Powering Through the Turn: Finding Time for Concept Exploration Before Industry Stagnation

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We examine how the tension between exploration and exploitation affects early-stage development within engineering teams of large corporations. Using survey data collected from over 900 system engineers and managers, we observed that exploration decreased as an organization's market growth declined, but dire market projections prompted a refocus on exploration. In addition, engineers routinely desire more concept exploration time than they perceive that they have available. We argue that engineering teams should more intentionally consider their innovation strategy, and that companies with stagnant market growth should invest in concept exploration before they get to a period of market decline.

Keywords: concept exploration, innovation, disruption

Introduction

An organization's ability to innovate and adapt to changing environments is crucial to its long-term survival. Indeed, innovation has been called the single most important business challenge of our era (Skogstad & Leifer, 2011). McKinsey found that organizations capable of dynamically allocating resources based on market opportunity will be worth 40% more than less adaptive organizations after 15 years. The increasing speed of changes is the most important factor that companies need to deal with. In the last few decades, we have been experiencing offshoring of R&D to global engineering, pervasive software technologies being introduced in every industry, and an ever quickening product development lifecycle. As organizational environments become more global and dynamic, the need for organizations to be able to adapt and innovate will only intensify (Smith et al., 2017).

Failure to handle innovation properly can be fatal to an organization, no matter how large or established it may be. Although long-term forces for competitive advantage generally remain the same and good firms seem stable, many companies such as Polaroid, Nokia, and Yahoo have faltered due to a failure to innovate and keep up with their changing environment. Other companies such as IBM and Microsoft have managed to successfully transition from one era to another, but even these companies no longer hold the same dominant positions. Unfortunately, the traits required to foster innovation are extremely complex. For example, too much exploration and the firm will never adequately develop any ideas to be successful; too much time exploiting existing solutions and the firm will fail to adapt as environments change.

Microsoft found that the recent transition to remote work has had a positive impact on engineering productivity by providing more freedom and flexibility to the work day and reducing wasted time. However, they also found that as a result of the transition, their innovation efforts have decreased (Knowledge at Wharton Staff, 2020). Despite the increase in productivity, why have the innovation efforts of engineering teams faltered? In this paper, we will explicitly scope the inquiry to engineers within a product development organization, asking "How do engineers understand and consider their organization's innovation strategy?".

The literature of innovation strategy and organizational learning uses the concepts of exploration and exploitation to distinguish the needs of exploring new innovation or creating new markets versus exploiting existing capabilities or markets. Through this research, broad managerial tactics and processes have been developed to help organizations and managers navigate the complexity of balancing exploration and exploitation. Yet, rarely have the tensions of exploration and exploitation been explicitly applied to engineering product development efforts, even though product development is an integral component of an organization's innovation strategy.

To select a design concept, often engineering product development teams will undergo a so-called "concept exploration" phase, where multiple potential concepts are explored and assessed, until one is ultimately selected (Bahill & Botta, 2008). This stage of exploration is instrumental in identifying innovative technologies and solutions for new and existing products alike, but without strong strategic direction or guidance, people naturally gravitate towards easier and less risky decisions (Christensen, 1997). So despite strong evidence suggesting that a broad and thorough exploration of the solution space leads to higher quality results (Ehrlenspiel & Dylla, 1993), organizations often pursue a very narrow focus to the concept exploration (Pahl & Beitz, 2013), with engineers favoring to exploit existing concepts and apply incremental changes/improvements.

In this article, we analyze how engineers think about the importance of concept exploration in their engineering processes and how the effort allotted to concept exploration aligns with their organization's innovation strategy. While there is extensive literature on how exploration and exploitation are (or should be) incorporated into innovation strategies overall, less attention has been paid to how this incorporation happens on the ground. Our investigation starts with a review of existing literature on disruption, innovation strategy, exploration versus exploitation, and engineering practices and processes related to concept exploration. We look at the tension between exploration and exploitation within the engineering department using survey data of 900 engineers. We look at how these two activities are carried out and impacted by the expected growth of the company. Based on our results, we identify areas for improvement and provide suggestions for implementation.

Background

Disruption and Innovation

As a whole, industry can often accommodate incremental changes, but if small changes go unnoticed by incumbents for too long, organizations may react too late to successfully adapt (Christensen, 1997). Alternatively, truly radical changes can quickly shift the landscape of an industry seemingly overnight. Such changes could range from sweeping societal changes like war or a pandemic (Gössling et al., 2020; Nicola et al., 2020). More often though, the shift comes from new breakthrough technology that can quickly change the needs and capabilities of a market, or even generate new markets.

