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PLATFORM-BASED DESIGN AND DEVELOPMENT: CURRENT TRENDS AND NEEDS IN INDUSTRY

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ABSTRACT

Many companies constantly struggle to find cost-effective solutions to satisfy the diverse demands of their customers. In this paper, we report on two recent industry-focused conferences that emphasized platform design, development, and deployment as a means to increase variety, shorten lead-times, and reduce development and production costs. The first conference, *Platform Management for Continued Growth*, was held November-December 2004 in Atlanta, Georgia, and the second, *2005 Innovations in Product Development Conference - Product Families and Platforms: From Strategic Innovation to Implementation*, was held in November 2005 in Cambridge, Massachusetts. The two conferences featured presentations from academia and more than 20 companies who shared their successes and frustrations with platform design and deployment, platform-based product development, and product family planning. Our intent is to provide a summary of the common themes that we observed in these two conferences. Based on this discussion, we extrapolate upon industry's needs in platform design, development, and deployment to stimulate and catalyze future work in this important area of research.

Keywords: Product Platform, Product Family, Product Variety, Modularity, Commonality

1. INTRODUCTION

Marketplace globalization, the proliferation of niche markets, increased competitive pressures, and demand for customized products have rendered the practice of isolated design and production of individual products nearly obsolete. Across many industries, the prevailing practice is to design families of products that exploit commonality to take advantage of economies of scale and scope while satisfying a variety of market segments. Successful examples can be found in a variety of companies, including Black & Decker [1], Seagate [2], Sony [3], and Volkswagen [4] to name a few. Planning families of products requires additional care and attention, since each product competes for market share not only with competitor products, but also with other products in the family.

A *product family* is a group of related products that are derived from a common set of components, modules, and/or subsystems to satisfy a variety of market niches. The key to a successful product family is the *product platform* around which the product family is derived [5]. Product platform definitions range from the "set of common components, modules, or parts from which a stream of derivative products can be efficiently developed and launched" [5] to the "collection of assets [i.e., components, processes, knowledge, people and relationships] that are shared by a set of products" [6]. Some industries view platforms at a more abstract level, defining not only the set of common elements but also the architectural rules that enable a set of planned product offerings where the architectural rules define geometrical, mechanical, electrical, and software interfaces between platform elements [7,8]. Firms developing infrastructures for oil [9] and space exploration [10], for example, will continue to expand and evolve this definition as they seek to exploit the benefits of using platforms.

Designing a product platform and corresponding family of products is a difficult task that embodies all of the challenges of product design while adding the complexity of coordinating the design of multiple products in an effort to increase commonality across the set of products without compromising their distinctiveness. Due to their difficulty, product family design and platform-based product development have been primarily practiced in an ad hoc fashion. Academic research efforts initiated about a decade ago sought to develop systematic methodologies for qualitative and quantitative product platform and product family design. The former address pertinent research issues from a business-oriented perspective while the latter focus on the engineering aspect. Product platform and family design has become a very active and increasingly relevant research topic, with its own share of special sessions in conferences and archival journals. A broad survey of existing methodologies can be found in Ref. [11], and an in-depth discussion of many of these methods can be found in Ref. [12].

As this research field has matured, it has attracted increased attention from industry, which has spurred renewed interest in academia. This has led to many industry-funded projects and case studies that demonstrated the potential of the developed methodologies. At the same time, application of academic efforts on real-world problems exposed limitations and needs for further research. We are encouraged by the two-way feedback process that is starting to occur between industry and academia. The two industry-focused conferences reviewed in the next section are the most recent examples of balanced interactions among academia and industry, where such challenges were identified along with additional potential sectors that may benefit from adopting product family design strategies and platform-based development approaches. Our intent is thus to report on these opportunities, identify common themes, and elaborate on future research needs and challenges to stimulate further growth in this important area of research.

The remainder of this paper is as follows. In the next section, we provide an overview of the two industry-focused platform conferences that motivated this paper. In Section 3, we discuss the common themes and trends that arose from these two conferences. Based on our observations, in Section 4 we discuss the challenges and future research directions in platform-based design. Section 5 provides closing remarks.

2. OVERVIEW OF PLATFORM CONFERENCES

2.1. Platform Management for Continued Growth

Twenty industry experts convened in Atlanta, Georgia on November 30 and December 1, 2004 for the first *Platform Management for Continued Growth* conference to share strategies and results of their internal product platform design and development efforts. The conference was co-organized by the Institute for International Research (IIR) and the Product Development and Management Association (PDMA), and drew a small, but wide-ranging audience from industry and academia.

