

# Exploring the Context of Product Line Adoption

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## 1. Introduction

The tremendous benefits of taking a product line approach for similar software-intensive systems are well documented [Clements & Northrop 02a]. What's not as clear, however, is how to effectively achieve an operational software product line, often called product line adoption. The "Launching and Institutionalizing" practice area of the Framework for Software Product Line Practice<sup>SM</sup> lays out what must occur in organizational adoption, as well as useful specific practices [Clements & Northrop 02b]. Related work has involved: Böckle and associates, who further studied software product line adoption and institutionalization needs from an organizational standpoint [Böckle et al. 02]; Bosch, who examined the maturity and evaluation of product line artifacts [Bosch 02]; and Schmidt and Verlage, who describe the economic impact of product line adoption [Schmidt & Verlage 02].

The road to product line success is really organization specific, and yet none of the above research has carefully considered the context in which product line adoption takes place, or the influence that context can and should have on the adoption strategy, and, consequently, on the success or failure of the adoption effort.

Our main objective in this paper is to explore the context for product line adoption at multiple levels and then to demonstrate the usefulness of that context characterization by means of an example. After discussing what product line adoption entails, we divide the context landscape into multiple levels, discuss the influencing factors at each one, and investigate the potential relationships between the levels. Choosing core asset development as a specific adoption objective, we show how understanding and characterizing the adoption context can help you choose an appropriate strategy. We summarize our results and then conclude with projections about how this reasoning can be further applied for greater advantage.

## 2. Product Line Adoption

Product line adoption involves moving from some form of developing software-intensive systems via a single-system mentality to developing a family of software-intensive systems that form a product line. A *product line* is defined as a set of software-intensive systems sharing a common, managed set of features that satisfy the specific needs of a particular

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<sup>SM</sup> Framework for Software Product Line Practice is a service mark of Carnegie Mellon University.

market segment from a common set of core assets in a prescribed way. The adoption endgame is to have a core asset base, to build products from it, and to have supportive processes and organizational structures in place.

An organization usually decides to adopt a product line approach with specific business goals in mind. Those goals will, at least to some extent, be unique to the organization and depend on the line of business and the market position. To achieve its goals, the organization selects one or more adoption strategies that specify how it will embrace product line practice. The chosen strategies must help achieve the goals, be appropriate for the organization's size and talent pool, and exploit any successful legacy assets or processes. An adoption plan then shows in detail what activities or tasks must be accomplished to implement those strategies. Figure 1 shows the tightly knit connection between the adoption goals, strategies, and plans.

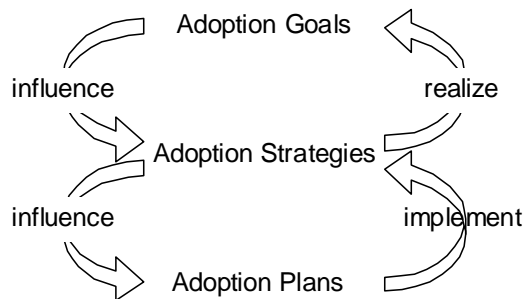


Figure 1: Adoption Goals, Strategies, and Plans

In any given organization, a hierarchical set of goals, strategies, and plans reflecting the different levels of the organization might exist. For example, an adoption task associated with a business unit could be the goal for a specific individual.

In this vein, the whole concept of product line adoption becomes very personal to the organization; the exact context seems to play a significant role in shaping the adoption.

### 3. The Context of Product Line Adoption

This context consists of multiple layers with the outermost one being the market of the products being produced. In any market, each specific organization plays a distinguishable role. Typically inside each organization, discrete business units exist, and within them, there are individuals who perform the work. Figure 2 depicts adoption context as these layers of influence, which can be peeled away one by one to gain visibility into the underlying rings—a sort of onion-skin model.