Abernathy discusses the distinctions between radical and evolutionary innovation (Abernathy & Utterback, 1978), while others have made comparisons between radical and incremental innovation (Popadić et al., 2015; Rainey, 2008), or continuous and discontinuous innovation (Veryzer, 1998).

Christensen categorized two primary types of innovation that led to disruptions he observed. "Sustaining Innovation" focuses on an organization's existing primary customer and their needs, while "Disruptive Innovation" targets under-serviced customers that are not currently the primary profit centers of the firm (Christensen et al., 2015). The latter term is often used to refer to a major innovation that leads to the failure of leading technology companies. Christensen further coined the term "Innovator's Dilemma", for the finding that incumbents often reject new technologies and products. This is not only due to the small fractions of the firm's total profit today, but more importantly, as these technologies and products often provide a new dimension of value undervalued by the firm, while performing poorly on the firm's existing dimensions of value. Christensen's work initiated extensive research around the effects of disruptive technology changes and the importance of innovation on firms and industries (Danneels, 2004), particularly in response to how organizations can strive for disruptive growth, and how established incumbents can protect themselves from disruptive challengers (Christensen, 1997; Christensen & Raynor, 2013; Danneels, 2004).

Innovation and the Process of Change

Disruptive Innovation

Christensen argued that it is very difficult for an incumbent to pursue disruptive innovations because they already have high profit and growth expectations that they need to continue to meet and exceed. Small organizations, on the other hand, have very few existing expectations and are able to adapt quickly and take on risk.

To pursue disruptive innovations, Christensen (1997) proposed that incumbents start and/or acquire subsidiary organizations. If the organizational units are sufficiently siloed from one another, they can operate effectively without interference. If a subsidiary ultimately succeeds at disrupting one of the primary organizations market segments, the corporation as a whole still benefits (Christensen, 1997; Christensen & Raynor, 2013).

Gaps in Disruptive Innovation. Christensen's Innovators Dilemma is founded around a specific trajectory of a disruptor that he has observed (Christensen, 1997). Not all forms of disruptive innovation cause this trajectory. Christensen et al. (2015) mentioned how it is often misapplied or is overgeneralized to all forms of disruption. As an example, Uber is often mischaracterized as a Disruptive Innovation. Despite the drastic hit to the taxi business, Christensen et al. argue that Uber did not follow the disruptive innovation trajectory

(Christensen et al., 2015). Rather than starting out with a lower-quality or unmet market, Uber brought together multiple sustaining innovations that enabled them to out-compete the taxi industry with their primary customer by developing a better, cheaper, more convenient product (Christensen et al., 2015).

Other research has gone on to question the premise that sustaining and disruptive innovations need to be operated separately in the first place (Paik & Chang, 2015). A study on the response of 88 businesses to disruptive change found that organizations responding to disruptive market-driven innovations are able to succeed in managing both disruptive and sustaining innovation without separate business units, whereas those responding to disruptive technologies benefited from creating separate business units (Habtay & Holmén, 2014).

Exploration and Exploitation

The concepts of exploration and exploitation have a rich history in computer science (Holland, 1975), economics (Hronsky, 2009), and decision science (Cyert & DeGroot, 1970). However, the terms were largely popularized by James March in his seminal 1991 paper (March, 1991), which used the terms to characterize how organizational structures and processes can affect the way in which an organization learns and adapts over time. Exploration is broadly used to characterize any process or outcome related to such things as search, discovery, experimentation, risk taking, and innovation. Exploitation on the other hand represents efforts of refinement, implementation, execution and efficiency (Auh & Menguc, 2005; Chebbi et al., 2013; Hronsky, 2009; March, 1991).

Because time and attention for innovation are conserved quantities, there is a trade-off between exploration and exploitation (March, 1991; Martini et al., 2013; O'Reilly & Tushman, 2013). Exploitation is said to improve the competence of existing procedures, products, and skills, but this process can make experimentation of other alternatives seem less attractive (Greve, 2007; March, 1991; Oshri et al., 2005). Conversely, exploring new alternatives comes at the expense of improving existing ones (Greve, 2007; March, 1991). In addition, although exploration has the potential to produce significant results, exploitation of incremental changes is not to be discounted. In fact, research has found that incremental changes generally result in more than half of the economic gain from an organization's improvement efforts (Abernathy & Utterback, 1978).

