and elaboration of dominant design (Christensen and Rosenbloom, 1995). The era of incremental changes would be continued until a new technology discontinuity comes into the market.

The sixth TLC is Rogers’s (2010) diffusion model. The aim of the diffusion model is to estimate the penetration rate of a new technology into markets and acknowledge the fact that a new technology would not be quickly accepted by the market. The diffusion model introduces five different groups of customers, each of which is a symbol of market needs and proper product specifications for the market. Rogers recognises innovators 2.5%, early adopters 13.5%, early majority 34%, late majority 34%, and laggards 16% in percentages of the whole technology market; while each group can be absorbed by different strategies. The diffusion model is the basis of technology adoption life-cycle (Park et al., 2015). Technology adoption life-cycle is the first stage of Market development life-cycle model by Moore (2002) which is mapped in accordance with technology penetration.

The seventh model by Moore (1998; 2002; 2004; 2005; 2011) is basically a marketing model while it illustrates different technology situations in the market area and give hints for proper product development strategies. Firstly, as Moore's model is market based, it does not have the introduction or embryonic phase and starts with the first appearance of technology into the market. Secondly, it has watersheds such as *the chasm*, *bowling alley* and *tornado* which suggest special strategies based on generic market behaviour towards the new technology. Therefore, having Moore's model in addition to other TLC models adds value; lots of innovation and strategic planning studies are done based on the model, not only for big organisations (Kim et al, 2015; Gudfinnsson et al, 2015) but also in small and medium enterprises area as well (Newby et al., 2014).

Table 1. Product development structure based on technology life-cycles

<table>
<tr><td></td><td>Basis</td><td colspan="11">Stages</td></tr>
<tr><td>Khalil (2000)</td><td>Performance</td><td colspan="2">Introduction</td><td colspan="6">Growth</td><td colspan="2">Maturity</td><td>Saturation</td></tr>
<tr><td>Little (1981); Erickson et al. (1990); Albert et al. (2015), Gao et al. (2013)</td><td>Competitive impact and integration</td><td colspan="2">Embryonic</td><td colspan="6">Pacing technology</td><td colspan="2">Key technology</td><td>Basic technology</td></tr>
<tr><td>Abernathy and Utterback (1978)</td><td>Innovative activities</td><td colspan="4">Performance Maximising</td><td colspan="4">Sales Maximising</td><td colspan="3">Cost Minimising</td></tr>
<tr><td>Ford and Ryan (1981)</td><td>Technology diffusion</td><td>Technology Development</td><td>Technology application</td><td colspan="3">Application Launch</td><td colspan="3">Application Growth</td><td colspan="2">Technology Maturity</td><td>Degraded technology</td></tr>
<tr><td>Anderson and Tushman (1990)</td><td>Product development and manufacturing</td><td colspan="5">Era of Ferment (design competition, substitution)</td><td colspan="5">Era of incremental change</td><td>New Technology arrival</td></tr>
<tr><td>Rogers (2010)</td><td>Adopters</td><td colspan="2"></td><td>Innovators</td><td colspan="2">Early Adopters</td><td colspan="3">Early majority</td><td colspan="2">Late majority</td><td>Laggards</td></tr>
<tr><td rowspan="2">Moore (2004)</td><td rowspan="2">Market</td><td colspan="2" rowspan="2"></td><td colspan="5">Technology Adoption Life-cycle</td><td rowspan="2">Growth Market</td><td colspan="2" rowspan="2">Mature Market</td><td rowspan="2">Declining Market</td></tr>
<tr><td colspan="2">Early Market</td><td>Chasm</td><td>Bowling Alley</td><td>Tornado</td></tr>
</table>



3.2 Product Development activities in Technology Life-cycle

In this section product development activities are discussed in different stages of TLC. The TLC used here is an amalgam of all the seven TLCs discussed in the previous section (table. 1). The transition of the stages are shown up as milestones as sometimes the borders of different life-cycle stages are not clear enough to draw an exact line, however in most cases there is an approximate territory for each stage.

In table 2 the degree of newness and competitive advances of product development activities are discussed to form a foundation for discussing product development activities. Classifying product development activities in accordance with the degree of newness is not a new challenge and it has been considered for decades by different studies theoretically and by different companies empirically (Wheelwright and Clark, 1992; Garud et al., 2015; Petro and Gardiner, 2015) while it is not only an important issue for strategic allocation of a company's resources but a pivotal subject for operating product development activities (Salerno et al., 2015). Different studies have suggested product development activities in line with the technology maturity by their degree of newness (Table 2). Consequently, table 3 illustrates how product development activities are allocated in the literature between the three different focus areas of *performance maximisation*, *cost reduction*, and *customisation* in accordance with their situation in the TLC.

Table 2. Degree of newness and competitive advances of product development in the literature (Familiarising with product development changes in TLC by Degree of newness and competitive advantages)

Technology Development transition into Technology Application (Ford and Ryan (1981)

Introduction, transition into application Launch (Little (1981; Khalil, 2000; Ford and Ryan, 1981)

End of Early market and "The Chasm" or "Gap" before major market (Moore, 2002; Callon, 1980; Abernathy and Utterback, 1978)

Beginning of sales maximising strategy (Abernathy and Utterback, 1978) and application growth start (Ford and Ryan, 1981) and product development trend is mostly incremental changes (Anderson & Tushman, 1990)

Transition of technology into Mature phase (Khalil, 2000) and entrance of major customers into the market (Moore, 2004), the Key technology (Little, 1981)

Transition of Sales maximising into Cost minimising strategy (Abernathy and Utterback, 1978)

