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Divergence and Lifecycle Offsets in Product Families with Commonality

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ABSTRACT

Commonality, or the reuse and sharing of components, manufacturing processes, architectures, interfaces, and infrastructure across the members of a product family, is an often leveraged strategy targeted at improving corporate profitability. Commonality strategies are widespread in the literature and in industrial practice, but a clear gap exists: The literature has a distinctly positive bias towards the benefits of commonality, whereas industrial success with commonality has been mixed. This article explores two phenomena, divergence and lifecycle offsets, that may prevent companies from properly assessing and realizing the potential benefits of commonality. Using a multiple case study approach, we trace commonality levels through the lifecycles of seven complex product families that span the aerospace, automotive, semiconductor capital equipment, and printing industries. The case studies indicate that commonality tends to decline over time, a phenomenon we title divergence. In contrast to the prevailing concept of parallel development in product families, we find that lifecycle offsets, or temporal separations between the development, manufacturing, operations, and/or retirement phases of two or more products, are prevalent in industrial practice. Through this exploratory study, we find that lifecycle offsets may reduce the potential benefits of commonality, make the realization of benefits much more difficult, delay the realization of benefits, and reallocate potential benefits across individual products. We predict that lifecycle offsets exacerbate divergence. We propose a framework for categorizing parts-level changes that explicitly recognizes the potential for divergence. We conclude with guidance for product family managers, namely, that commonality be managed dynamically throughout the product family lifecycle, rather than as a static property. Additionally, we articulate the need to make commonality decisions from a product family perspective, a perspective that may lead to decisions that create near-term costs for one variant but result in larger long-term savings for a second variant and for the product family as a whole. © 2012 Wiley Periodicals, Inc. Syst Eng 16

Key words: commonality; platform strategy; platform management; product development; divergence; lifecycle offsets

1. INTRODUCTION

Commonality, or the reuse and sharing of components, manufacturing processes, architectures, interfaces and infrastructure, across the members of a product family is an often leveraged strategy targeted at improving corporate profitabil-

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ity. Through establishing commonality across products, companies expect to reduce lifecycle costs (e.g., product development, manufacturing, and operations) [Madni, 2012], product development lead times [Sheu and Wacker, 1997; Blecker and Abdelkafi, 2007], and risks. These expected benefits are traded against the potential penalties of commonality, such as product performance penalties that lead to a lack of market competiveness, a lack of product differentiation that drives self-cannibalization of revenues, and the potential for common component problems to propagate across product family members.

Examples of commonality are readily identified in industrial practice. The automobile industry has pursued varying approaches to commonality since the time of Henry Ford [Ford, 1926]. Widely cited successes include the Volkswagen A platform [Bremner, 1999] and C platform [Csere, 2003]. Nissan's D platform was the basis for multiple vehicles including the Murano Sport Utility Vehicle and Altima coupe [Stewart, 2008]. Aircraft families such as the Boeing 777 [Sabbagh, 1996] and Airbus A380 employ commonality strategies as well. The Airbus A380 "uses the same cockpit layout and operating procedures as the Airbus A320 and A330/A340 Families, ensuring that pilots qualified on other Airbus fly-by-wire aircraft can step into the A380 with minimal additional training" [Airbus, 2008]. In the context of software systems and software-enabled products such as handheld devices, Cusumano [2010] discusses "industry platforms" as being extensions of basic commonality: Industry platforms rely on component and service contributions from multiple companies, and users derive significant value from these externally supplied components and services. Commonality has also been leveraged in much simpler products such as Black and Decker's power tools [Meyer and Lehnerd, 1997] and the Sony Walkman [Sanderson and Uzumeri, 1995]. Even services, such as patient services in hospitals, routinely employ commonality [Meyer, Jekowsky, and Crane, 2007].

Although commonality is a routinely pursued strategy for increasing corporate profitability, success has been mixed, and the expected benefits of commonality do not always materialize. The 1983 *Fortune* magazine cover that pictured four nearly identical General Motors cars, each of which was a different GM brand [Burck, 1983], illustrates the lack of differentiation that can result when commonality is taken too far [Sköld and Karlsson, 2007]. After Black & Decker's highly successful and often quoted power tool revamp around commonality, the company shifted away from the approach in pursuit of other sources of cost reduction [Meyer and Lehnerd, 1997]. Toyota has experienced the costs associated with the failure of widely used common components both in the past [Shirouzu, 2006] and again more recently with the purported failure of common components that resulted in the recall of over 8.5 million vehicles in 2010 [Bunkley, 2010].

The objective of this paper is to contribute to an improved understanding of why the expected benefits of commonality are not consistently realized in practice. Specifically, this research focused on a multiple case study exploration of two concepts, "divergence" and "lifecycle offsets," and their relation to challenges faced in realizing the benefits of commonality within product families. "Divergence" represents the idea that commonality declines throughout the product family lifecycle. The working hypothesis is that many firms fail to achieve intended commonality levels, leading to reduced benefits. "Lifecycle offsets" represent the temporal differences between the corresponding lifecycle phases of two or more products. In a simplified view, lifecycle offset can be viewed as the separation between the development start dates for Product A and Product B. The hypothesis is that lifecycle offsets are a potential cause of divergence, which in turn may help to explain historical challenges with product platforms and underlying commonality.

The remainder of this paper is divided into eight sections. First, the conceptual foundations of commonality are presented as they relate to the objectives and findings of this work. A brief discussion of research methods is presented next, followed by summarized research data. Two sections then present the core conceptual contributions of this research: divergence and lifecycle offsets. The two concepts are then connected via a unifying framework that is intended to more accurately reflect the realities of commonality and platform-based product development, a critical connection for both the extension of academic theory and industrial practice. Implications and recommendations for managers are discussed prior to concluding.

2. CONCEPTUAL FOUNDATIONS

Strong and continued industrial interest in commonality, combined with challenges in fully leveraging the benefits of commonality, has resulted in a rich stream of research that spans general management, quantitative management models, and engineering design and optimization. The research provides useful insights into the management of commonality, engineering design aspects of commonality, and the overall benefits and penalties of commonality. With few exceptions, the literature shows a positive bias towards commonality and product platforms [Halman, Hofer, and Van Vuuren, 2003]: The pursuit of commonality will result in benefits. While the research discussed in this paper also assumes that a net benefit is realizable in most cases, the concepts of divergence and lifecycle offsets significantly temper the expected benefits while also providing warnings regarding the very real challenges associated with realizing these expected benefits. This section examines existing work related to lifecycle offsets, then divergence.

2.1. Concepts Related to Lifecycle Offsets

The concept of lifecycle offsets is a combination of the product family map and the individual product lifecycle. The product family map, which illustrates differences between the introduction timing of the individual products within a product family, is well documented [Robertson and Ulrich, 1998; Cusumano and Nobeoka, 1998; Maier and Fadel, 2001; Umeda et al., 1999; and, to a lesser extent, Uzumeri and Sanderson, 1995]. The product family map explicitly recognizes that products may be introduced at different times and, typically, into different market segments. The product family map is primarily used to understand the market timing aspects

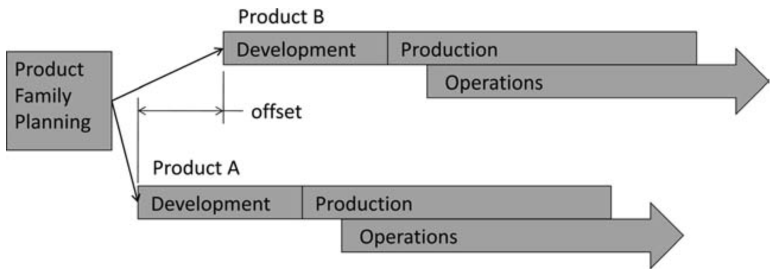

Figure 1. A two-product family with lifecycle offset.

of a product family, rather than the development relationships between the models. The second topic, the individual product lifecycle, has also been well addressed, particularly within the design literature [e.g., Ulrich and Eppinger, 2000; Pahl et al., 2007]. The combination of the product family map and the individual product lifecycle results in the lifecycle offset framework (Fig. 1).