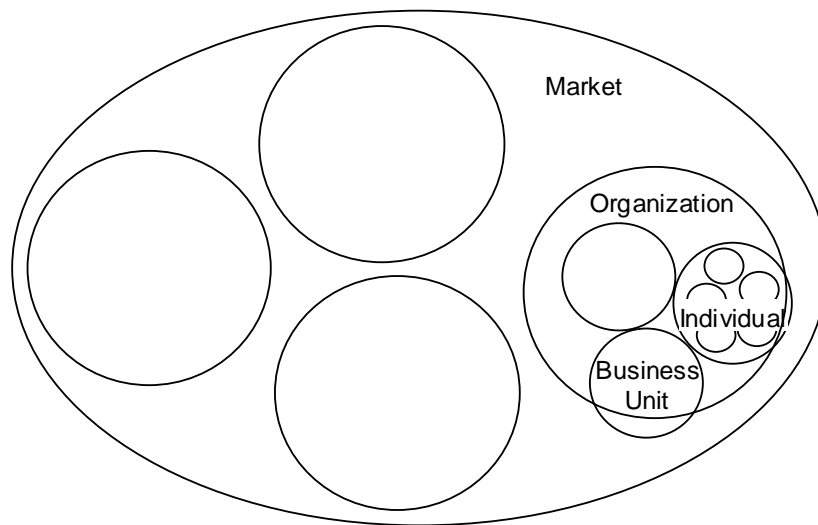


Figure 2: The Circles of Adoption Influence

More importantly, relationships exist among the circles. The outer circles provide resources for and put constraints on the inner circles. Goals of the inner circles depend on a characterization (and the resulting plans) of the outer circles. Market conditions affect organizations—that is, organizations in a certain market cannot make context-free decisions. In turn, organizational goals, strategies, and plans affect the business units within, and individuals take their lead from unit-wide decisions and plans. It is also possible that some business units have their own market relationships and community efforts. The ability to alter the state and inclinations of the entities represented by the concentric circles becomes more difficult as you move from the inside out; it is much more difficult to influence the market than to influence a particular individual. The next four sections examine the four circles of influence with their respective influencing factors.

### 3.1 Market

Although the market itself is not goal driven, it defines the intercompany playing field. The following market characterizations directly influence any product line effort within an organization belonging to that market:

- *How large is the market volume (the number of products potentially needed)?*  
Whereas a large market is no guarantee for the successful adoption of a product line strategy, a small market leaves almost no chance to successfully exploit the potential product line benefits.
- *How mature is the market?*  
The better a market (i.e., the products, and the targeted market segments and its needs) is understood, the easier it is to predict the evolution of the products in it and, consequently, to increase the likelihood that investing in product line core assets will pay over time. In very immature markets, such predictions are difficult, therefore increasing the investment risk. On the other hand, the market cannot be too homogeneous. It must

be “similar enough” so that a set of features can be shared across product variants. But there must also be differentiating characteristics so that individual features can be developed to meet the specific needs of each market segment. For example, in developing countries, the markets might be large enough but too homogeneous to warrant product lines.

- *Do open standards exist for this market?*

Open standards are a good basis for establishing a reference architecture. That architecture, in turn, enables buying and selling components from/to competitors in the market, which supports the infrastructure build-up of product lines.

- *How safety-critical is the software in the products that constitute this market?*

For example, server and client products pose very different safety and reliability requirements. Server products need to be reliable because they typically provide the infrastructure for many clients. Often, client applications, like typical desktop products, are less safety-critical because their failure does not cause severe damage or injury. Typically when a product is built from a set of high-quality product line assets, it will also be of high quality. Such a product obviously fits better into a market that requests a high level of reliability.

- *Are there clear market leaders?*

To some extent, the market leader can define the direction in which a market will evolve, and establish or influence emerging standards [Cusumano & Selby 95]. The leader is well positioned to invest in the right product line assets to protect or even improve its market position in the future. Often, competitors in the same market must follow de-facto standards set by the market leader’s products, making predictions about the return of investment (ROI) from core asset development difficult.

The individual organizations within the market largely determine these characterizations, with the exception of market size and maturity. Conversely, these characterizations influence what any of those organizations can do. If we assume that the market conditions are favorable for product line development, we can move to the next circle of influence, namely the organization.

## **3.2 Organization**

The organizational context is roughly defined by the market conditions. Organizational goals therefore have to fit in this context. Additionally, the following organizational characteristics influence an organization’s goals and, consequently, both its product line adoption process and its business unit (the next layer in the circles of adoption influence).

- *What is the organization’s current position in the market? How high is the probability that the organization will become a market leader?*

Depending on the market’s form (monopoly, oligopoly, or polypoly), the current market share (leader, stable position, or newcomer), and the organizational goals, the organization can follow different strategies to maintain or improve its market position. Examples are sumo (i.e., buying competitors or crushing them with superior force),

classical (i.e., being an early mover in new technologies, leveraging the installed base, and locking in customers by creating switching costs), and judo (i.e., moving rapidly to uncontested grounds and giving way when attacked by a superior force) [Cusumano & Yoffie 98]. When it adopts a product line approach successfully, an organization can expand its total market penetration by addressing the needs of new market segments related to its existing segments with relatively limited costs. But that organization would also face some jeopardies. For example, in the face of fierce competition, it might need to move to new markets before it has enough resources or the appropriate domain knowledge. Thus, a good and stable market position can help build a reasonable asset base for the market.