Transition of mature / key technology into saturation stage (Khali, 2000; Little, 1981)

	Introduction	**Growth I**	**Gap**	**Growth II**	**Maturity**	**Decline**
Product development Degree of newness	Basically radical and theoretical innovations, which try to define concept but tend to find practical solution by the end of the stage (Albert et al., 2015; Little, 1981, Erickson et al., 1990; Gao et al., 2013)	Applications for the technology have been found but still there are many breakthroughs (Haupt et al., 2007). The technology should be modified with current infrastructure or products (Ford and Ryan, 1981). Product innovations widely to identify market needs (Abernathy and Utterback, 1978)	Product development decisions go from *Product centric* to *Market Centric* (Moore, 2002). The winner is not the owner of the *state of art technology* but the one who knows market needs (Abenathy and Utterback, 1978)	Better usage of advanced technology in the products result in more product variations or new components. Innovations not only for products but the process (Abernathy and Utterback, 1978). Breakthrough is not preferred because it confuses the customers (Moore, 2002)	Product centric incremental development (Albert et al., 2015). Variation, customisation (Anderson and Tushman, 1990) and cost reduction (Abernathy and Utterback, 1978) are the keys for product development activities by newness level.	Small changes, cost reduction (Ford and Ryan, 1981). Process modifications to new technologies (Abernathy and Utterback, 1978). Some customisation (Hofer, 1975).
Product development Competitive advantages	The best design and performance (Anderson and Tushman, 1990). Also, time-to-market can be seen important (O'Reilly and Tushman, 2013) especially when the product development team is looking for external funding or partnership (Linden and Fenn, 2003)	Time-to-market is important (O'Reilly and Tushman, 2013). In the beginning of TLC when the products are not reliable and applicable enough, integration (especially internal integration) can be a trump card, means newer technologies can be mixed with reliable older technologies in a single product (Christensen et al., 2001). Early adopters are more eager to see new and special applications of the new technology (Moore, 2002)	The company should go through *application and customer centric* product development instead of *Innovation centric* product development. Products should become ready for the new market (Moore, 2002). Technology application in the market, or the company itself, prefers to improve the current integration and then release (Ford and Ryan, 1981)	From product development viewpoint, the company should provide the best *solution* to the selected niche. Therefore proper customisation and providing a *whole product* are the main competitive strategies of the product development team (Moore, 2002). More competition based on differentiation and dominant designs (Abernathy and Utterback, 1978). The demand is high therefore time-to-market should decrease. Delay in production means losing the value of technology (Ford and Ryan, 1981). Cost, efficiency, incremental innovation (O'Reilly and Tushman, 2013)	Competition is High (Albert et al., 2015). Mostly established companies (Asthana, 1995). The number of companies in the ecosystem increase by the technology maturity (O'Reilly and Tushman, 2013). Whole product +1 product development strategy at maturity stage (Moore, 1998)	The new Technology is in bowling alley and the current technology is in decline market, the target is divesting the capabilities and platform in addition to satisfying customers. Therefore the product should be cheap and available. Moreover, as the customers in the markets are mostly laggards who are not very happy using technology, simplicity and user friendly interfaces can be aspects of competitiveness (Moore, 1998).

In order to provide samples of products and technologies, as table 2 illustrates, introduction phase of Khalil's (2000) model has a transition in accordance with Ford and Ryan's (1981) model, where the development transfers from defining concepts into productising applications. Probably the best example of the transition is the first application of 5^{th} technology generation (5G) of mobile telecommunication in 2005 by NASA in Machine-to-Machine Intelligence (Bluck, 2006). Nevertheless, the introduced products should be prepared to meet more conservative customers than the early adopters with more reliable functioning and more reasonable prices, which leads to transition into Growth phase (Little 1981; Khalil, 2000; Ford and Ryan, 1981). One of the best examples of growth phase transition is the introduction of Lotus 1-2-3 spreadsheet introduced to the market by IBM. The spreadsheet was easier, faster and more reliable compared to previous spreadsheets and became a trump card for IBM for some time (Gandal, 1994). Although Lotus 1-2-3 was the best version of spreadsheets compared to its competitors such as VisiCalc developed by Apple for Apple II, it stood in the chasm due to lack of reliability and speed (Grad, 2007). Passing the market and technology gap and entering the sales growth is the next phase, where the iPhone introduction by Apple is among the best examples of being born from the chasm ashes of another company, the simplicity and user friendly interface of iPhone made it the market success which caused other companies to copy the idea with pride (West and Mace, 2010). Eventually, technologies transform into mature technologies with incremental changes and the existence of major customers. Although the transition to the decline phase is the time that a technology is getting aged, companies are still trying to enjoy the cash cow situation, and for sure investing in newer technologies may prove beneficial as for example how Nokia did in the 1980s, when they were earlier well known in the pulp and paper industry and in the rubber production. Simultaneously with enormous amounts of cash coming from mature technologies, Nokia looked forward and invested heavily into mobile phone technology in the 1990s (Moore, 2007) resulting in significant success, and the story still continuing.

Competitive advantage is a crucial issue that changes along technology penetration and can affect product development activities (Harrigan, 2015; West et al., 2015; Murray, 2014). This was described in Table 2 as an introduction to Table 3 which allocates different product development activities into the TLC.