While the literature on the product family map and individual product lifecycle is vast, the literature examining the connection between the two is much more limited. Rothwell and Gardiner [1988, 1990] describe "robust designs" as product designs that are capable of evolving based on future needs and give examples from the jet engine and copier industries. Cusumano and Nobeoka [1998] provide an overview of four development strategies that explicitly account for potential overlap. They find that partial overlap between the development of individual vehicle models provides the greatest benefit in terms of commonality and reuse. The authors conclude: "Managers are better off if they leverage investments in new technology (such as through multi-project management) as opposed to not leveraging these investments at all. And they are better off if they leverage these investments quickly across markets (as in concurrent technology transfer) rather than slowly across time (as in sequential technology transfer)" [Cusumano and Nobeoka, 1998: 184]. Cusumano and Nobeoka focus on the intersection of technology transfer and the product family, citing that the technology has a half-life in the market, as well as internally in the organization. They do not explore offsets at the granularity of parts, choosing rather to focus on technology transfer invariant of whether it yields common, similar, or unique parts. As such, the implications of offsets for corporate savings created by shared parts, while potentially contained within Cusumano and Nobeoka, have yet to be explored in terms of outcomes at a part level. Lenfle, Jouini, and Derrousseaux [2007] recognize the temporal separation between product family members as well, pointing out the challenges associated with reusing existing, intended common elements, but they do not develop a theory or evidence for the connection between offsets and reuse challenges.

Although insights about lifecycle offsets can be gleaned from the literature, the preponderance of the literature assumes that the variants of a product family are developed, produced, and operated in parallel. In the limited cases where offsets are presumed, the differences between parallel and offset lifecycles are noted as minor considerations. For example, Robertson and Ulrich [1998: 24] mention potential impacts on manufacturing investments and on the relative incremental costs associated with later product models, but then describe offsets as a matter of preference rather than salience: "Some companies choose to issue several products simultaneously; others choose to launch products in succession." Therefore, the literature's dominant investigation of parallel development has left unexplored the gap between parallel and offset development performance, including the impact offsets have on parts-level commonality.

2.2. Concepts Related to Divergence

The concept of divergence is tangentially addressed by the qualitative management literature. This literature recognizes that platforms change in response to stimuli such as shifting market needs and the advent of new technologies [e.g., Meyer and Lehnerd, 1997; Sundgren, 1999; Mahmoud-Jouini and Lenfle, 2010], but in the absence of comparative investment performance data on platforms [Pasche, Persson, and Löfsten, 2011], changes to the underlying platform are discussed with a positive bias. In the context of independently developed products (products that are developed without an overarching commonality strategy), Meyer and Lehnerd [1997: 56] state: "Seeking to build the perfect product for each new customer group, engineers lead the corporation away from commonality." Fricke and Schulz [2005] also recognize the evolution of a product family over time and present "Design for Changeability" as a proactive way to address this evolution, but with the key presumption that decisions are taken at the platform level, not the product level, therefore leaving out the potential for product level change decisions with negative platform-level results. Within their framework, platform-based development is an approach to the development of preplanned variants. Lenfle, Jouini, and Derrousseaux [2007] challenge the assumption that a platform is static throughout time as well, but do not provide data in support of negative or positive consequences resulting from changes. Halman, Hofer, and Van Vuuren [2003: 152] note: "Unlike the benefits of product family development, the risks related to product family development have not been addressed widely and specifically yet in literature." Halman et al. raise "risks" of dampening technology infusion in platforms and integration effort for overscoped common elements, but do not project these risks forward to the impact on commonality levels or return on investment.

The design engineering and model-based economic literature typically does not address divergence, assuming (often implicitly) that the common elements are selected, developed, and then utilized across the members of the product family; i.e., that commonality is static once design decisions are made [e.g., Simpson, Maier, and Mistree, 2001; Johnson and Kirchain, 2010]. For example, the valuation model of Gonzalez-Zugasti, Otto, and Baker [2001] assumes that an investment is made in a platform and then a later decision is made to either use the platform in its entirety or develop a completely new platform. Krishnan and Gupta [2001] also make a static platform assumption. Related literature on modularity and interface design discusses a concept of commonality where the products and their configurations are open ended, although the primary focus of this body of literature is the identification of potential subsystem groupings. Martin and Ishii [2002] distinguish between modularized components where changes will or will not propagate across the interface. Change in modular product families is more commonly discussed in the context of recombination of modules and unique parts [Sundgren, 1999], rather than in the design evolution of modules. Real options have been proposed by Otto, Tang, and Seering [2003] and Jiao, Kumar, and Lim [2006] as a planning mechanism to enable product evolution; but the aggregate effect of the exercising of these options on the family as a whole is not evaluated, nor are any descriptive studies of the use of options in product development available.

To summarize, key consequences of lifecycle offsets and divergence appear to be unaddressed by the existing literature. Specifically, the incidence of parallel versus offset development programs, the investment performance of parallel vs. offset development programs, and parts-level investigations of intended vs. realized commonality represent gaps in our current understanding of platforms. The concepts of lifecycle offsets and divergence also appear to be widely prevalent in practice and bear investigation as to their explanatory power relative to the outcomes of commonality.

3. RESEARCH METHODS

The high level objective of this paper is to explain why the expected benefits of commonality are not consistently realized in practice. The associated research objectives were to describe divergence in product families, describe lifecycle offsets in product families, and to begin exploration of the dynamics that produce these two phenomena. The intent was to identify key themes and their limitations, not to provide statistical analysis of the universe of potential product families. The framing hypothesis for this work was that divergence is a widespread phenomenon, not confined to individual project failures, and with causation factors present in many industries, of which lifecycle offset is one significant causation factor.

3.1. Methodology

A mixed-methods, multiple-case study was utilized to investigate divergence and lifecycle offsets. Case studies were selected as the methodology best suited to capturing the multiperiod feedback and complex causal relationships at work in large product families, as described frequently in the literature identified in Conceptual Foundations. Multiple case studies (seven) were conducted in a research design focused on replication logic, rather than statistical sampling [Yin, 2008]. The unit of analysis for each case study was an individual product family within an industrial firm.

Mixed methods were employed to better understand both the quantitative and qualitative aspects of commonality within product family lifecycles, with the intent being to develop an improved understanding of the topics through triangulation [Creswell, 2008]. The collection of qualitative data was necessary to capture an understanding of design intent, as well as to represent decision-making factors. The collection of quantitative data was pursued to ground the qualitative data in historical timelines and to provide a check against internal validity challenges arising from historical interviews.

A total of 16 preliminary interviews were conducted with platform executives and platform researchers, with a view to testing the research concepts of divergence and lifecycle offsets. These preliminary interviews surfaced the importance of constructing a broadly based development history for each product family, in order to place the potential research concepts in context.

3.2. Case Selection

The research design for these cases focused on understanding whether divergence and lifecycle offsets are unique to challenges in one industry, or whether they span multiple industries. As such, the case selection focused on generating variety along theoretically important dimensions. The population the cases sought to generalize across was narrow along the product dimension, confined to product families displaying intentional commonality planning. The theoretically important dimensions on which the cases sought variety were industry, product planning horizons, unit volumes, and prices. Variation in planning horizons was sought in order to investigate whether divergence and offsets pose fewer challenges in industries with more stable products. Variation in unit volumes was sought to investigate whether low volume industries could help explain divergence on the basis of missing economies of scale.

Cases were selected from the aerospace, automotive, semiconductor capital equipment and printing industries (Table I). In an effort to mitigate bias towards poorly executed product platforms, the specific companies and product families were selected as leaders in their respective fields: the selected products were viewed as market successes and were believed by the authors to have successfully leveraged commonality based on available public source information. The represented companies are all publicly traded. All but one of the cases involved commercial products, the exception being the military aircraft family. Production runs ranged from production of a single unit to several hundred thousand units per year. Unit prices ranged from the automobile, a consumer product typically priced at greater than $20,000, to satellites and military aircraft, both of which exceed $100 million per unit (Fig. 2). The cases are described in detail within Boas [2008].