There has been a long tradition in organizational literature to address exploration and exploitation as separate activities (Shane, 2008). Similar to Christensen's conclusion, some researchers have found that organizations perform best when they adopt mutually exclusive processes and organizational structures to tackle exploration and exploitation separately (Martini et al., 2013). However, other studies have shown that organizations can embrace a combination of exploration and exploitation to drive innovation. A balance of the two approaches has become a key concept in organizational success (O'Reilly & Tushman, 2013; Shane, 2008). Finding the right mix, however, of exploration and exploitation is not easy. Many studies have shown that organizations often overemphasize exploitation, to the detriment of their exploration needs.

Tensions and the Ambidextrous Organization

In addition to the tension between exploration and exploitation, organizations also need to balance other tensions like being collaborative and competitive, focusing on mission or market, and having global integration or local distinction (Smith et al., 2017). Rather than shy away from these tensions, embracing them can help leaders and organizations be more innovative (Andriopoulos & Lewis, 2010).

Paradoxical thinking is a process of identifying and defining contrasting characteristics in order to consciously bring about their positive characteristics (Fletcher & Olwyler, 1997). This process has been shown to promote innovation by leveraging the paradoxes as a means to question the status quo (Andriopoulos & Lewis, 2010; Fletcher & Olwyler, 1997). Additionally, organizations led by paradoxical thinkers are thought to be better at managing organizational tensions and fostering innovative behaviour (Andriopoulos & Lewis, 2010; Ingram et al., 2016).

Literature on ambidextrous organizations focuses on understanding the challenges and benefits of developing a capability with the two underlying conflicting components of exploration and exploitation (O'Reilly & Tushman, 2013). Ambidexterity acknowledges the tension between exploration and exploitation, but looks to unlock the benefits of developing and leveraging this tension (Martini et al., 2013). The balancing of exploration and exploitation of ambidextrous organizations has been shown to enable organizations to learn and adapt faster and with better synergy across the organization (Koryak et al., 2018; Popadić et al., 2015; Princes, 2019; Sinha, 2016; Saeed et al., 2022).

Product Development and Engineering Processes

New-Product Development

The concept of New-Product Development describes a process that is specifically geared towards developing radical or discontinuous products (Calantone & di Benedetto, 1988; Takeuchi & Nonaka, 1986), but the majority of new-product development research focuses instead on development of evolutionary products (Veryzer, 1998). Robert Veryzer (1998) found that the process for engineering teams pursing discontinuous new-products was significantly different from the typical new-development process. Specifically, there was heightened focus on delivering prototypes earlier in the process, and market research and financial analysis occurred later (Veryzer, 1998).

Takeuchi observed this trend a decade earlier, and proposed the "New new-product development" process (Takeuchi & Nonaka, 1986). Instead of developing projects linearly and passing the development from team to team as it progresses, development should be done as a single integrated and comprehensive team, where everyone is working together simultaneously to get the product developed. Rather than the development process being a relay race, Takeuchi called for the new new-product product development process to be more like a game of rugby.

The sports analogy contributed to the emergence of the Agile methodology and "scrum," two highly iterative development processes that are popular in the innovation and startup communities. Interestingly, Agile methodologies are obsessively customer-focused, and the development process consists of many small incremental changes delivered quickly. Throughout the entire cycle, there appears to be little time for exploration.

Exploration vs. Exploitation in Engineering

Beyond the concept exploration phase itself, the distinction between exploration and exploitation is less commonly found in engineering management literature (Yitmen, 2011). A recent paper referenced the ideas of exploration and exploitation as analogous to the product development phases of concept design and detail design phases, respectively (Xiong et al., 2019). The authors explicitly differentiated between exploration and exploitation efforts by emphasizing the exploratory nature of concept exploration (Xiong et al., 2019), and characterizing the process of detailed design as a source of design exploitation.

Implementing an Innovation Strategy

An innovation strategy aims to align an organization's innovation efforts with their overall business strategy (Pisano, 2015). An innovation strategy helps an organization make trade-off decisions and choose the elements of their innovation system, which in-turn help to keep the innovation efforts across the organization aligned with the primary business strategy (Chapman, 2006; Pisano, 2015).