Table 3. Allocation of product development activities between *performance maximisation*, *cost reduction*, and *customisation* vs. Technology Life-Cycle

		Introduction	Growth I	Gap	Growth II	Maturity	Decline
Product Development	**Performance Maximisation**	Important task for the stage (O'Reilly and Tushman, 2013), while there is no products in the beginning (Ford and Ryan, 1981). The created applications and products are difficult to use (Linden and Fenn (2003), moreover no standards or processes exist (Abernathy and Utterback, 1978)	New technology performance level is low (Albert et al., 2015; Christensen et al., 2001) In the beginning when the products functionality is not ideal, companies compete on the performance level (Christensen et al. 2001)	Not proven technology (Ford and Ryan, 1981) Business risk, identification of competitors, and low customer satisfaction due to low performance level of the technology (Asthana, 1995)	As producers and users gain experience, the uncertainty decreases, while even at this point technology performance improvement should be evident to the customers and high performance could be a competitive strategy (Abernathy and Utterback, 1978; Prajogo, 2015)	Technology performance level is acceptable and constant while the competition goes through cost and customisation (Albert et al., 2015; Christensen, 1992)	The performance levels are the highest, and performance capacity has been reached (Ford and Ryan, 1981). The process efficiency and productivity goes high but flexibility and innovation goes down (Abernathy and Utterback, 1978)
	Cost Reduction	The critical target in the stage is finding out best performance while cost efficiency is important for crossing the chasm (Moore, 2002; Ford and Ryan, 1981) though it is not taken as important as performance creation (Albert et al., 2015)	Cost reduction priority in growth stage is lower than performance maximisation Albert et al., (2015). The standards are created to ease Product Development (Fenn and Linden, 2003). In the beginning cost is not the priority of any new adopter customer groups, they demand only for new technologies with the best performance level to make a difference (Moore, 2002)	At this point the new technology is not only unreliable but also expensive (Ford and Ryan, 1981). This, even if the technology itself has reasonable price due to high uncertainty and related costs of infrastructure. (Park et al., 2015). The pragmatists do not tend to enter to the market (Moore, 2002)	The cost reduction is the target in this stage. (Moore, 1998) More technology applications and standardisation are the product development strategies here (Ford and Ryan, 1981; Albert et al., 2015; Haupt et al., 2007; Ford and Ryan, 1981; Villalba-Diez, and Ordieres-Mere, 2015). Abernathy and Utterback, (1978) call this stage *cost reduction* stage. O'Reilly and Tushman, (2013) argue that the competition is basically against price in this stage	The known strategy in this market situation is *Whole Product+1*, where the "+1" can be cost (Moore, 1998). The customers expect complete product with cheap prices, the reference of the price is not industry leader but the followers (Moore et al., 1998; Lilischkis, 2013)	Cost reduction is the ultimate expectation of the laggards and conservatives (Moore, 2002)
	Customisation	Customisation possible with two targets: Sponsorship, by big companies for small start-ups make the beneficial ideas come out (Linden and Fenn, 2003; O'Reilly and Tushman, 2013). Pioneering: big companies ask to have allies with the developer company to be pioneer in its own industry (Moore, 2002).	Growth Market customisation will be done mostly for the niche buyers. The customer feedback can map the strategic development and repair the bugs (Moore, 2002). Mass customisation is the strategy that can add value at this stage (Mueller-Heumann, 1992, Shoham Paun., 2015)	Customisation is the next competitive strategy if the technology performance gets reliable (Christensen et al. 2001) Segmentation and customisation a solution to cross *the chasm* (Moore, 2004) Recently Kitajima (2015) studied success of customisation in 3D printer market.	Segmentation is the strategy to cross the chasm and begin to penetrate the growth market (Moore, 2002; 1998). Standardisation and process improvement in the late growth stage when the technology goes into *Tornado* watershed (Moore, 1998) A controversial area (Cedillo-Campos, 2013) Smart customisation in growth market (Oliver et al., 2004)	Customisation, mass customisation and segmentation are known and highly recommended strategies in maturity stage (Parrish et al., 2006; Cedillo-Campos, 2013; Tseng, 2014)	Customisation for bigger customers (Utterback,1996)

4 Empirical results

The empirical part first discusses product development activities in TLCs, followed by discussing product development efforts in terms of performance maximisation, cost reduction, and customisation.

4.1 Product development activities in technology life-cycles

The studied technology generations in the case company are: A, B, C and D. The analysed generations are mostly in different stages of the technology life-cycle, whilst A and B have passed all the stages (Figure 2).

[Please insert figure 2 here]

The generation A idea creation phase might have started in other companies at different times, while the case company tried to develop its knowledge capabilities in the first known standard of the A in the European union countries and in some other countries in year 1987. The generation A technology was more capable in many ways. Moreover, it resulted in introducing smaller and cheaper products due to less power needs as an interviewee indicates "*the new generation products were so compact in comparison with previous generation that providing more efficient services became possible, and power usage was less, therefore implementing them was not only sufficient for end users but also from the power point of view they were more economical for service providers"* The most obvious factors of technology A compared to previous generation was new functionalities for end customers.

The first technology A based product was sold to the customers in 1991. The products were similar to previous generations with high efficiency levels, hence the customers were familiar with the whole idea of the technology. Thus the reason of the *chasm* at the point was due to additional functionalities of the technology. There were no end customer devices for using the new features at the time, and in fact customers did not even know about the features until 1994. An R&D manager stated: "*we had the technology of the infrastructure but the end user devices were not in the market yet, while after the first end user product introduction the infrastructure products were selling like hell"*.