The conference began with a keynote speech by Marc Meyer, co-author of The Power of Product Platforms: Building Value and Cost Leadership [5]. He highlighted successes and failures, which he used as key aspects of platform development. Other presentations were given by representatives from IBM, Eastman Kodak, DuPont, Intel, and Lockheed Martin as well as mid- to small-sized companies such as Harley Davidson, Playtex, Aventis Pasteur, Case-New Holland Global, Cingular Wireless, Argon Engineering, and Innovation Focus. Patrick Gordon from PRTM hosted a discussion-filled post-conference workshop entitled, *Tapping the Full Potential of Product Platforms*, which helped coalesce the previous two day's talks. Several common themes arose that were applicable to the new product development processes for both goods and services as discussed in Section 3. The workshop agenda and list of speakers can be found at: http://www.iirusa.com/platform/.

2.2. Product Families and Platforms: From Strategic Innovation to Implementation

The second platform-oriented conference was held at the Massachusetts Institute of Technology (MIT) on November 9-10, 2005. In total, 114 individuals participated, split almost evenly between industry and academia, including 20 students from various universities in the U.S., Europe, and Asia. There were three primary objectives for this conference:

1. bring together a community of practitioners and academics to learn, think, debate and discuss the latest trends and achievements in platform-based product family design;
2. present state-of-the-art methods and tools for product platform and product family design, coincident with the release of a new edited volume on the topic [12]; and
3. understand how the concept of platform-based product family design can be extended to new areas such as services and software, beyond the traditional focus on electro-mechanical products.

The complete conference agenda and speaker presentations can be found at: http://cipd.mit.edu/pd/.

The keynote speakers were Marc Meyer (Day 1) and B. Joseph Pine II (Day 2). Meyer focused on the relationship between product platforms and the lifecycle phases of an enterprise (see Figure 1): early innovation, characterized by low sales volumes and technological discontinuities, the middle phase where some companies emerge as niche players, while others experience rapid growth with concomitant market expansion, followed by a third phase of either stagnation and gradual decline or continued enterprise growth and rejuvenation. He argued that managing the transitions between the phases (gray vertical bars in Figure 1) was critical, and that product platforms, and more generally modular product architectures with well defined interfaces, play a critical role during those transitions. Rather than focusing on cost savings that can be achieved through commonality, future research should increasingly focus on new market applications, product development speed and enterprise growth enabled by product platforms.

On Day 2, Pine, the author of the Mass Customization: The New Frontier in Business Competition [13], gave his vision of future trends in the area of mass customization and how platform-based development can support customized product and service offerings. He also emphasized the important role of modularity and product architecture in allowing companies to best combine their capabilities and technologies to serve a wide variety of (changing) customer needs.

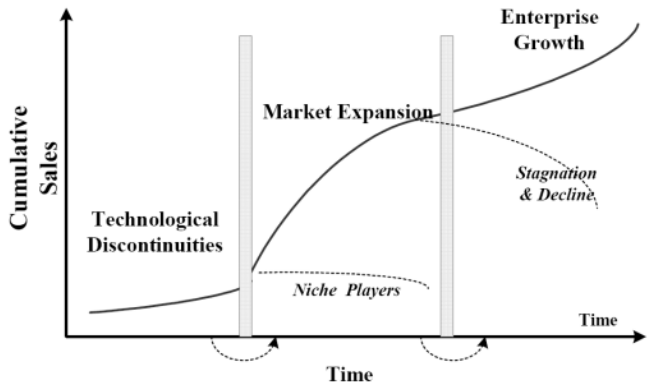

Figure 1. Innovation and Enterprise Growth [14]

The remainder of the conference provided an overview of platform research and practice (Session I) and focused on research trends and industry accomplishments in traditional industries such as the automotive industry, industrial equipment, and appliances (Session II). In many of these industries, product variety is increasingly achieved by modularizing products, defining standard interfaces, and explicitly accommodating variety at later points in the assembly process (i.e., postponement). Session III focused on recent expansions of the platform concept into "non-traditional" areas such as the service industry and software product line architecture. Research is still emerging in these areas, and specific examples of firms that have successfully developed a modular reuse strategy (e.g., Aramark, HP Business Services) were given. The conference ended with a panel session (IV) on the effects of globalization on product development in general and product platforms specifically. As the panelists commented, platforms enable firms to offer global portfolios of products, while accounting for regional differences in design, styling and regulations.

3. COMMON THEMES AND TRENDS

Several common themes and trends arose among the presentations and examples discussed at the two conferences. These themes present common challenges and solutions that can be studied and utilized for the development of platforms and platform-based goods and services. The following themes demonstrate how to succeed in leveraging the benefits of a holistic platform and platform-based development process.