Successful Innovation Strategies

Strategy and leadership are critical factors to successful and effective product innovation management (Cooper et al., 2001; Pisano, 2015). Adopting any of the various innovation practices is unlikely to be successful without a clear overall strategy that is aligned with the corporate strategy (Pisano, 2015). Koryak et al. (2018) showed how organizational attention and focus on exploration and exploitation, combined with a clear written vision is crucial to an effective innovation strategy.

Engineering managers and management processes play a pivotal role in directing innovation efforts and conveying innovation strategy to their teams. Effective product innovation relies on co-operation across the organization, and it is imperative that managers develop consistent priorities with all their teams (Cooper et al., 2001). A study of 422 small and medium-sized enterprises in the UK found that the focus of managerial attention directly affected the development of their exploration and exploitation capabilities (Koryak et al., 2018). In addition, a field study of high-technology engineering firms revealed that the alignment of management systems had a significant impact on the outcome of exploration projects, while exploitation projects were far less affected by alignment/misalignment of management processes (Burton et al., 2012).

A critical function for senior managers is portfolio management for product innovation (Cooper et al., 2001). All the projects in the portfolio should be a manifestation of the organization's corporate and innovation strategy. This approach has been shown to be an effective tool to help managers evaluate and prioritize which projects to pursue in order to better align their total engineering efforts with the innovation strategy (Cooper et al., 2001; Sinha, 2016).

Overemphasis on Exploitation

Despite the benefits of balancing exploration and exploitation, research shows that organizations often overemphasize exploitation efforts to the detriment of long-term performance (Ehrlenspiel & Dylla, 1993; March, 1991; Shane, 2008; Walrave et al., 2011)—a situation is sometimes referred to as the "success trap" (Walrave et al., 2011). There are various theories attempt to explain why so many organizations suffer from this phenomenon, but the success trap is most commonly attributed to strategic myopia (Walrave et al., 2011). People are naturally risk adverse and favour immediate rewards (Christensen et al., 2015; Greve, 2007). Therefore, engineers and leaders may find it more appealing to exploit existing concepts and apply incremental changes/improvements, rather than spending the time and resources to explore a wider range of concepts (Pahl & Beitz, 2013). In addition, managers, executives and corporate planners may be more tentative to pursue exploratory efforts simply due to the unknown nature of it (Walrave et al., 2011).

Inertia and Resistance to Change

Inertia can provide many benefits to an organization, e.g., economies of efficiency/routine, greater reliability in delivering a robust and feature-rich product (Miller & Chen, 1994). Hodgkinson (1997) found that cognitive inertia can cause firms experiencing a down-turn to unintentionally perpetuate their demise because strategists fail to adapt their mental models quickly enough to the changing environment. Hull et al. (2012) observed that organizations who were able to minimize sources of political inertia and cognitive bias performed considerably better than other organizations. The ease in which capital was able to flow from one business opportunity to the next supported stronger shareholder returns.

Summary

Throughout the organization and innovation literature, one common thread is the trade-off between exploration and exploitation. The tensions between exploration and exploitation was first applied to organizational learning to draw the distinction between exploring new capabilities versus exploiting known certainties. Broad managerial tactics and processes have been developed to help organizations and managers navigate the complexity of balancing exploration and exploitation. The tension between exploration and exploitation, however, has rarely been applied to engineering product development efforts. We find this to be a notable gap because product development should be an integral component of an organization's innovation strategy, and the dichotomy of exploration and exploitation seems particularly relevant to the engineering challenges of architecture design and development.

Method

The Data

Data used in this paper was collected through surveys (see Exhibit 10 in Appendix for survey questions) conducted with participants in a 2019 online course on the Architecture of Complex Systems. The course is geared towards engineering professionals who want to expand their knowledge and expertise in the use of system engineering and architecture design. Participants were not graded on their poll submissions, and completion of the surveys was entirely optional. All participant names and identifying information were removed in the descriptions that follow.

The Participants

In total, 946 participants responded to the surveys. All respondents came from within engineering organizations, and most had system engineering experience. Exhibit 1 illustrates the breakdown of respondents by years of experience as a system engineer.