In 1994, when the first devise with the exciting new capabilities was introduced to the market, the *tornado* of the generation A started. In couple of months the product sales sky rocketed and the case company's strategy became just to keep up with the big demand of the market area, and to find an increasing number of new suppliers to install as many new products as possible. The generation A was not only producing more efficient infrastructure, but also emitting less power, therefore, not only infra-structure equipment were smaller but also the end user devices were becoming smaller and cheaper. Thus the emergence of A and derivative evolutional products resulted in a revolution for the industry, while average people found having related products useful. One of the R&D directors described the situation as: "*The end user devices had big new functionalities that most of the end users were fond of, therefore the service providers were eager to implement it in their systems"*.

In 1995, the technology entered maturity phase, at the time the sales volumes were still growing rapidly. Simultaneously, the concept definition and product development activities of the generation B were started. The first product family of the generation B was sold to the customers in 2001. Although the integration levels were not yet ideal and the devises utilising the B were not there until 2005. Therefore, the generation B experienced *the chasm* from 2001 to 2006, during which the integrated devices were low in sales and very expensive. In 2005, when more applicable integrated products were introduced to the market the demand for the new generation escalated. This was particularly due to the new features of the generation B products and new applications which brought a completely new horizon for the industry. *One of the R&D directors stated: "The new functionality changed not only the concept of end user devices, but also the life-style of the end users, therefore buying the new generation products was a must for all our customers to perfectly satisfy their own customers, now the question was buying the new generation products from which market player? Obviously we were the best one and in two months we sold as much as we planned to sell in 5 years".* The high demand continued to escalate until 2007 with a high trend as a *tornado*.

In 2007, while the market volume was still growing, the technology B generation moved into its maturity phase, and continued with a lower growth trend until 2014. Noteworthy is that the generation A was in the maturity phase until 2010, for about 15 years due to its special specifications. The aging stage of the A started in 2010, while it is still selling in the present day due to the high integration, cheaper prices and special applications and is currently used for example in traffic lights. *An interviewee described this as: "We cannot kill the technology products, because it still has its own customers and huge amounts of cash is still coming to the company with low levels of internal costs".*

The generation C was born in 2006 as a child of product development activities conducted for the previous generations. The C had higher capacity. The first product utilising generation C technology was ready in 2011 enabling the customers to enjoy the better performance, whilst the customers were unable to use the improved performance yet. *"Our product development teams were not looking for a new generation but improving the previous one, eventually generation C was born with capacities far above generation B and lots of new functionalities" as one of the R&D directors stated.* Therefore, the technology was in *the chasm* until 2013 because of low devices integration. Likewise, C infrastructures were not fully functionalised and they were too expensive. It was only in 2014 when more integrated products were sold to the market, the technology encountered the high demands of the *tornado* only for a year. From the beginning of 2015 C technology reached the maturity phase.

According to the interviewees, the generation D technology which has been in the concept definition since 2013 is still in the *introduction* phase and so far no actual products have been built. *"All the leaders in the industry are trying to collaborate in concept definition process with huge amounts of funds for their internal R&D units or external organisations to be part of standards of the new coming generation" as one of the R&D managers described.*

Based on the analysis, it is evident that each stage duration of technology life-cycle varies by different technology generations, which is in line with the potential of each of them. Moreover, as *the chasm* and *tornado* are seen as important watersheds within the TLC, greatly influencing the success of technologies and products, it is important to learn from the experience. According to the interviewees *the chasm* situation occurred mostly due to the low integration of user's interfaces, low technical capabilities of the technology, and the price.

Hence, for the next generations the best practice would be initiating parallel activities between device and infrastructure producers to keep *the chasm* situations as short as possible. Additionally, the *tornado* phase occurred in the latter parts of the growth phase for all the generations, and the technologies entered the maturity phase after the tornado. Fast transformation of the technology into *maturity* stage just after *tornado* might be a result of the long duration of the chasm. Based on the empirical work, when the company had a ready product and low customer demands because of low integration, they found the technologies transferring into maturity phase immediately after tornado form the technological boundaries viewpoint.

4.1.1 Product development focus areas: Performance Maximisation, Cost Reduction, and Customisation

Based on the interviewee comments it appears that, product development activities can have three drivers: either small or big enhancements to improve the performance of the products, cost reduction, and customisation. The customisation activities are seen to cover a bigger portion of product development activities compared to other sectors due to the company operating in business-to-business markets where the number of customers is somewhat limited. Therefore, Product development activities of each technology generation stage can be classified into three focus areas: *performance maximisation*, *cost reduction* and *customisation*. These three focus areas of product development activities have different impacts in different phases of the technology life-cycles in line with the strategic situation of the technology. Each of these three are defined in a way that all the product development activities are included.

Performance maximisation can be seen as all the product development activities that try to improve any aspects of products or technology quality. Both technical and appearance viewpoints are covered by the quality considerations. The integrations and modifications that aim to connect the technology into previous generations, or the following ones are also known as performance maximisation. However, those modifications and integrations that aim to catch customer infrastructure specifications, or special needs, are seen to belong to the customisation focus areas. The performance maximisation that contains not only increasing reliability and also internal integration of various technology generations has a pivotal role in the company products and customer satisfaction as one interviewee described: *"Our customers' customers should have the possibility of using the products, therefore the products that are providing services for two or more technology generations are more successful and they can provide services for more financial customer segmentations"*.