Table I. The Seven Case Studies

	Case A	Case B	Case C	Case D	Case E	Case F	Case G
Product Type	Automotive	Military Aircraft	Commercial Aircraft	Business Jets	Printing Presses	Communications Satellites	Semiconductor Manufacturing Equipment
Number of Products in Family	2 main product lines, many options within each	3	5+ (evolving number of models)	4+ (evolving number of models)	3 product lines, 10+ models over history	10+	3 product lines, 15+ models over history
Typical Annual Production Rates for Products in This Industry	100,000+	200 (approximate plan for this product)	100+	50+	100+	1+	50+
Indicative Product Price	$20k+	$100M+	$50M+	$30M+	$100k+	$100M+	$1M+
Study Focus	Development of two models with a proactive approach to enabling commonality	Development of three models with a proactive approach to enabling commonality	Commonality within the historical evolution of product models	Commonality within the historical evolution of product models	Commonality within the historical evolution of product models	Commonality within the historical evolution of product models	Commonality within the historical evolution of product models; more recent proactive approaches to developing multiple models

3.3. Data Collection

Data collection within each case study centered around a week-long site visit. Prior to the site visit, exploratory conversations were held at the senior executive level for the purpose of identifying and properly bounding the product platform under study and for building the interviewee list. The interviewee list sought to cover a series of key individuals, notably the product family manager, all of the variant managers, and the executive sponsor, and then to obtain coverage of engineering in each of the major product subsystems. The purpose of the subsystem interviews was to identify specific incidences of technical decisions around divergence. Finally, within each case, interviews were sought from functional

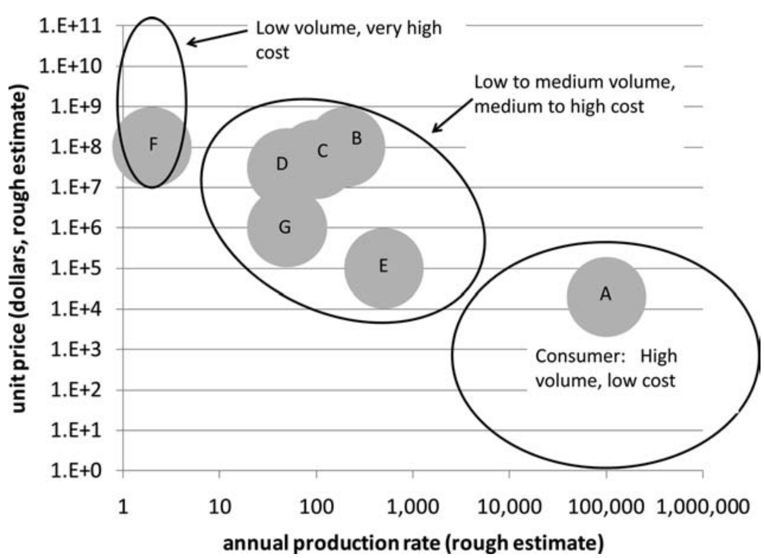

Figure 2. Rough indications of the annual production and unit prices for the case study products.

departments (e.g., procurement, manufacturing, and field operations) which were represented at design reviews, with a view to capturing all of the perspectives involved in divergence and offset decision making. Saturation (achievement of appropriate sampling of the target population) was gauged with respect to the list of covered variant managers, subsystems, and functional groups. Some additional snowball sampling was in effect as the interviews proceeded, but only insofar as to gain additional coverage of the above expressed dimensions.

A total of 32 days were spent on site at the seven case study companies. A total of 119 interviews were conducted, with each interview typically lasting one hour. In addition to the on-site interviews, all of the cases involved subsequent phone and e-mail traffic, primarily around delivery of quantitative data identified in the on-site interviews.

A semistructured interviewing technique was employed for the case studies. The philosophy behind this technique is summarized by Marshall and Rossman [2010: 144] as follows: "[T]he participant's perspective on the phenomenon of interest should unfold as the participant views it…, not as the researcher views it." While an interview guide was carefully designed and distributed to each participant in advance, each interview was adapted to the knowledge and role of the interviewee, with some level of guidance being provided by the interviewer to ensure the interviews uncovered useful information about the product family history and divergence and offsets within this context.

3.4. Data Analysis

The within-case examination consisted of analysis of the qualitative interview results, and where possible, quantitative analysis of program financial information and common component design data. The raw interview notes from the individual cases were coded in order to facilitate identification of themes related to the two primary concepts of divergence and lifecycle offsets. The emergent themes from the qualitative interviews were cataloged for later cross-case analysis. Where bill of material data was available, commonality metrics were constructed as a source of quantitative data on divergence over time. The primary output was a product family history told from the perspective of commonality. Specific emphasis was placed on understanding the drivers and impacts of divergence and lifecycle offsets, along with overall implications for the benefits and penalties of commonality. The reports were reviewed by each participating company in an effort to improve reporting accuracy.

Upon completing the individual cases, a cross-case analysis [Stake, 2006] was performed in order to better understand the central topic of commonality and the more detailed topics of divergence and lifecycle offsets. The cross-case analysis crossed the emergent themes from the individual cases against the full set, identifying case context spectra, patterns, and exceptions to these themes, the latter being helpful in establishing bounds on the generalizability of the research. The case concept of Intended Common, presented later as a framework, was used to recast case data, as the firms studied did not initially employ this distinction.

4. RESEARCH DATA

Divergence behavior was observed in all seven case studies, but to varying extents. Evaluations of the magnitude of divergence are given in Table II, binned from Low to High, where Low represents small changes, such as moving from 80% of parts shared to 77% of parts shared, and large represents changes on the order of decreases by 50% (half of the Intended Common parts became Unique Parts). A sample trace of a commonality metric is provided in Figure 3, illustrating decreases in common Bill of Material (BOM) items across the three product lines for Printing Press. The corresponding product family map for Printing Press is shown in Figure 4, showing offsets among variants in each product line. Parts commonality measures are binned for confidentiality reasons and to facilitate comparison across cases that had varying levels of quantitative and qualitative data, not for lack of more sophisticated commonality indices (see Simpson, Maier, and Mistree [2001] for examples).

Table II. Research Data Categorization of Observed Divergence Together with the Range of Offsets

	Automotive	Military Aircraft	Commercial Aircraft	Business Jets	Printing Presses	Communications Satellites	Semiconductor Capital Equipment
Divergence	High	High	Moderate	Low	Moderate	High	Moderate
Offset as % of Development Time	100% (24 Months)	10% (6 Months)	25%-280%	0-120%	75%-250%	0-170%	0-130%

Not all calendar offsets (number of months) can be given due confidentiality limitations.

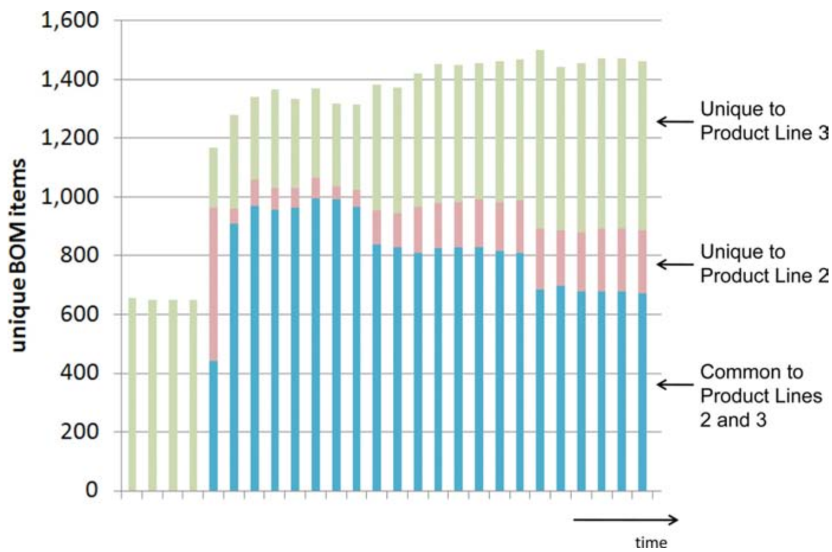

Figure 3. Evolution of parts-based commonality within the printing press product family. The number of parts common to Product Lines 2 and 3 decreases over time. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Lifecycle offsets are also shown in Table II. The offset is calculated as the time between the development start dates of the lead product and a follow-on product, as a fraction of the total development time for the lead product. Where more than two variants were built, and the offsets were different between variants, a range is given. The calendar offset is given in the first two cases, but masked in the last five, due to more restrictive disclosure limitations mandated by some of the case study companies.