Participant Professional Goals. In Question 2 and Question 6, we asked respondents what job title they currently have, and what title they wish to have in 2 years from now. We used these two questions to roughly categorize participant's future goals within their firm. If both responses are roles as a System Engineer/Architect (including senior positions), then we classified the respondent as a system engineer. However, if they are currently a System Engineer/Architect, but hope to be in a different role in 2 years, we classified them as someone looking to move "Beyond System Engineering." Conversely, a respondent who was previously not a System Engineer/Architect, but would like to within the next two years was classified as someone hoping to "Become System Engineer." Lastly, respondents that are not currently, and do not wish to have a title of System Engineer/Architect was classified as a "Non-System Engineer." Exhibit 2 illustrates the distribution of respondents by goal.

Using this categorization of goals, combined with the respondents' years of experience (Question 4), we identified three primary categories of participants. As shown in Exhibit 3, one group consists of relatively junior system engineers, with 1-6 years experience. We speculated that this group is looking to hone their skills in order to advance their career in system engineering. Another group consists of the senior engineers (15+) and engineering leaders. Finally, we have a group of non-engineers (or past engineers) from a wide range of overall work experience. We believed this group consists of employees looking to improve their understanding of system engineering in order to better support or interact with their engineering teams.

The Companies

The survey respondents came from over 177 different companies and organization, but a large portion of respondents came from a handful of organizations. In particular, 23.0% of respondents worked for one large organization, while the 10 companies with the most participants in the sample combined accounted for just over 50% of the total respondents.

As shown in Exhibit 4, very few respondents came from companies in the bottom half of their respective markets. This bias within our data was not entirely unexpected and can be explained by several factors. First, companies in a stronger position within their market are likely to be in a better position to provide employees with the time and flexibility to pursue learning and professional development opportunities. Similarly, this course could be considered a premium learning opportunity. Alternatively, employees may have an inflated perception of their organization's performance. Whether through internal indoctrination, or the above-average effect, employees may believe their organization is in a stronger position than it really is. Lastly, extensive research has shown that investing in professional development programs for employees can have significant benefits to overall organizational growth and success (Aragón-Sánchez et al., 2003). Therefore, organizations that are predisposed to invest in their employees' professional development are also more likely to succeed within their markets.

The Industries

Respondents came from a range of industries. The survey asked respondents to self-report their industry from a list of 40 potential industries (Exhibit 5). The majority of companies could be categorized into 6 primary industries, with the Automotive industry as the largest industry in our sample, followed by Space and Defense.

Reliability of Data

We applied two techniques to quantify the reliability of survey responses. In some cases, we intentionally asked participants the same, or similar, questions multiple times within a 6 month period. For example, Question 27 and Question 33 both ask the respondents: "what percentage of total product development manpower should be dedicated to architecture?" This technique allowed us to measure how much a participant's answer varies when repeatedly sampled. We also used known cross-participant relationships to compare answers to the same question. For example, we noted how "Company Age" differed between the responses provided by employees within the same company.

Within-company Data Variance

Exhibit 6 lists the response variations for company age across several organizations. To normalize the standard deviation for easier comparison, we divided the standard deviation by the mean age of each company. From there, we found that the average normalized standard deviation for company age (Question 8) is ±13.1%, which suggests that respondents had a relatively consistent understanding of their organizations' age.

Biases and Sentiment

Some questions specifically ask the respondent what they think or how they feel. For example, were asked "What percentage of total product development time do you think is appropriate to spend on concept exploration and concept selection?" (Question 29). Therefore, these data reflect the individuals' mental models and feelings rather than the actual manpower dedicated in product development. For example, a respondent that is frustrated with how much time is being spent on concept exploration, may overestimate/exaggerate their estimate of current concept exploration time, or conversely they may exaggerate how little time they think should be spent.

Irrespective of bias in the absolute responses provided, the employee's sentiment is useful. By comparing the amount of time/effort they would prefer, against the amount of time they think is currently spent, we derived a simple metric of whether the participant feels their company currently spends too much, not enough, or about the right amount of time on concept exploration. Similarly, we used the comparison between the preferred and perceived time spent as an indicator of overall frustration levels.

Results.

With our survey data, we tested two hypotheses to examine how industry, disruption, and market potential relate to organizational impact on early-stage concept development. Our survey questions around this activity used the term "concept exploration" and "architecture design," and we did not expect respondents to distinguish whether their activity was exploration or exploitation in the academic sense.