Performance maximising in all the first three generations had descending trend over the TLCs (Figure 3). Obviously, performance maximising activities trend is descending during life-cycles. The amount of work for performance enhancement in B and A were the same in the introduction phase; while in C, the performance maximising activities reduced by 20% in introduction and around 25% in growth phase. The percentage for C in terms of maturity phase is not available due to recently entering the phase, the same applies for B for aging. Noteworthy is that there had been an emphasis shift in product development when C was introduced, a shift that is visible when comparing performance maximising to cost reduction and customisation efforts in later figures. The shift can be explained by there being different players in the industry, and the company was trying to introduce a new generation to the market with more reasonable prices to avoid long duration of *the chasm*. Additionally, timing wise, C came into the market during the maturity phase of A and B. As C had better functionalities but was expensive, some amount of B's performance enhancement could go into cost reduction efforts to not to let C win the market in some segments.

[Please insert figure 3 here]

Cost reduction means all the product development activities that have the target of cost reduction from standardisation and modularisation to other cost efficiency activities. As the scope of this study is product development, the cost reduction activities relevant to processes and the supply chain are not included. However, the product development activities in the aging phases that try to generate standard components, or software for products with aging technology to make them functional with newer products and reduce costs in their production using an old line is included in the cost reduction category. The following interviewee comment exemplifies the importance of cost reduction: *"Cost minimisation is a big incentive especially in the beginning of the technology introduction to the market as our customers are service providers, the cost differences can be huge"*.

The cost reduction based activities had an ascending trend over all the discussed technology life-cycles (Figure 4). It can be seen how the company's strategy in C, opposed to the way with previous generations, was reducing costs from the very beginning to not to stay in the trap of *the chasm* for a long time. In contrast to performance maximisation, cost reduction activities have ascending trend over technology the life-cycle as cost reduction activities were seen as more crucial for the generation C. In the growth phase of C, half of the product development activities were assigned to cost reduction.

[Please insert figure 4 here]

The percentage share of cost reduction activities for B escalated in the maturity phase compared to A, where the trend had been almost constant over time. The reason for this can be quite simple, the major customers did not trust B until 2006 for an integrated product being able to be produced with the capability of providing both A and B services. Also, before 2007 when B went into maturity phase, the market and the industry expected to see A going into aging phase and dying after the tornado of B. This was a huge misunderstanding. Beside the fact that A technology infrastructure were more reliable in some ways, A products and integrated products for end users, including cell phones have been cheaper than B. Therefore B not only cannibalised technology A but also was expected to become cheaper in the maturity phase and convince sceptics and conservative customers. The exact percentage information for B in terms of aging phase is not available due to recently entering the phase, while the same applies for C for maturity.

Customisation can be both the customisation according to customer requests in project based product development, and customisation and modifications based on market segmentation plans, or other customer relationship programs and demands. The company's customers have their own criteria in various parts of the world where the products are being sold with high levels of customisation possibility, as an interviewee described: *"some products and generations which have not been utilised in some parts of the world, have high market possibilities in other parts of the world with special specifications, therefore our market has high level of customisation possibility".*

The customisation focus area have had different trends along the generations (Figure 5), which shows the powerful impact of other factors than the technology maturity level (see Figure 4). In contrast with two previously discussed categories, *customisation* area of product development activities trend have not been sustainable. All the three generations have had fluctuations over time in this focus area, they did not even have harmonised fluctuations with each other. The chaotic ups and down of customisation percentages illustrate the fact that customisation is dependent on lots of other factors. Technology B started it life-cycle by a customised project: according to the interviewees, the zero model of B was customised for a specific customer. During growth and maturity phases the customers were still demanding customisation, however, there were no big differences between different stages of product development with regards the customisation target. The percentage information for B in terms of aging phase, and for C for maturity are not available due to recently entering the phases.

[Please insert figure 5 here]

5 Discussion

This study illustrates the evolution of different technology generations with a specific focus on product development. The scientific implications of this study include emphasising the importance of product development focus areas in terms of performance maximisation, cost reduction and customisation during TLCs. The targets of any company when developing new technologies involve maximising the performance of the technology to transform it into applicable products. When a company wishes to build a business on a technology, cost issues become crucial. Also, the customers become sensitive about the cost at some point. In addition, in the analysed industry one way of adding value has been customisation. This study provides new contribution to the TLC discussion by focusing particularly on product development. In fact, it seems that previous studies have not analysed the three different product development targets together through the TLC, and hence this approach provides new contribution. This study analysed the trend of product development activities along TLCs.

All technologies have limitations, for this reason as time goes by less *performance maximising* product development activities can take place. The results of this study are in line with the literature on the limitations of technologies (Sahal, 1981), and the work discussing performance maximising development activities (Albert et al., 2015; Christensen et al., 2001).

During the later parts of TLC, particularly from the maturity phase onwards, also the competitors are capable of producing similar products with *similar performance*. The results of this study indicate that less efforts are put into performance maximisation at this stage and *cost reduction* efforts become more important for product development. The results are hence in line with the previous literature on the competition going into “whole product +1” mode (Moore, 1998), and that that price should become either reasonable or cheaper (Moore, 1998; Lilischkis, 2013).

The results of this study indicate that *customisation* can be a tool for crossing *the chasm*, where the difficulty lies in finding customers for the products, when either they are still too expensive, there are still issues with integration, or the market does not yet fully support the products. Also this is in line with the previous literature discussing strategies for facing the chasm situation (Moore, 202; Christensen et al. 2001).

Apparently, *Chasm* should be avoided by all companies and product development teams, the three reasons of chasm identified in this study are price, technical reliability and integration. Price and technical reliability can be solved by time, while integration problem of end user devices with infrastructures can be solved by preventive strategic decisions of having allies or partnerships. All these three reasons are discussed in the previous literature (Asthana, 1995; Ford and Ryan, 1981; Park et al., 2015) and the findings of this study are in line with previous studies. However, the previous studies mostly focus on external integration, this study provides new contribution by emphasising the internal integration that is not discussed widely in the previous literature. The internal integration was possible to analyse by studying different generations of a single company. The previous old reliable technology were introduced by a single product which caused the shorter chasm duration for technology B and C. The previous literature often views the interaction of different technology generations as a negative thing such as cannibalisation (Cravens et al., 2002; Pan and Yu, 2015). Opposed to previous literature, this study sees possibilities in the interaction of different technology generations, for example the reputation of previous generations can benefit later generations which come with added features by presenting an integrated product.