A brief note on the sources of bias in this research design is merited, in light of the fact that divergence was observed in all seven case studies. Case studies were not selected for divergence, but rather for programs that planned for commonality. Possible bias sources include the definition of divergence (inconsequential or nondiscriminant) or the application of the definition to minority views. Categorization of cases against divergence definitions were reviewed by four members of the research team in an effort to mitigate against capturing inconsequential changes and to determine if the definition was discriminating between the presence and absence of divergence. The existence of a range of divergence magnitudes supports the concept of discrimination. The col-

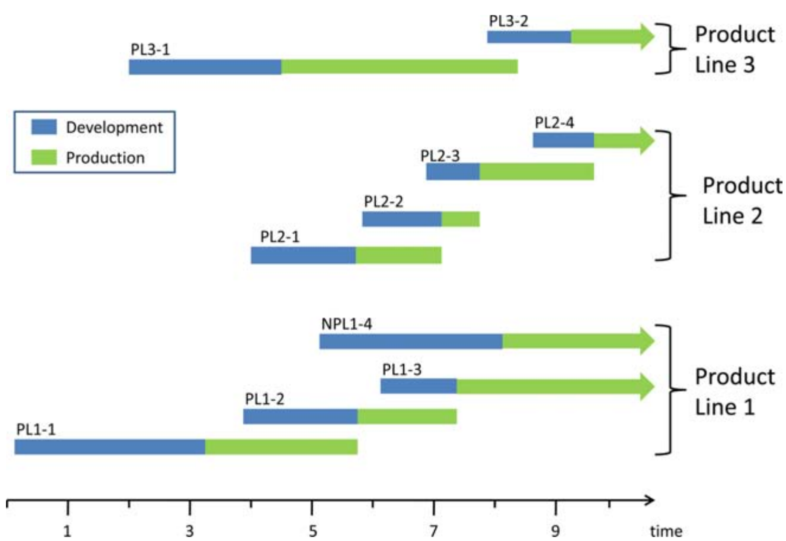

Figure 4. Printing press product family history showing offsets in variant development and production. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

lection of quantitative data in support of qualitative interviews was important to establishing convergent validity; i.e., qualitative and quantitative measures were correlated in the measurement of the concept of divergence.

5. DIVERGENCE: CONCEPT, DRIVERS, IMPACT

We define divergence as the net decrease in commonality between the early planning phase goals and the realized commonality in end products. The changes causing divergence can occur in planning, development, manufacturing, or operations. A common component may be replaced by two product-specific components. A manufacturing process may be slightly modified to accommodate end product variations. An accumulation of these small decreases results in the phenomenon we title divergence.

The concept of divergence is best illustrated with the automotive case. The auto program pursued intended commonality in architectures, components, and manufacturing processes across an SUV and a Truck, and assigned an executive to own commonality to ensure proper emphasis. As the program progressed, high expected levels of commonality transitioned into very low levels of actual commonality. Common brakes were eliminated in favor of product-specific designs, a decision that eliminated cost and weight penalties associated with unneeded capabilities in the less demanding vehicle application. Suspensions were modified to improve ride quality in each vehicle. Common manufacturing lines were customized to address initially unanticipated differences in product architecture and design. Initial visions for commonality became design similarity among unique parts. The resulting SUV and Truck were significantly less common than planned.

Increases in commonality were not observed during the lifecycles of any of the platform-based product families within the case studies. We observe that anticipated commonality is highest during the planning stages of a product family lifecycle and then tends to decline over time (Fig. 5). At the planning stage, executives and program managers are optimistic about the potential for commonality, and knowledge about the individual product designs is relatively limited. As time progresses and as changes occur, the dominant trend is for commonality to decrease: Observed increases in commonality were seldom, and only the result of large-scale redesigns that represented a shift to a new set of common elements and processes. Within the auto industry, this increase would be aligned with the shift to a new vehicle platform.

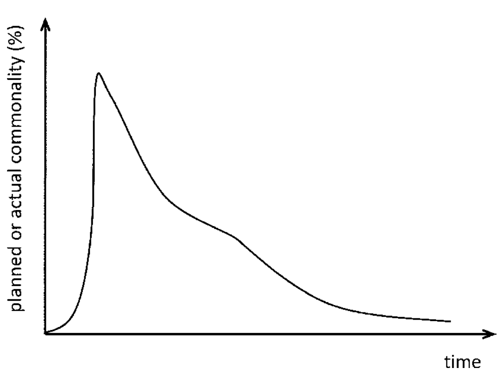

Figure 5. The basic concept of “divergence” or the decline of commonality over time. Commonality reaches a peak during the planning stages of the product family, when optimism about benefits is high and penalties are uncertain, and then declines throughout the remainder of the lifecycle.

5.1. Concept: Beneficial Versus Nonbeneficial Divergence

The case studies suggest divergence represents a mix of both beneficial and nonbeneficial changes; i.e., the impact of any given change and the overall trend is not necessarily negative. For a given situation, the elimination of commonality may produce a net benefit, and, if so, commonality should be eliminated.

As an example of a net benefit resulting from divergence, the commercial aircraft manufacturer realized early in the product family development process that each aircraft model would incur unacceptable weight penalties for the sake of commonality. The manufacturing benefits of increased scale and learning would be far outweighed by customer operating cost penalties that would ultimately translate into reduced aircraft pricing and likely reduced aircraft unit sales. As a result, the initially planned variants moved to unique designs on key structural elements such as wings and empennages.

While examples of beneficial divergence are readily identified, the case studies also indicate that nonbeneficial divergence is prevalent in practice. In the next section, we examine the roots of divergence, with a view to distinguishing between beneficial and nonbeneficial divergence.

5.2. Drivers of Divergence: Pursuit of Changes That Produce a Net Economic Benefit

Divergence, and the degree to which divergence is beneficial, can be better understood by examining the individual changes that contribute to the overall trend. It is important to emphasize that a change represents a potential source of divergence, rather than a guaranteed contributor to divergence (Fig. 6). A change to a common part that is implemented across all products that use the common part does not impact commonality in any way. Divergence results when a common component change is not implemented across all products models that previously utilized the common component.

Changes often lead to divergence, and should lead to divergence, when the beneficial component of divergence outweighs the nonbeneficial component plus the cost of the change. Commonality creates penalties, including reduced sales revenue caused by lower performance products, reduced sales revenue due to self-cannibalization, and increased costs caused by overdesigned components. Therefore, reducing commonality can sometimes reduce these penalties. For every proposed change to a common part, there is a downside in terms of fewer benefits of commonality (economies of scale, learning curves, etc.), a downside which must be weighed

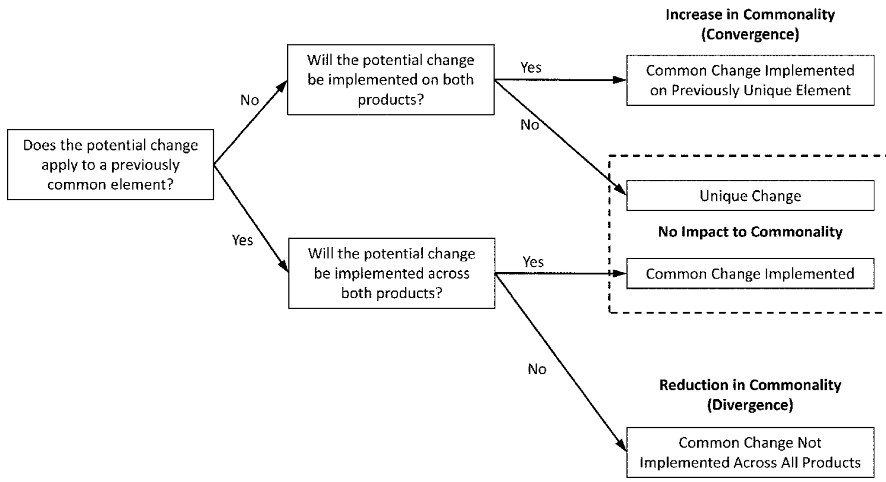

Figure 6. Potential impact of design changes on commonality. For simplicity, a two-product family is illustrated although the logic applies to a product family of any size.

against the potential for revenue gain and reduction in the penalties of commonality.