- H1: Organizations anticipating high market growth will spend more time on system design innovation to exploit the growth.
- H2: Organizations anticipating a decline in their market will emphasize system design innovation to explore new ways to expand their market prospects.

Organizations anticipating high market growth will spend more time on system design innovation to exploit the growth.

First, we looked to understand how organizations with different market expectations spend their time. Literature has theorized that market growth encourages managers to find ways to capture the additional business before their competitors do (Miller & Chen, 1994). We tested this theory with engineering teams by investigating whether higher market growth encourages engineering teams to spend more time on early stage product development. In Exhibit 7, we observe that organizations anticipating a steeper rise in market growth appear to dedicate more time and resources towards concept exploration in engineering product development compared to periods of stagnant or steady rising market growth. To validate this visual inspection, we constructed a null hypothesis: anticipation of "Sharp Increase" in market growth does not affect the amount of time and effort organizations spend on early-stage development. Testing this hypothesis on our dataset, we found a p-value of 0.053, which suggests (with a confidence level of 94.7%) that a "Sharp Increase" in anticipated market growth does impact early-stage development.

Organizations anticipating a decline in their market will emphasize early stage development to explore new ways to expand their market prospects.

Our second hypothesis addressed how organizations handle the pressure and risk of potential decline in market growth, and how the anticipated decline affects engineering teams. Some literature theorizes that shrinking markets motivate change by inducing managers to explore new ways to compete (Miller & Chen, 1994). We hypothesized that this pressure results in engineering teams spending more time on early-stage concept development.

Looking at the difference between stagnant and declining market growth, shown in Exhibit 7, we notice a sharp up-tick in concept exploration time spent by organizations in a declining market. On average, participants from a company anticipating a market decline reported to spend 35.4% of development time on concept exploration, while participants from stagnant organizations reported to only spend 24.0% on average. This increase of almost 50% could be the equivalent of spending an extra half-day per week on concept exploration. This increase supports the hypothesis that managers are motivated to spend more time exploring product innovation when they feel more certain that their market is declining and not just stagnant. We tested our confidence via a null hypothesis: a market in "Decline" does not affect how much time and effort organizations spend on early-stage development. We calculated a p-value of 0.0006474, which confirms the effects of a Declining market on early-stage development with a confidence level of 99.94%.

It is human nature to resist change and when market growth is stagnant; managers and employees may not be ready to act until they are convinced that the company will decline unless something is done. To further support this theory, we also looked at the respondents' sentiment and frustration. Question 29 of the survey asked participants how much time their organizations should spend on concept exploration, irrespective of how much time is currently spent. Exhibit 8 illustrates the difference between current and desired exploration time based on market growth expectations. Immediately, we see that on average, employees typically want to spend more time on exploration. However, if we look at the delta between the current and desired exploration time responses, we observe that there is a stronger desire from within engineering to spend more time on concept exploration when the market prospects look grim.

In Exhibit 9, we calculated the delta between engineers' desired exploration time versus reported current exploration time. These data quantify the degree of urgency employees feel about changing their current focus and resource allocation. As shown, even though engineers already spend the highest average time on concept exploration during declining markets, they continue to have the greatest desire to spend even more time.

Discussion

Lack of Clear Strategy

In our findings, we observe two seemingly contradictory relationships. On the one hand, engineering focus on early design and architecture appears to be positively correlated with market growth. That is, the more market growth an industry is expecting, the more product development is incentivized to explore concepts to best capture the growth. On the other hand, we observe that organizations only seem to refocus on design and architecture efforts once they begin to feel the pressures of anticipated market decline rather than perceiving the pressure earlier during the stagnant phase. On average, we observed a 50% increase in exploration time when compared to organizations that consider their market growth relatively stagnant. This reversal in trend suggests that the development strategy is not driven by a consistent behaviour.

Furthermore, in our findings we observe the striking result that engineers struggle to consistently quantify their views on early-stage development. Based on the gap between desired and actual exploration time (Exhibit 9), respondents do not appear to have a clear understanding or mental model of how much effort and time their organizations should be spending on early stage development. We argue that this is a strong signal that the engineers surveyed lack a clear strategy for how to balance their efforts in early-stage development.