6 Conclusions

In this study technology life-cycle is observed from seven most popular viewpoints (Khalil, 2000; Little, 1981; Ford and Ryan 1981; Abernathy and Utterback, 1978; Andersson and Tushman 1981; Rogers, 2010; Moore, 2002) to keep track of technology changes over time by following different patterns. The aim was to support decision making criteria in product development. This study analyses the direction of three high-tech generations with product development insights. The product development activities were observed through the targets of; *performance maximising*, *cost reduction* and *customisation* as product development focus areas. Each of the focus areas have different strategic implications along the technology life-cycle stages.

It seems that product development activities can be mapped over technology life-cycles based on analysing the trend of each analysed focus area. Product development can potentially help to determine competitive advantage of the company for the market based on the technology that can differ based on technology maturity. Product development strategies based on degree of newness can be various in different stages of technology life-cycles based on different technology maturity and market needs.

Concurrent technology generations seem to interact with each other over technology life-cycles both constructively and negatively. Naturally there can be negative interaction in the form of cannibalisation especially when the newer technology proves its reliability. The positive interaction can emerge in the form of smoother technology introduction to the market, in the form of mixing newer and older technologies within a single product so that services can be provided according to the previous reliable technology while introducing something new. This is based on the market trust on the earlier technology generations. This piggy bag approach can be mediated by for example integrated products.

The trend of product development activities prioritisation can be analysed in different ways. This study grouped the product development activities into three target based groups. The trend of performance maximising and cost reduction priorities remained the same through all the analysed technology generations. However, the trend of customisation has been more chaotic. The trend of performance maximisation activities priority was descending while the cost reduction ascended. Therefore, it seems that the length of the chasm situation can be somewhat influenced by the focus of the product development efforts. For example, the case company intentionally increased the product development efforts in cost reduction in comparison to performance maximisation to influence the chasm situation.

The managerial implications of this study include pointing out how seeing product development activities in the big picture in the context of technology life-cycle can help in analysing the technology life-cycles of those technologies that are currently being worked on. This can also enable companies to map product development activities more efficiently and to obtain new insights by taking into account the interactions of different technologies the company is working with. Product performance maximisation should have more priority during the early stages and on cost reduction during the later stages of TLC. Also, companies tend to have different teams for different technologies, this study indicates that something is needed to obtain a comprehensive insights across the different technology generations. These insights can support managing the product development activities.

The limitations of this study include analysing the different technology generations of a single company in the high-tech sector. Also, as the study focused on product development, while process development activities are not included in the analyses. The analyses are conducted against selected technology life-cycle descriptions and any other descriptions are ignored. Hence, in addition to addressing the limitations, the future research topics could include further analysing the role of customisation as a product development strategy against the technology life-cycles. This could include focusing on different factors of customisation in accordance with technology maturity levels. Future studies could also implement technology life-cycles and product life-cycle in a unified context to better empower product life-cycle management methodologies.

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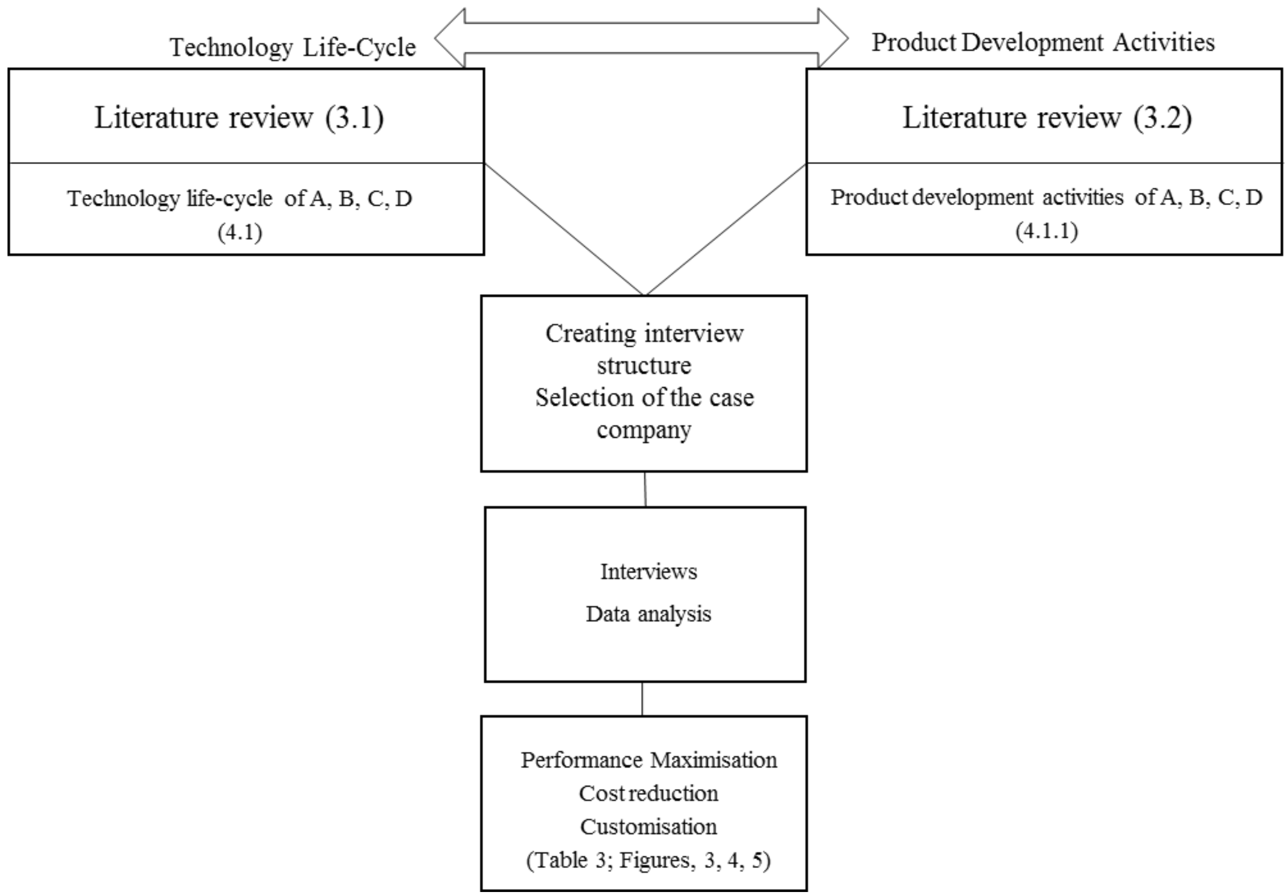