- *How closely is the organization connected with its customers?*

If the organization has a close connection to its customers, it usually has a better understanding of their needs. This understanding enables the organization to both develop the right core assets and appropriately adapt existing assets. Both activities are a prerequisite for achieving an effective product line. A close connection to the customer is a key factor for optimizing the asset base. If the organization is just loosely connected to the customers, it needs a strong market position to “dictate” product standards.

- *How much control does the organization have over the product specification?*

Having control over the product specification is another important factor for an organization. The more the organization can control how features, user interfaces, and other aspects are implemented, the more it can gain from core asset development and the better it can plan for evolution of the product line. However, in some market segments, full control over product specification is not easy to achieve. For example, customer needs in the automotive supplier market often include individual design constraints such as the use of specific commercial off-the-shelf (COTS) components or the support of customer-specific interfaces. These constraints might limit the optimization of core assets and need to be negotiated carefully. Typically, good control over product specification can be achieved when the organization is in a leading market position and offers new products that the market has not been anticipated or when the customers are the end users of the products (i.e., they don't impose hard constraints on the organization's development).

- *How likely is it that the organization will sell the asset base as well as products built from it?*

In addition to selling products in the product line, an organization can generate revenue by selling platform standards, that is, the asset base itself. If the market is mature and demands a product line for a specific domain (e.g., telecommunications), the organization can sell the asset base to competitors as a kind of “open platform” or “framework.”

- *How high is the motivation to use a product line approach?*

The readiness to adopt a product line approach (from the organization's point of view) basically depends on two factors: (1) is the organization forced to use a product line approach to remain competitive, and (2) can some other organizational strategy be leveraged to maintain or even extend its market position? If the organization firmly

believes that a product line approach is essential to achieving its goals, both its motivation for adopting the approach and its commitment to stay the product line course would likely be high. If, on the other hand, a product line approach is not critical to its success or was chosen arbitrarily, the probability of a successful product line adoption will likely be low.

- *How stable is the funding source for development and evolution of the core asset base?*  
The funding source for an asset base might be key customers, other product lines or business units, corporate development funds, or project business (i.e., selling tailored solutions and services). Key customers are a viable option because they can provide a comprehensive view of essential assets in the corresponding domain. Typically, key customers are or evolve into trusted long-term partners who can tolerate higher risks with respect to defects and unexpected development problems than normal customers. They often provide more stability for asset development than internal champions (e.g., top managers) because all too frequently champions change positions and leave the product line effort without the needed financial backing. On the other hand, the organization has to be sure that the paying customers are the right ones—that is, that they truly represent the needs of the targeted market segments. The organization needs a backup plan or migration strategy to avoid unnecessary risks with “wrong” customers. To ensure stability, a balanced mix of funding sources is best.
- *How strong is the high-level management commitment for a product line approach?*  
The decision to adopt a product line approach for the organization requires commitment from high-level management. That commitment is needed to ensure adequate resources of manpower, time, and funding, and to provide the necessary direction and orchestration, organizational structure, training, and proper incentives for business units and individuals to move to the product line approach.

The organization-wide strategies to achieve product line goals can involve a top-down dictum or policy; for example, “All business units will use a product line approach for the families of software-intensive products within its sphere of influence.” Alternatively, the organization can proceed bottom-up: pilot product line efforts are begun in one or more business units and tracked carefully, and then product line practices are systematically rolled out to the entire organization. Many organizations choose some combination of top-down and bottom-up strategies. Independent of the direction the strategies take, a plan should exist for enacting them. Such a plan defines goals for individual business units as depicted in Figure 3.