We consider several reasons to explain this behavior: lack of experience or exposure; no strategy to begin with; communication and alignment gap; and challenges translating strategy into action. First, the simplest explanation is that our respondents are new or less experienced with the concepts of design and architecture, and therefore struggle to reliably answer the questions concerning the amount of effort spent on early-stage development because they don't necessarily recognize the differences. After all, the respondents are taking a course to learn more about system architecture. Similarly, one might expect that junior engineers could have less exposure to the full engineering process at their organizations, and thus are simply unaware of their organizations' focus across the entire processes.

The second possibility is that there is no innovation strategy at the company level and not just at the engineering function level. This could explain why organizations appear to decrease focus on early efforts when markets prospects decrease. We observed, however, how once the market prospects appear particularly dire, engineering teams undergo a drastic shift in focus. Engineering teams hit a tipping point where they redirect efforts back towards early stage development. The re-emphasis on early-stage design and architecture shows that, at some level, there was a strategic shift within the engineering team (and likely the entire organization) to instigate this change. Moreover, many of the organizations in our study are large established organizations. Organizations of their size are likely to have at least some level of corporate strategy and innovation planning. Therefore, we find it unlikely that there is a complete lack of planning, but the strategy could be weak or misaligned between the business and engineering.

The last two reasons assume a strategy at the company level. This strategy may not have been clearly communicated to engineering due to a communication gap between the corporate strategy and innovation planning. Alternatively, even with a clear message, engineering managers may not know how to apply the strategy to their everyday decision-making and engineering processes.

Suggestions for Organizations and Managers

Improvements can occur at the corporate level and engineering management levels. We propose a few actionable items that corporate leaders and engineering managers could do to improve their engineering operations.

Have a Clear Corporate Innovation Strategy

Without strong strategic direction or guidance, people naturally gravitate towards easier and less risky choices (Christensen et al., 2015). Rather than exploring a wide range of concepts, it can be far more appealing to exploit existing concepts and apply incremental changes and improvements. Thus, organizations may only pursue a very narrow focus to their concept exploration (Pahl & Beitz, 2013), despite strong evidence suggesting that a broader more thorough exploration of the solution space leads to higher quality results (Ehrlenspiel & Dylla, 1993). To counteract this tendency, Koryak et al. (2018) showed that having a clear written vision with attention to exploration and exploitation efforts is fundamental to implementing an effective innovation strategy.

Power Through the Turn

Making drastic changes in an organization can be very challenging and painful. Going through large strategic change is often fatal to an organization as it can be an immense disruption, met with resistance, and often comes too late. However, based on the findings, it appears there is a clear and substantial shift in product development focus at the point in which organizations begin to feel their market share is in decline. Even more troubling is the fact that firms appear to decrease their early-stage development efforts as the market growth slowed down. To avoid the jarring reversal in trend, we believe organizations should "power through" market slowdowns with more (or at least the same) level of exploration.

Align Engineering with Innovation Strategy

Even with a clearly communicated innovation strategy, it is not of much use if engineering teams and managers do not adjust their development processes to align with the strategy. Burton et al. emphasized this when they showed how the alignment/misalignment of management systems strongly impacts the outcome of exploration projects (Burton et al., 2012). Translating an innovation strategy, however, to real world actions and processes is not necessarily easy.

Rather than prescribing or suggesting specific tactics, or processes, we feel the most important aspect for managers to improve is awareness and attention. Managers need to be aware of the corporate-level strategies, with particular attention to how the strategy relates to innovation. As already discussed, a clear corporate-level innovation strategy that can be written down and shared across the organization is vital to an effective innovation strategy. If managers are still unclear about the high-level strategy, then it is important to raise this issue and open a communication channel to get this resolved. From there, managers first and foremost need to keep the strategy top of mind and ensure that they continually consider how their decisions and actions align with the strategy. Koryak et al. (2018) highlighted how important managerial attention is to the development of explorative and exploitative capabilities. Additionally, adopting a portfolio approach as a means to prioritize and accept active projects can be an effective way to balance the engineering efforts and ensure they are inline with the innovation strategy (Sinha, 2016).

Managers: Identify Misalignment

To ensure that managers and leaders stay on track, we discuss several signals and indicators that managers watch for to assess how well they are aligning with the overall strategy or if they are starting to veer off course.

One indicator we see from our survey data is that team sentiment towards early-stage development could be an indicator that more time and effort is required. The absolute metric of how much effort and time employees feel should be budgeted towards early-stage development may be quite noisy (Jeffcoat et al., 2019). However, a Goldilocks approach of just measuring employee sentiment towards the current processes (too much, not enough, or it is just right) could be used to assess if engineers feel they should be spending more time.