It is also important to consider the costs of the change, in addition to the eventual benefits and costs of commonality. At early program stages, changes are inexpensive as the detailed design has not yet begun. However, the cost of a change increases significantly with product maturity. Lifecycle offsets coupled with divergence pose a unique challenge for platforms, in that offsets imply one variant will be mature while another may only be at the front end of the development process. The cost of implementing a change may be significantly higher for a more mature product, relative to implementing the same change in a less mature product. Lifecycle offsets imply an asymmetry in the costs of change (Fig. 7).

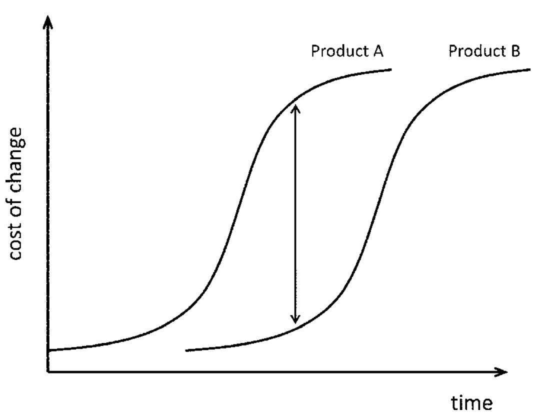

Figure 7. The asymmetric cost of change for two products with lifecycle offsets. When Product B is beginning development, the cost of a change to Product B is low while the cost of the same change to the more mature product, Product A, may be prohibitively expensive. Divergence results.

The Automotive case provides an example of this cost asymmetry. When Automotive began development of its truck, its SUV was already in production. As changes to Intended Common components arose, the SUV team was almost categorically unwilling to implement these changes, regardless of whether or not the changes were retrofittable to the existing SUV. In order to retrofit the new designs to the in-production SUV, the revised vehicle would have been required to undergo testing and would have accepted significant risks associated with changing a completed product. What was the high level rationale for not implementing the changes on the more mature product? The costs of maintaining commonality simply outweighed the benefits. The asymmetric economics described here were routinely cited during case study interviews as reasons for the elimination of common components, manufacturing processes, and infrastructure.

The cases indicate that the decision to eliminate commonality for economic reasons is often made intuitively by managers, with little to no supporting analysis. While this approach is likely acceptable for decisions that have obvious benefits or penalties, smaller impacts or more complex decisions require a deeper analysis. Only one case, Military Aircraft, demonstrated a consistent, formal analysis of changes that could have led to divergence. This program conducted a formal assessment of the impact of a move away from commonality from the perspective of each aircraft model in order to more accurately determine whether divergence should be allowed or prevented. The analysis covered factors including cost, performance, and risk, and the results were ratified by the Change Control Board. Military Aircraft appeared to have struck a balance between effective decision analysis and controlled overhead.

Looking across the cases, we identified three types of change that serve as drivers of beneficial divergence, divergence that yields a net economic benefit:

Market requirements change, due to changing customer preferences and the actions of competitors. As a result, the market drives changes into the product and its supporting infrastructure. Communications Satellite experienced market-driven push towards progressively higher-power systems that exceeded the capabilities of the original platform. The result: repeated, major investments in the underlying platform that totaled more than 140% of the original platform investment.

Learning occurs in development, manufacturing, and operations. This learning creates the desire and potential requirement to make design and process changes. Commercial Aircraft planned to employ a high degree of commonality within its airframe components in the early stages of product family planning and development. As development progressed, it became clear that customer operating costs would be significantly increased due to the weight penalties associated with common components. The penalties of commonality outweighed the benefits, and commonality was eliminated.

New technologies become available, some offering significant benefits to the end customer and/or significant cost reductions to the manufacturer [Halman, Hofer, and Van Vuuren, 2003]. Faster clock speeds in technology [Fine, 1998] than the underlying product lifecycle force a confrontation: New technologies are often a must-have requirement for new products, especially in high-technology industries with rapid paces of advancement. New technologies are easily folded into new product models while the retrofit of existing models is often avoided, due in part to the asymmetric costs of change described previously (Figure 7). More than one interviewee explicitly stated that they avoid making any changes to previously developed products in order to eliminate the cost, time, and risk associated with design "churn." Printing Press continued to develop the core process technology through subsequent development programs, consciously infusing it into new product variants while avoiding retrofit of preexisting variants.

5.3. Drivers of Divergence: Lack of Coordination

Lack of coordination between product teams, either unintentional or intentional, represents a second, significant driver of declining commonality that may lead to nonbeneficial outcomes. Establishing and maintaining commonality requires cross-product coordination throughout the product family lifecycle, similar to Browning's discussion of integrated product team coordination for complex systems development [Browning, 1999]. The automotive company provides an example of the impact of lacking coordination. An executive and a supporting team were initially charged with managing the common components and processes across the vehicle models. Upon completion of development of the first vehicle and Intended Common components (the platform), the executive was moved to another assignment and the entire platform team was disbanded. When development of the second vehicle started, a key coordinating mechanism (the platform team) was no longer present. Many Intended Common components were eliminated in favor of unique components, due, in part, to a lack of coordination.

Unintentional lack of coordination appears to be prevalent in industry. Companies simply focus on developing one product at a time. In this mode of development, decisions are made without considering the broader impact on the product family. Commonality may produce penalties from the perspective of an individual product model, even though a benefit is produced at the product family level. This is especially true when considering the lead product model.

Lack of coordination can also be intentional. Maintaining coordination across multiple products and their associated development programs can be both challenging and costly. For Commercial Aircraft, the complexity of developing an individual product is high: thousands of people working across a globally distributed supply chain, multibillion dollar investments, and years of development. Therefore, the complexity of linking two or more Commercial Aircraft programs is very significant. The costs of coordination may easily outweigh the potential benefits resulting from commonality. Development teams may also intentionally avoid coordination due to their desire to optimize around the market needs of an individual product, i.e., to make decisions from the individual product perspective. This intentional optimization, while seemingly an excellent approach to meeting market needs, may have negative impacts on profitability if trades are not properly evaluated from the product family perspective.

5.4. Impact of Divergence

The primary impact of divergence: The anticipated benefits of commonality do not materialize, even though the significant costs associated with pursuing these benefits are incurred. The Military Aircraft program saw its development cost grow by 25% over the period that airframe commonality fell from 40% to 19%. Commonality within the Communications Satellite family declined as common elements became unique elements, customized for specific satellite programs. The customization efforts required an additional investment of 1.4 times the original investment in Intended Common components. An idealized view of commonality, one in which commonality is certain and stable, would have predicted no additional investments beyond the initial development of the Intended Common components. Whether these observations are correlated or causal remains to be proven, but the discussion of drivers has identified mechanisms by which product managers may suboptimize the platform by failing to coordinate or by making decisions at the product level, rather than at the product family level. The theoretical concept of divergence is essentially a restatement of the Second Law of Thermodynamics: Systems tend toward increasing states of disorder. Effort is required to counteract this otherwise inevitable outcome when doing so will result in a net benefit.