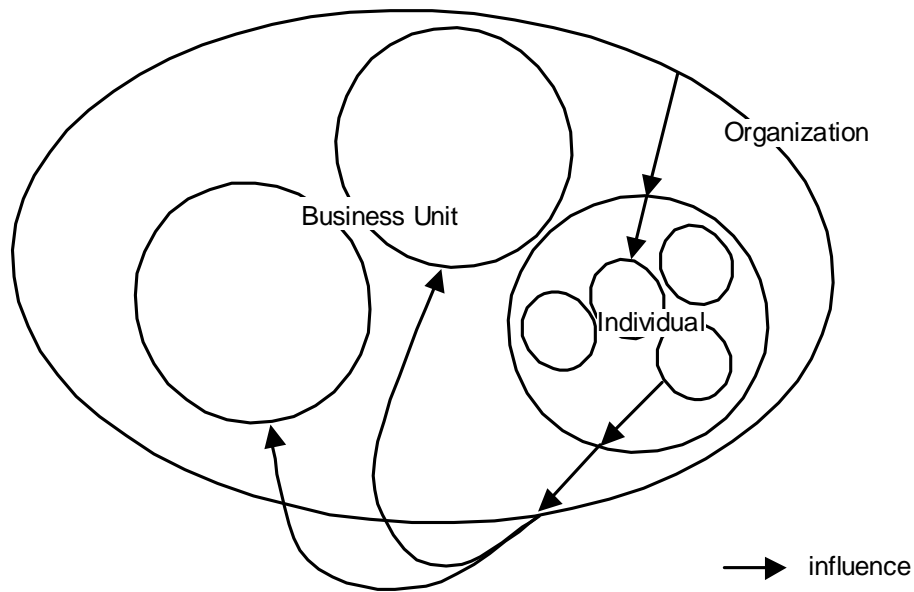


Figure 3. Interdependencies of Organizational Adoption Strategy and Business Unit Goals

### 3.3 Business Unit

Typically, an organization is composed of multiple business units. Each unit accepts the goals that are imposed on it by the organization and might define some of its own goals as well as the strategies to achieve them. For example, an organization might impose cost-reduction goals over its business units. However, different business units might choose different ways to achieve those goals. For example, one business unit might apply a strategy to improve its production capabilities to achieve better yield rates, while another unit might decide to merge two product lines to reduce its development and maintenance effort.

The following business unit characteristics directly influence product line adoption:

- *How much experience has the business unit had with products in the targeted product line?*

When a business unit has developed plenty of “successful” products for the relevant domain, it understands that domain and can find the essential assets relatively easily. In contrast, if the business unit is going to develop an asset base for a new (and unknown) market, the probability of successful adoption declines.

- *How many high-quality legacy assets does the business unit have for this product line?*

Business units that already have high-quality assets from single-system development (i.e., essential artifacts that are highly reusable among several products) are in a better position to build up a stable and valuable asset base than those who don’t. Despite the high quality, however, the adaptability of these legacy assets can still thwart adoption success.

- *What is the current degree of process discipline within the business unit?*

If the business unit has already embraced standardized engineering procedures for developing its products, the discipline required to smoothly adopt a product line approach will be much more natural than in an organization with chaotic procedures. Existing process discipline will simplify the adoption process and accelerate the development time of the core asset base.

- *How much domain-specific talent already exists in the business unit?*

Domain-specific knowledge is essential in developing a reasonably stable asset base. If domain-specific talent does not already exist from single-system development, it might be unclear which assets are the same among different products and which are different. The business unit in this case has to be aware that additional time and/or cost is needed to further develop this talent. If domain-specific knowledge is unavailable, it must be acquired, thus making adoption more lengthy or costly.

- *How keen is the software engineering expertise, in particular the software architecture skills?*

Software engineering expertise (not just programming experience)—in particular, software architecture skills are essential for product line adoption and success. The business unit should be evaluated with respect to its software engineering capability, especially in software architecture practices. Business units with well-honed architecture skills are more likely to develop successful product lines.

- *How deeply engrained is the single-system mentality within the business unit? How intrinsically adverse to a product line approach is the workforce?*

If the organizational structure and culture are fixed to single-system development, there is no visible need to change processes, or there is no strong leadership to carry the tide, the adoption is likely to fail. Cultural resistance to any technology change is a steep barrier that takes years to overcome.

- *How dependent is the business unit on proprietary tools built and used to support a single-system approach?*

If the business unit is heavily vested in “legacy” tools constructed specifically for single-system development, adoption of a product line approach would require that the tools be reengineered, or that new ones be acquired and taught to individuals. This would involve a significant investment that might hamper product line adoption.

- *How clear are the current business and product strategies? Is there a willingness (or an ability) to communicate the business strategy throughout the business unit?*

Communicating the motivation for product lines (or at least the reason why things should change) is a key factor when dealing with organizational change. If the proposed strategy is unclear or ineffectively communicated, there is little chance that the organizational goals will be met.