Figure 1: Reasearch process of the study

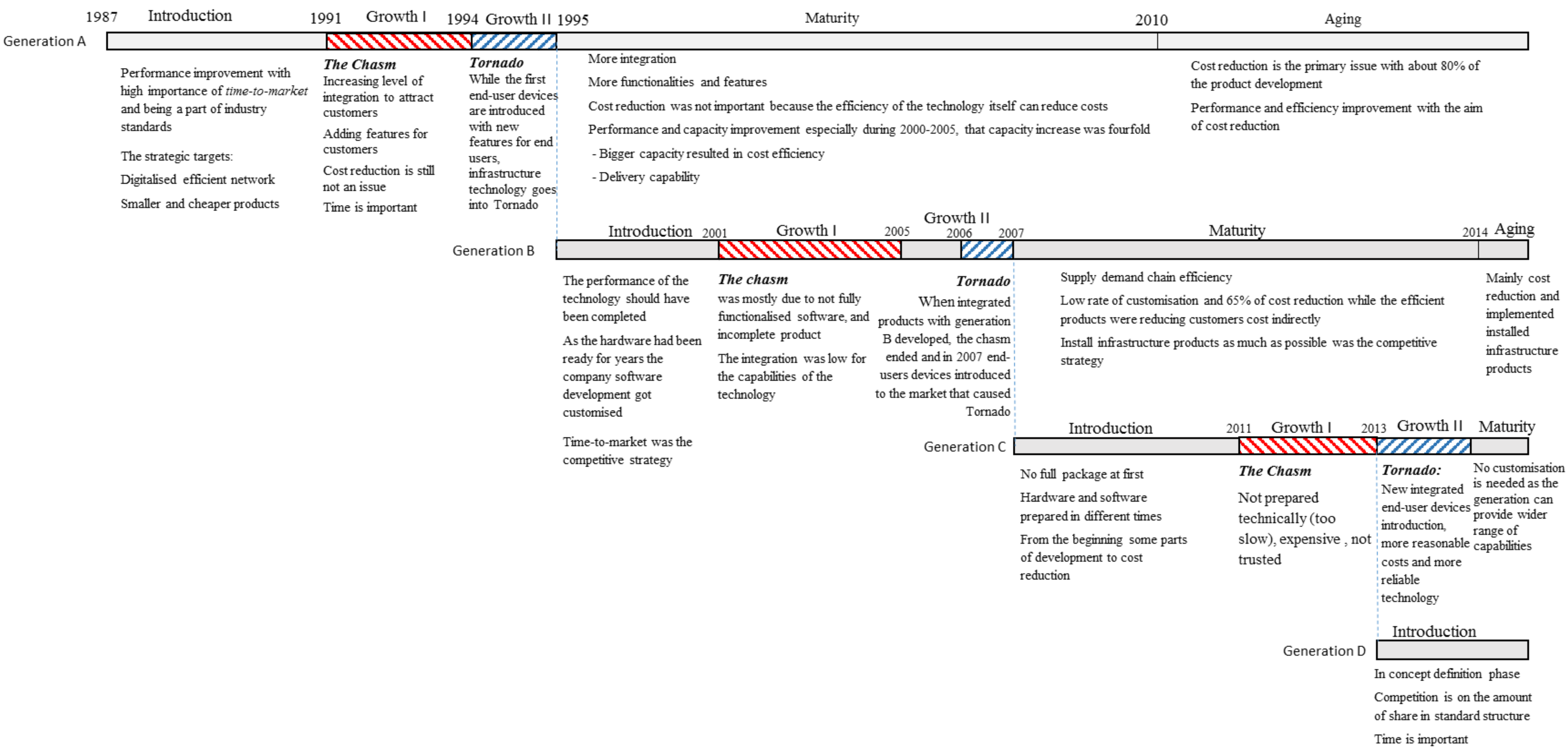

Figure 2: generations TLCs and targets of product development activities

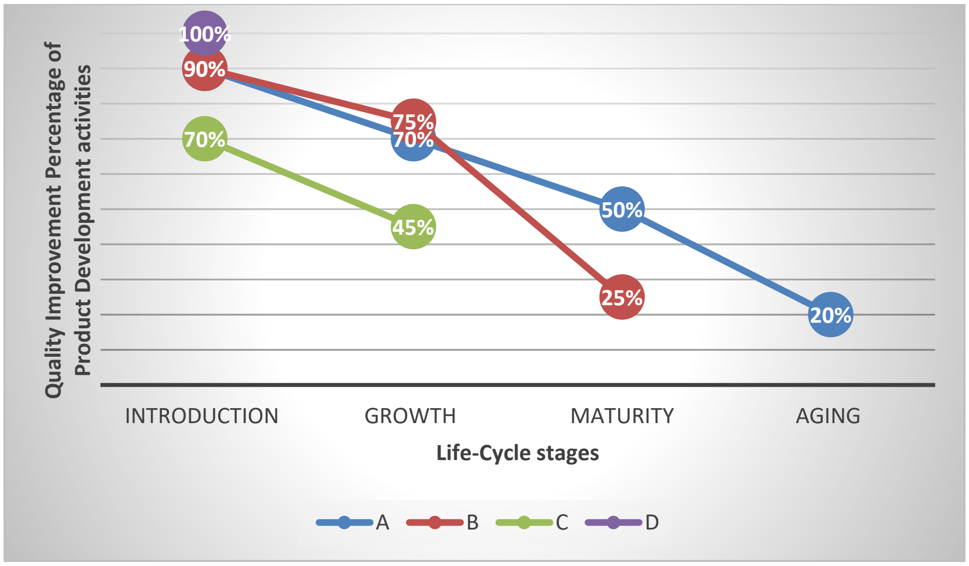

Figure 3: Performance maximisation in percentages of product development activities