Second, both retrospective and prospective assessment of time allocation and budgets of various stages of the development process can be used as a simple quantitative measure of innovation focus. This can be used as an easy smoke test for managers. Additionally, if, over time, the focus changes, managers can reconsider if the shift is inline with the innovation strategy.

Finally, incoming project proposals can be a good indicator of engineering focus. Each proposal could be classified as exploration or exploitation, and then compare the balance of project proposals. For example, if most project proposals are related to optimizing various components, but the innovation strategy suggests higher emphasis on exploration efforts, then the engineering team may be out of alignment. A classic example of dealing with this situation is the way PreQuip got its development efforts under control and properly aligned with its corporate strategy by developing, tracking, and maintaining an aggregate project plan (Wheelwright & Clark, 1992).

Suggestions for Research

March (1991) discusses two sides to organizational learning through the lens of exploration and exploitation. Using this tension, the field of organizational learning has made leaps and bounds towards how organizations can learn and adapt in changing environments. However, the same trade-off between exploration and exploitation is very applicable to engineering ability to improve their technical capabilities and core competencies.

Conclusion

We argue that like organizations, engineering teams also internally trade-off between exploration and exploitation during development and would benefit with more intentional and explicit consideration of their strategy. Using survey data collected during an online system engineering course, we find that engineering departments struggle to adopt and follow effective innovation strategies. We cannot be sure of the exact cause in these cases. It could be that there was no fleshed-out innovation strategy to begin with or because the strategy was not communicated effectively to the engineering department or because the engineering department failed to follow it.

Change in markets, customer needs, new technology, and other disruptions, means that what was the right decision today, may not be the best choice for tomorrow. Therefore, an organization's ongoing ability to innovate and adapt to changing environments is absolutely crucial to its long-term survival.

Without strong strategic direction or guidance, people naturally gravitate towards easier and less risky decisions. In product development this behavior can be seen by a strong tendency to exploit existing designs by applying incremental changes or improvements rather than exploring a wider range of new designs when selecting concepts for new products.

This interplay of exploration and exploitation has been around for ages. It is commonly used to distinguish the needs of exploring new innovation or creating new markets versus exploiting existing capabilities or markets. For decades, this concept has been studied in organizational learning and innovation strategy literature. However, very little literature correlates these learnings with product development lifecycle and engineering processes. Our study addresses part of the gap by examining how exploration and exploitation manifest themselves at the engineering level.

What we did find was that as an organization's market growth decreases, attention to architecture and design innovation within engineering also decreases. This trend continues until the organization hits a tipping point where the development teams appear to undergo a drastic shift back towards design innovation. We argue that this behaviour is best explained by risk aversion and internal inertia rather than an intentional strategic decision. A more effective strategy should include a more intentional response to market change that considers the overall innovation and corporate strategy. For example, as the markets begin to stagnate, a stronger strategy may be to consider shifting priorities towards additional exploration efforts, rather than simply decreasing exploitation.

Furthermore, we suspect that development teams often do not articulate an appropriate strategy for each of the product development phases, and engineers struggle to maintain a consistent mental model of how much time and effort their organization currently wants to (or should) spend exploring the design space. So, although the organizational level may have developed a more intentioned innovation strategies, this fails to disseminate down to the development level.

We suggest engineering teams and strategy teams pay more attention to how their focus and efforts align in the context of innovation management. It is critical that innovation be clearly written and communicated across the organization so that engineers can understand the implications of the innovation strategy. Early-stage development phases need to be reasoned and budgeted in a manner consistent with the innovation strategy. Finally, management needs to ensure that the correct motivations are in place to ensure that the strategy is followed.

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Exhibit 1. Distribution of respondents by experience as a System Engineer

Exhibit 2. Respondents by Goal Category

Exhibit 3. Clustering of Participant by Role and Experience

Exhibit 4. Company Market Position of Respondents

Exhibit 5. Industry Responses

Exhibit 6. Average and Standard Deviation of company age responses by organization, for organizations with over 5 responses.

Exhibit 7. Reported Concept Exploration Time by Anticipated Market Growth

Exhibit 8. Desired Concept Exploration Time by Anticipated Market Growth

Exhibit 9. Concept Exploration Time Delta by Market Growth with Error Bar

Exhibit 10. Survey Questions