- *How equipped is the business unit to perform activities situated within each of the 29 practice areas described in the Framework for Software Product Line Practice [Clements & Northrop 02b]? What availability of talent will be needed to compensate for any expertise shortages?*

To address the 29 essential practice areas, appropriate talent is required. A business unit has to determine if that talent is available in the unit, or in other business or cross-sectional units of the organization. If existing personnel are not able to satisfy the demands, external domain specialists, architecture specialists, or other experts are needed to educate, coach, and support the business unit personnel. The more knowledge and expertise already on hand, the easier the adoption process will be.

Typically in very small organizations, there is no need for business units, and so there is little distinction between the organizational and business unit contexts. For those organizations, their contextual factors and the business unit levels of the adoption influence circles apply together.

### **3.4 Individual**

Individuals, of course, make up business units, and it is individuals who ultimately determine whether new processes, methods, and tools are adopted in their everyday organizational practice. The following characteristics of individuals influence product line adoption strategies:

- *Do the individuals have the necessary (additional) capacity to “learn” product line engineering?*

Personnel often have only the time to fulfill their routine job responsibilities and no more. The move to a new approach demands additional time to learn new processes and possibly acquire new skills. If the business unit is not willing to offer enough time, training, compensation, and other necessary support, the individuals’ investment will not be adequate for successful adoption.

- *Do the individuals have the necessary expertise? And if not, how will they get it?*

Without appropriate expertise, individuals cannot understand, contribute to, and execute the new processes. Additional training and/or knowledge-transfer is necessary to create and use a stable, high-quality asset base.

- *How motivated are the individuals? Are they willing to learn and apply product line engineering methods?*

Change is difficult for most people, and so like business units, individuals need motivation to embrace a product line approach. The reason for the shift to a product line approach should be transparent to all individuals in the business unit.

- *Will the individuals gain or lose from product line engineering?*

In most cases, individuals are willing to exert the additional effort to change only if they benefit from it. Often when new processes and tools are implemented, some people benefit, while others just get more work. Thus, the organizational goals and business unit strategies should be designed to benefit as many individuals as possible. Moreover, the anticipated benefits should be communicated broadly and well.

Different from the previous layers (market, organization, and business unit), the individual factors are more psychological. Individuals’ views change based on their comfort level and

their perceptions as to whether the change will adversely affect them. The individuals in any organization need to be carefully enlisted in the adoption process; the adoption of a product line approach must be carefully orchestrated to empower the workforce instead of making it feel uncomfortable or exploited.

#### **4. Using Context Characterizations in Choosing an Adoption Strategy for Core Asset Development**

As described in Section 2, a product line approach involves three essential activities: (1) development<sup>1</sup> of core assets, (2) development of products, and (3) management of the product line operation at both technical and enterprise levels [Clements & Northrop 02a]. For a business unit moving to a product line approach, the development of a core asset base is part of the adoption process. In fact, having the core asset base may well be a product line goal of the business unit or at least an objective that is tied to a goal. However, the order in which core asset and product development occur is not fixed, and hence, a business unit can choose from different strategies. It can choose a strictly proactive strategy that focuses first on developing the core assets [Krueger 02]. In so doing, the unit would first define the product line scope (which provides a kind of mission statement for the other core assets) and then design the product line architecture, components, and other assets accordingly with the right built-in variation points to cover the scope [Thiel & Hein 02]. The business unit could also select a reactive strategy, which suggests that it begins with one or more existing products and uses them to generate the product line core assets. The products might actually have been built before product line adoption was considered.

An incremental strategy, which is yet a third option, is a proactive/reactive hybrid [Muthig 02]. Following it, a business unit develops the core assets gradually and develops products during the process. For example, it would develop part of the core asset base, presumably the product line architecture and some components; develop one or more products, and then evolve part of the rest of the asset base; develop another set of products; evolve more of the asset base; and so on. An incremental strategy assumes the ambition to build a product line from the outset.

The proactive approach has obvious advantages—once the core asset base has been developed, products come to market extremely quickly with a minimum of code writing. However, developing the product line architecture, components, and other core assets is a significant up-front investment that requires considerable up-front predictive knowledge. The reactive approach has the advantage of a much lower cost of entry to product lines, but requires that the quality of the architecture and the product components used as the basis for the asset base must be robust, extensible, and appropriate for future product line needs. The incremental approach seems to offer the best of both worlds, but in many respects has the same disadvantages of both its reactive and proactive siblings—just in weaker doses.