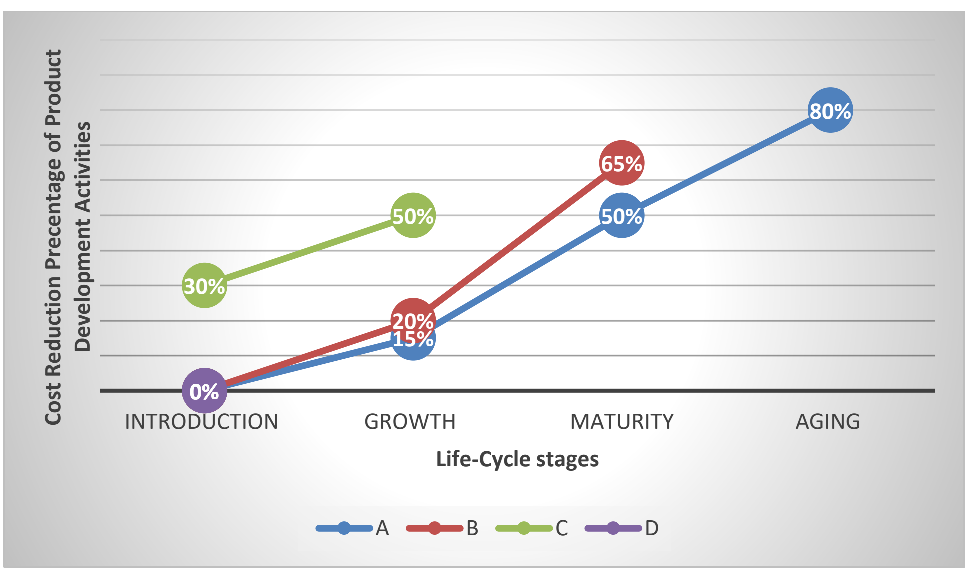

Figure 4: Cost Reduction in Percentages of product development activities

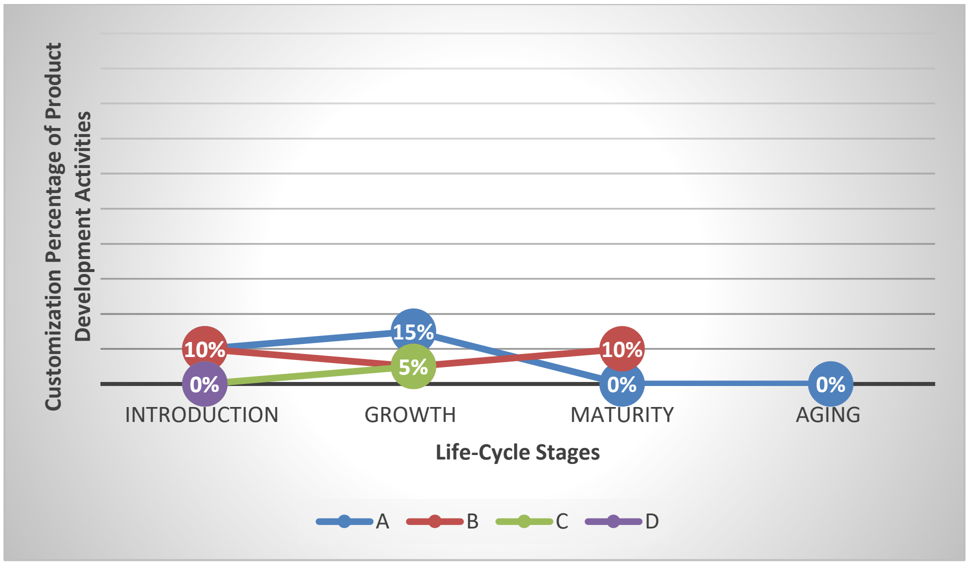

Figure 5: Customisation Percentages in of Product Development Activities