The phenomenon of divergence has important implications for commonality theory and for platform-based development. The management literature's tendency to focus on the benefits of changes to common elements (e.g., innovation within the members of a product family and their underlying platform) [Halman, Hofer, and Van Vuuren, 2003] has been partially balanced by examining the negative, undesirable outcomes of lost commonality. The theory of divergence extends work of Meyer and Lehnerd [1997] and Sundgren [1999] on platform responses to market stimuli, by defining the unaddressed potential negative implications. These negative implications are grounded in the first parts-level data regarding intended versus realized commonality, which was identified as a gap in prior work [see Cusumano and Nobeoka, 1998; Lenfle, Jouini, and Derrousseaux, 2007]. The data presented in the paragraph above on the reduction of benefits, while exploratory, help fill the identified gap regarding the investment performance of platform development programs. Incorporation of the concept of divergence into economic models of commonality will improve the accuracy of these models by reducing the estimated benefits of commonality. Extension of the engineering design methods and models to account for the dynamic and uncertain nature of commonality will improve accuracy and likely reduce recommended platform scope.

6. LIFECYCLE OFFSETS: CONCEPTS, DRIVERS, IMPACT

Excluding the product family planning phase, the cases indicated that the lifecycles of complex products tend to be offset relative to one another (Fig. 1). Automotive developed its SUV model first and then developed a truck model 2 years later. Military Aircraft developed common concepts and then staged the development of its three aircraft models, each of which was intended to have high degrees of commonality with its peers. Commercial Aircraft developed a medium-sized aircraft, then sequentially shrunk and extended this aircraft to create follow-on product models that addressed different customer needs in terms of passenger capacity and range.

In many cases, product family planning was based on a parallel concept: An initial vision was established for multiple products, including commonality between those products. Thus, product family planning in the case context echoed the dominant parallel development perspective of the literature.

The initial visions of the product family demonstrated wide variety in their maturity. At one end of the spectrum was Printing Press. The vision for the Printing Press family was documented, but almost no effort was invested in defining each of the envisioned models. At the other end of the spectrum was Military Aircraft. Years of conceptual development, prototype development, and prototype testing were conducted on multiple aircraft models before focusing on the development of the first production model.

Subsequent to creation of the initial vision for the product family, each product family went through a clear transition from parallel development to offset development of the individual models. After creating the high level vision, the Printing Press team focused entirely on developing the first printing press model. Likewise, Semiconductor Capital Equipment envisioned the development of a common core that would be utilized to create a number of different manufacturing systems. Little effort was invested in building out the designs of each individual model during the product family planning stage, and, subsequently, 100% of the design effort was placed on full-scale development of the lead model.

6.1. Drivers of Offsets

Companies develop their products in an offset manner due to:

- Financial limitations
- Market need timing and uncertainty
- Technological capability restrictions
- Human resources limits.

First, financial limitations appear to be the strongest driver of offset development, particularly in the development of complex products. Developing a commercial aircraft is a multibillion dollar, multiyear effort. Developing two or more in parallel represents an undertaking that few companies are able or willing to take on all at once. The cash flow requirements are simply too great, especially when evaluated against the risks.

Second, market need timing and uncertainty may drive companies to pursue offset development. The market may dictate differing need dates for the various product models, creating a motivation for offset development. Additionally, companies in this study used lifecycle offsets as a strategy to test the needs of the market with one product model and then develop follow-on models calibrated by the market experiences of the first product. For example, Printing Press used PL1-1 (see Fig. 4) to develop new printing technology and to test the market's reaction. Follow-on models such as NPL1-4 were then created through extensive modifications to the original product; modifications that were driven by revealed market needs in areas such as customer ease of use. Only the core printing technology was retained.

Third, technological capability restrictions may be a factor, particularly in less mature product lines. Less capable models may be developed as stepping stone advancements toward the more capable product models. In this manner, development teams are able to incrementally advance their technical capabilities, minimizing risk and uncertainty in the development process. For example, Printing Press envisioned a family of products that had increasing performance levels, with each increase depending on an associated technological advancement. Additionally, Military Aircraft decided to develop the "easiest" aircraft model first in order to control development risk. Once the "easy" model had been developed, the more difficult models then followed, with less risk incurred at each stage relative to the alternative of developing the most difficult model first.

Fourth, human resource limitations can drive a company to pursue offset development. Qualified people are often not available to develop multiple, similar products in parallel. While financial resources can address human resource limitations to an extent, issues such as hiring and training often limit the ability to which capital can be deployed in an effective manner, as cited by interviewees in Military Aircraft.

6.2. Impact of Offsets: Reducing the Benefits of Commonality

Lifecycle offsets have four impacts on product families. Lifecycle offsets:

- Reduce the potential benefits of commonality
- Make the realization of benefits much more difficult

- Delay the realization of benefits
- Reallocate potential benefits across individual products.

These factors significantly differentiate the parallel product lifecycle framework from the offset lifecycles observed in practice. To emphasize, the parallel framework was unobserved in our case study research, yet central to the literature on product platforms and commonality. Each of the above points is discussed in more detail below.

Offsets reduce the potential benefits of commonality. First, increased uncertainties associated with later product models decrease the likelihood of reusing Intended Common components and, therefore, the benefits of commonality. Second, multiproduct economies of scale in production only exist when the products are actually produced in parallel with one another, are reduced when production of two or more models is only partially overlapping, and are lost when purely serial production exists. A similar outcome results during the operational phases of the lifecycle.

Offsets make the realization of the benefits of commonality more difficult and less certain. Coordination between programs becomes a challenge because all products are not adequately represented during the development activities of any one product. The lead product and Intended Common components are often developed with limited input from the future envisioned products, as discussed for Automotive. This lack of input is driven primarily by a lack of staffing and investment in the future product model due to the longer time horizon. When the follow-on product is developed, the interests of the lead product are no longer represented, often because the development team has been disbanded. Divergence results and potentially beneficial commonality is eliminated.

Offsets delay realization of the potential benefits of commonality and reallocate the benefits of commonality with respect to individual products. From a development perspective, offsets create an upfront development penalty associated with developing common components, processes, etc. that meet the needs of multiple products. The first program must absorb the penalty associated with the more complex task of developing components that address the needs of two or more products. A future development benefit is only realized if a later program utilizes enough of the Intended Common components to offset their initial development penalty. From a production perspective, the first program is again likely to incur a penalty until the follow-on product enters production, thus delaying the potential benefits of commonality. Further, a common component must be capable enough to meet the needs of multiple products. This excess capability has a production cost that can only be offset by the increased economies of scale and learning curve benefits associated with higher production rates and higher cumulative production totals, respectively. If a component is not utilized by the follow-on product, the first product pays a net penalty for the duration of its production run.

Many interviewees, spread across the cases, demonstrated awareness of the above penalties and issues with offsets, although awareness was far from universal. The primary mitigation elicited from interviewees was to avoid commonality in offset situations in order to avoid potential penalties to their individual products, regardless of the potential long-term benefit to the product family as a whole. This form of risk aversion merits further study. Our hypothesis, as yet unproven, is that avoidance results from a failure to assume a product family perspective: managers seek product level optimization (grounded in organizational performance measures and incentives) and, as a result, forego the potential current and future benefits of commonality that would result in a net increase in the product family's overall profitability.

The above observations about offsets suggest further research opportunities, opportunities that have the potential to make theoretical contributions that significantly improve the corporate bottom line. The management literature addresses offsets to some extent [e.g., Cusumano and Nobeoka, 1998; Lenfle, Jouini, and Derrousseaux, 2007; Rothwell and Gardiner, 1988, 1990], but this paper addresses the concept directly and illuminates the prevalence of offsets in industrial practice. Many opportunities exist for furthering the management guidance around offsets. Additionally, opportunities exist to extend the economic models of the benefits and penalties of commonality to explicitly account for offsets, in light of the emergent data provided on realized investment return. Existing quantitative models such as those of Ramdas, Fisher, and Ulrich [2003], Krishnan and Gupta [2001], and Gonzalez-Zugasti, Otto, and Baker [2001] are likely to serve as solid foundations for extension. An initial, simplified model was developed in Boas [2008], but development of a more detailed model is best left to the management science community.

7. INTENDED COMMON FRAMEWORK: COUPLING LIFECYCLE OFFSETS AND DIVERGENCE

The preceding sections allude to the closely intertwined nature of divergence and lifecycle offsets, and this section presents a simple framework that explicitly relates these two concepts. The framework is developed by first starting with a simple framework that ignores divergence, then introducing divergence. The often assumed case of parallel development without divergence is not addressed here.