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<sup>1</sup> The term *develop* is meant generically and might actually involve building individual assets anew, buying them off the shelf, or mining them from existing assets. This use of the word *develop* as it pertains to core assets and products is consistent with its usage by the Software Engineering Institute (SEI) [Clements & Northrop 02a].

If the contextual characterizations described in Section 3 influence product line adoption as we suggested, the organizational factors mentioned in Section 3.2 constitute the context for the business unit. Therefore, there should be some context-dependent heuristics to help a business unit choose which strategy to follow for core asset development. Table 1 presents such guidance in terms of dependencies between the context characterizations and core asset development strategies.

H/M/L=Needs to be at least high/medium/low		Adoption Strategies for Core Asset Development							
		Proactive		Incremental		Reactive			
Organizational Factors	Market Leader (H, M, L)	H		M	M or L				
	Degree of Connection with Customers (H, M, L)				H or M			L	
	Control of Product Specification (H, M, L)	H		M	L			L	
	Sell Asset Base (H, M, L)		H			L			
	Strength of Motivation to use Product Lines (H, M, L)	H	H	H or M	H or M		L		
	Stable Funding for Core Asset Base (H, M, L)	H		M	M				L
	High-level Management Commitment (H, M, L)	H	H	H	H				

*Table 1: Dependencies Between Organizational Context Characterizations and Core Asset Development Strategies*

The first column of Table 1 lists the factors that influence the choice of an organizational adoption strategy as described in Section 3.2. The remaining columns list the mentioned categories of adoption strategies: proactive, incremental, and reactive. The body of the table depicts the dependencies between the organizational factors and adoption strategies whereas every column represents necessary factors for the corresponding adoption strategy. The cells of the table body are marked with “H” for “needs to be high,” “M” for “needs to be at least medium,” “L” for “needs to be at least low,” or left empty meaning that the respective factor does not influence the choice to be made. The columns should be read as an AND condition: the respective adoption strategy is applicable only if all conditions in the corresponding column are met.

For example, to choose a proactive or incremental strategy, there must be high-level management commitment; if high-level management commitment is medium or even low, only a reactive strategy is applicable. One possible precondition set for choosing an incremental strategy is: a medium likelihood to become market leader, high or medium motivation to use product lines, medium control of product specification, a medium stable funding source for core asset development, and high-level management commitment. A good

connection to customers can compensate for not being in control of product specification (customers will communicate their requirements for future products early) and even outweigh a less desirable position in the market.

Once the business unit chooses an appropriate strategy, it should baseline its current state according to the dimensions of the business, architecture, process, and organization (BAPO) framework [America et al. 00, Wijnstra 02], the 29 practice areas of the Framework for Software Product Line Practice [Clements & Northrop 02b], the PuLSE™ customization factors [Schmid & Widen 00], or some other comprehensive software product line yardstick, and then perform a gap analysis. Using the results of that analysis, the business unit can then follow a planning process such as the one proposed by Jones and Northrop to develop an adoption plan [Jones & Northrop 99].

## **5. Conclusion**

Adopting a software product line potentially affects all levels of an organization. To do so successfully, each affected organizational level must set its adoption goals, conceive a strategy, and implement a plan to attain those goals. The adoption goals, strategies, and plans are influenced by the characteristics of market, organization, business unit, and individual.

Future research is needed to validate whether the levels and characteristics identified in this paper are minimal but sufficient to predict successful adoption. It should also refine and empirically validate the model of the interdependencies between organizational characteristics and adoption strategies. Furthermore, models of the interdependencies between the business unit, individual characteristics, and the adoption strategies need to be developed.

There is also an interorganizational context level possibly distinguishable from the market that we did not discuss. More and more companies are organizing into relatively complex value networks that utilize layered product architectures. Each layer serves as a platform (asset base) for the next layer and utilizes the services of the underlying layer. Companies that want to become major players in their market should develop and control their platforms so that the maximum number of high-quality products and services are built on top. In such an interorganizational context, the product lines become virtual and recursive—that is, each platform represents productized core assets and the layers built on top of it are platforms as well. Companies can choose to focus only on the development of productized core assets for one layer or vertically integrate across layers. It would be interesting to investigate how this context affects the characteristics in the four lower levels identified in this paper.

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