Figure 8 illustrates a simplified view of offset development that ignores divergence. At Time 1, Product A is developed along with the underlying platform or Intended Common elements. At Time 2, Product B is developed. At that time, the Intended Common elements (Class 4) are utilized by the Product B team and are combined with new, Unique to B components (Class 5) (called "Platform Extension Parts" by Meyer, Tertzakian, and Utterback, [1997]). Although offset, the lifecycle of Product A overlaps with Product B. At Time 2, the Common components are produced for both Product A and Product B.

Figure 9 describes a more realistic view of offset development, as observed within the seven case studies. At Time 1, Product A is developed, along with the Intended Common components and Intended Unique components. At Time 2, Product B is developed. At this time, the Product B team does not consider whether a Product A component was intended to be common or not. Instead, the Product B team looks back at

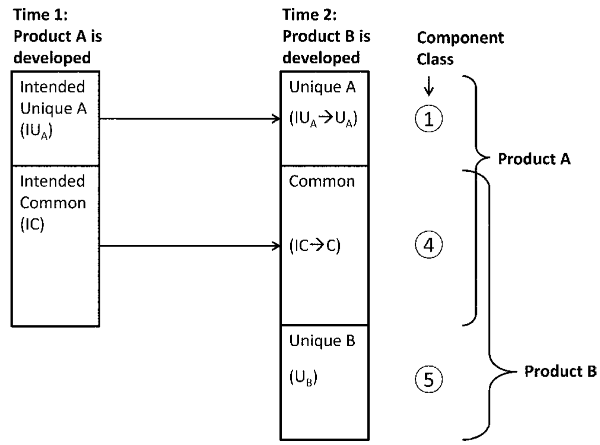

Figure 8. A simplistic view of offset development without divergence.

all available development associated with Product A and searches for potential reuse options. The Product B team is essentially asking the question "Which elements from Product A are beneficial to Product B?" rather than "Can Product B reuse Intended Common elements from Product A?"

The extended framework contains five potential component classes rather than the three classes associated with the idealistic framework of Figure 8. Components developed by Program A and intended for use solely by Product A may in fact be passed over by the Program B team (Class 1 components). Likewise, Intended Common components developed during Program A may go unused by Program B (Class 2). In this case, the penalties incurred in the development and production of Intended Common components are not offset by a benefit from realized commonality, resulting in a net penalty. Class 2 has not been identified in previous commonality frameworks [Martin and Ishii, 2002; Thevenot and Simpson, 2006; Meyer, Tertzakian, and Utterback, 1997].

In some cases, Program B chooses to use the Intended Unique components from Product A (Class 3). In these cases, Program B benefits from avoided development costs and previously achieved benefits of learning and scale from the combined Product A and Product B volumes, while Product A benefits from an increased learning rate associated with higher production volumes and from the same volume discounts. In Class 3, no upfront commonality driven penalties were incurred by Program A; yet benefits were realized at a later time. This is essentially "ad hoc reuse" [Kimura et al., 2001]. The framework designates Intended Common components that are used by Program B and, therefore, are common to Product A and Product B, as Class 4 (Realized Common). Lastly, Program B may develop unique components (Class 5). This framework was further developed into a simple parametric economic model in Boas [2008], although this model can and should be extended by others.

In the Automotive case discussed in Section 5, powertrains, chassis structure, steering, brakes, and suspension

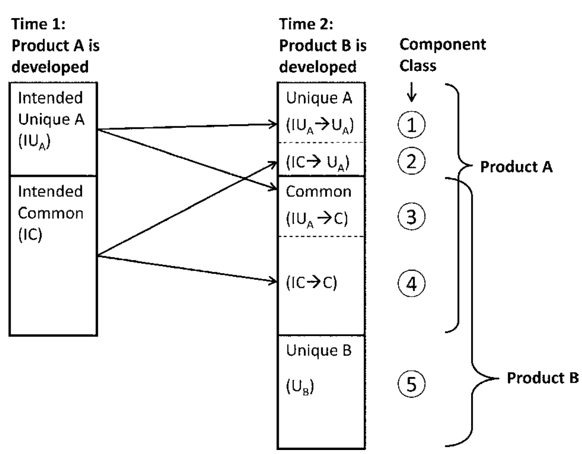

Figure 9. An extended view of offset development with divergence, which incorporates the concept of Intended Common parts becoming Unique parts.

components were all Intended Common, and body panels were an example of Intended Unique A (Class 1) and Unique B (Class 5). During truck development, many of the Intended Common parts diverged to become Unique A parts (Class 2), such as the brakes and suspension components. Almost no Intended Common parts were 100% carried over into Class 4 (Realized Common): Only 2% of the finished products were identical common parts. No instances of Class 3 parts, reused Intended Unique parts from the SUV program (Product A), were identified. This framework enables an explicit accounting of the resulting common architecture of a platform-based product family.

The extended framework helps to explicitly tie together the impact of offsets on the potential outcomes of commonality. Intended Common components may or may not become Realized Common components when a follow-on product model is developed. Likewise, Intended Unique components may or may not become common when a follow-on product model is developed. The outcomes of Product A components are determined by the previously discussed economic benefits analysis and varying degrees of cross-product coordination. The key to the framework is revealed information: Program B, unless otherwise caused to do so, will not differentiate between elements originally developed as Intended Common or those that were Intended Unique, because it has revealed information about the as-designed performance and cost of Product A parts. All prior development simply represents a "parts bin" that can be leveraged to reduce the development cost, lead time, and risk of the follow-on model(s).

This framework yields a couple of predictions. We can predict that greater lifecycle offsets result in greater divergence, namely, higher conversion of Intended Common parts to Unique to A (Class 2) parts. We can predict that Intended Common parts which meet the originally stated cost and performance goals of the follow-on products are more likely to become common (Class 4) parts than are Intended Unique A parts likely to become common (Class 3).

An organizational perspective is useful for better understanding the difference between the idealized parallel view of development often assumed explicitly or implicitly in the literature and the offset situation observed in practice. A possible organizational structure for the development of two products with commonality is illustrated in Figure 10. In this case, two program teams supporting Product A and Product B are tasked with developing a common platform along with the unique portions of their respective designs in order to create a two-product family with commonality. In the parallel case, both product teams and the platform team are equally staffed and funded, creating a tension as the two product teams seek beneficial opportunities to employ commonality within their products. As was stated previously, the example of Figure 10 is often either explicitly or implicitly identified in the literature but was not observed in practice.

The offset development scenario observed in all seven of the case studies adds a time dimension to Figure 10. Specifically, the time dimension creates an asymmetry in funding and staffing between Programs A and B, where Program B lags in budget and human resource levels. Figure 11 represents development Program A in an offset situation, during which time Program B has limited to no funding and staff. Upon transition to Program B, the state progresses to Figure 12, where Program B dominates but also inherits the result of Intended Common parts from Program A.

The central challenge in the offset case is one of conflicting goals for the lead product and associated program, Program A. The first goal, creating the lead product, was well understood and acted upon within the case study companies. This goal was both clear and near-term. In accordance with this goal, traditional product level resources and incentives, such as ROI goals, can be applied. The second goal, *often only implicitly stated*, entailed the creation of the Intended Common elements at additional cost to the lead program. Pursuing this goal ran counter to the incentives and norms of the lead program managers. By contrast, Program B also faced conflicting goals (accept suboptimal Intended Common parts or pursue Product B optimization), but retained less control over the platform, as the Intended Common parts had already been designed.

From an organizational perspective, these conflicting goals were either owned by the lead product manager (as demonstrated in five of the seven cases) or by a platform

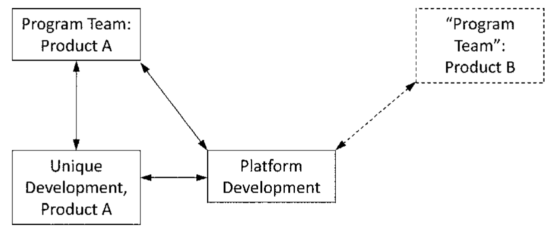

Figure 11. Development organization in support of the first product (Product A) in a two-product family with offsets.

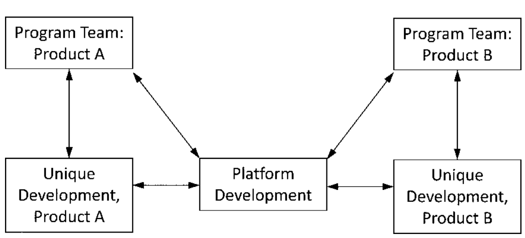

Figure 10. Idealized version of an organization that supports the parallel development of two products.

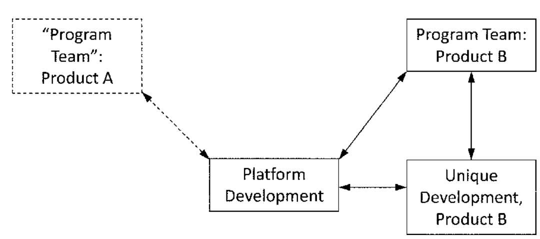

Figure 12. Development organization in support of the second product (Product B) in a two-product family with offsets.

manager (Military Aircraft and Automotive). When owned by the lead product manager, near-term constraints tended to shift operational decisions away from a product family perspective toward individual product rationales. A "fox guarding the henhouse" situation was therefore created, and the Intended Common elements of the product family were skewed toward the needs of the lead product model. For situations where the conflicting goals were owned by a platform manager, we propose a more subtle dynamic: The influence and efficacy of the platform manager is governed partially by imbalances in the maturity of the individual product designs and the relative staffing levels associated with each program. These imbalances are created by lifecycle offsets, and, in turn, lifecycle offsets create divergence. In the Automotive case, the small team in charge of future variants (small size driven by the presence of lifecycle offsets) could not bring the same depth of design trades nor the same immediacy and certainty of need to bear on mediation sessions with the platform manager, and, as a result, commonality decisions were weighted toward the immediate needs of the current variant.

8. IMPLICATIONS FOR MANAGERS AND RECOMMENDATIONS

Divergence and offsets are prevalent in industry, significantly impact the benefits of commonality, and are relatively unaddressed in practice and the literature. Divergence represents a reduction in the initially planned benefits of commonality. While divergence is not necessarily a negative, the case studies indicate that a significant amount of divergence is likely nonbeneficial, representing an opportunity for improvement. Lifecycle offsets reduce the potential benefits of commonality, make the realization of benefits much more difficult, delay the realization of benefits, and reallocate potential benefits across individual products. Offset situations lend themselves to higher rates of divergence and, based on the case studies, appear to be the norm in product development. Managers must carefully consider both phenomena in order to unlock the true value of commonality while avoiding the potential pitfalls.

8.1. Be Realistic About the Potential Benefits of Commonality

Given the presence of divergence and offsets, managers must be realistic about the benefits of commonality as they plan their product families. During the early stages of development, all of the companies were overly optimistic about the potential benefits of commonality and tended to deemphasize the potential penalties. A more realistic assessment of the benefits of commonality will help companies limit investments in unrealistic commonality levels; i.e., investments that result in a loss. While the outcomes of commonality will always be probabilistic (i.e., planned commonality across a product family will never be achieved with 100% likelihood), companies can identify areas that are more or less likely to be effective opportunities to employ commonality and can then focus their investments accordingly.

8.2. Manage Product Families Toward the Achievable Benefits of Commonality

Firms can learn three specific product family management lessons from the case context studied:

Manage commonality throughout the product family lifecycle. Managers must invest additional effort into the lifecycle management of commonality. Either explicitly or implicitly, many interviewees treated commonality as a static property of a product family, when, in reality, commonality declined significantly throughout the lifecycle. Without active management throughout the product family lifecycle, commonality trades are decentralized, ad hoc, and, in the presence of lifecycle offsets, often skewed toward current products. As mentioned previously, the goal should not be to retain commonality, but rather to allow the appropriate loss of commonality through proactive management. The best example of proactive management of commonality came from Military Aircraft. Military Aircraft required design changes to common parts to be approved by a change control board that included representatives from each of the three aircraft models. Prior to the change control board meeting, a benefits and penalties analysis was performed relative to each aircraft model. In this way, the change control board could quickly assess the overall benefit of the change from the product family perspective while also understanding the impacts on the three product models.

Make decisions from a product family perspective. Platforms embedded in product-centered organizations face strong engrained processes focused on maximizing profit at the individual product level. This case-based research has demonstrated that commonality strategies often create burdens on individual variants, while still yielding a net benefit at the product family level. This burden is particularly heavy for lead variants, which often bear responsibility for creating common parts with few benefits attached. The product family perspective ensures that decisions are always made in the interests of maximizing product family, rather than individual product, profitability (Fig. 13).

Organize to create and reward commonality. Active management of commonality at the product family, rather than individual product level, requires proper organizational structures and processes along with a culture of commonality. The organizational structure must ensure the common elements are owned by an influential manager who is empowered to analyze the needs of the individual products and to make decisions in a way that will benefit the product family overall. Ownership of common components ensures that the common components are not owned within any one product development effort, eliminating the previously mentioned "fox guarding the henhouse" situation. Simple organization structures such as the one illustrated in Figure 10 establish an ideal tension between the individual product programs and the underlying platform. While offset situations prevent this idealized

Individual Product Perspective		Product Family Outcome: Beneficial	Product Family Outcome: Non-Beneficial
	Beneficial	Accepted (net gain)	Accepted (net loss)
	Non-Beneficial	Avoided (missed opportunity)	Avoided (loss averted)

Individual Product Outcome		Product Family Perspective: Beneficial	Product Family Perspective: Non-Beneficial
	Beneficial	Accepted (net gain)	Avoided (loss averted)
	Non-Beneficial	Accepted (net gain)	Avoided (loss averted)

Figure 13. Two decision making perspectives: individual product (left) and product family (right). The latter is better aligned with corporate profitability. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

scenario, proximity can be achieved by increasing funding to programs that are not currently under full development. In addition, organizational processes, such as the product development process, must account for commonality decisions. These processes typically focus on individual products, rather than a product family, immediately sending the organization down a path that leads to the loss of beneficial commonality opportunities. Change control boards should examine the impact of a change on the economics of each product and the product family as a whole, as was done by Military Aircraft. Ultimately, the organization structure and processes should be bolstered by an awareness of commonality that starts with the leadership and pervades the entire organization. Commonality decisions are made at all levels of the organization and design hierarchy, from an executive making a decision about a high level requirement to an engineer adjusting the design of a common component.

9. CONCLUSION

The research on divergence and lifecycle offsets presented in this paper represents a narrowing of the gap between the theory and practice of employing commonality within product families. Where comparative data were previously unavailable for the targeted versus realized parts sharing in product families, this paper provided a comparison of parts-level trajectories, suggesting firms tend to realize significantly less commonality than intended. Where previous literature on platforming focused almost exclusively on platform-level decision making, an investigation of the theoretical and empirical implications of product variant actions revealed potential mechanisms leading to individual product optimization and resulting product family suboptimization. To these ends, a parts-level framework was discussed, noting that while the Intended Common parts design and cost become concrete after their development, the likelihood of realizing commonality along with the expected benefits decreases with larger offsets.

With a view to exploring the underlying dynamics of the phenomenon of divergence, we identified several concepts that emerged from the case studies. Notably, lifecycle offsets reduce the potential benefits of commonality and create asymmetries in the balance of power during development of individual variants, asymmetries in benefit allocation across variants, and asymmetries in the cost of change implementation for each variant. The case studies were used to provide rich descriptions that linked the above concepts to the observed end result of divergence.

From a management perspective, the concepts of divergence and lifecycle offsets imply that product family managers face a number of tasks: maintaining realism when estimating the benefits of commonality, instituting processes for the dynamic management of commonality throughout the product family lifecycle, evaluating commonality decisions from a product family perspective, and building an organization that takes commonality into account. The theoretical concept of divergence is essentially a restatement of the Second Law of Thermodynamics: Systems tend toward increasing states of disorder. Effort is required to counteract the nonbeneficial portion of this otherwise inevitable outcome.

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