3.1. Corporate Culture Change

Corporations that have embraced *cross-functional product platform teams* have routinely demonstrated the ability to quickly reinvent themselves and successfully enter new markets. Traditionally, corporations have employed functional management structures. These individual 'fiefdoms' often have their own R&D Centers, Manufacturing, and Supply Chain Management organizations. Little information, technology, or business lessons are shared among the different business units. At IBM, this type of organization led to a lack of innovation and response to market shifts, reaching a zenith in 1993, when corporate losses topped $8 Billion [15]. Symptomatic of the organizational problems was their business server model line. As Mugge [15] discussed, in 1996 several divisions were model line-oriented, each producing uniquely 'branded' products. The servers had upwards of 3,500 components; with divisions having less than two percent of common, shared parts (any reuse was unintentional). In response, IBM reorganized itself into cross-disciplined market-facing platform teams, which included marketing, sales, engineering, manufacturing, and logistics. These teams have been designed to integrate and master four core competencies:

1. increase ideation through Market Planning and Analysis,
2. improve investment decisions from disciplined portfolio management,
3. increase innovation yield and flexibility from Platform Management, and
4. faster time-to-market through better Pipeline Management.

Since the reorganization, the eServer line has been developed and launched to critical and sustained sales success. Using common and preferred parts, there has been a 70-80% reduction in part numbers, and over $700 Million eliminated from IBM's cost structure since the late 1990's. Historical data, noting reduction in the number of components and cost reduction, are shown in Figure 2. Additionally, Mugge stated that the number of new products increased by 270% percent. By implementing cross-functional teams combined with platform management, IBM has demonstrated the tangible benefits of culture change.

		1997	1998	1999	2000	2001
	Metric	Year End Actual	Year End Actual	Year End Actual	Year End Actual	Year End Actual
Corporate Composite	P/N Reduction	Baseline	20%	33%	35%	38%
	P/N Reuse	35%	47%	57%	60%	56%
	% Preferred	N/A	45%	46%	47%	62%
	YTY Cost Reduction	N/A	$250M	$180M	$205M	$140M

$775M taken out of IBM's cost structure in 4 years

Figure 2. IBM P/N Reduction, P/N Reuse, and Cost Reduction [15]

3.2. Upper Management – Catalyst for Change

Reorganization will fail without strong support from upper management. Corporations are difficult to 'turn-on-a-dime,' but changing heading is only possible if they have the means and will to complete the necessary course corrections. IBM's reorganization, for example, produced dramatic results, but it was only because IBM's CEO at the time, Louis V. Gerstner, spearheaded the culture change by appointing senior management to lead the effort and commit the required resources [16]. A related example of support for culture change occurred at Intel. In 2000, Intel's Desktop Platform Group strategy was changed from developing components to developing platforms. Since that time, management has fully supported evolutionary improvement and implementation of a coherent Platform Development Management System. [17].

The examples from IBM and Intel have a common attribute of upper management integration into adopting platform management. Additionally, although IBM and Intel are entities with different corporate customs, each tailored a management support and integration methodology that worked with their existing culture. IBM appointed a change manager, while Intel fostered an evolutionary change environment. As such, each corporation is unique, and how the change is realized will also be unique. The commonality, however, begins with desire and support of upper management, which is key if firms are to avoid stagnation and decline of their product portfolio.

3.3. Product Development – Results through Teamwork

Cross-functional product development teams are essential for implementing a successful platform development strategy. An example of a fully integrated approach is Sanofi Aventis, developer and manufacturer of vaccines. Their product platform team consists of representatives from R&D, manufacturing, marketing, quality assurance, logistics, and even the legal department. The framework shown in Figure 3 allows Aventis to develop early partnerships among team members and establish a smooth transition from research into the critical path of FDA approval [18]. As McGill discussed, by tearing down the developmental 'walls' and increasing communication between the subsystems of the corporation, product development cycles are reduced with the end result often being higher quality products. Taking a step further, these cross-functional product development teams can be aligned to have inter-team access to common R&D, subsystems, and components. Cross-functional teams have been used to great effect in other industries, including automotive and aerospace.

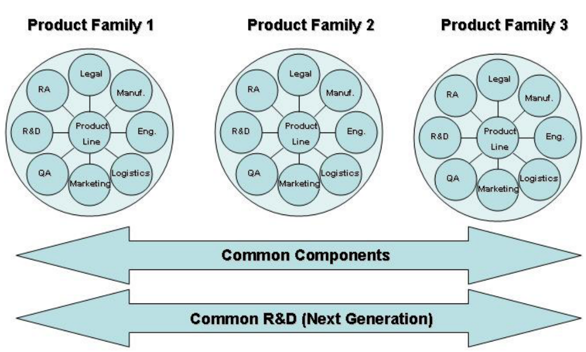

Figure 3. Shared Resources during Development [18]

IBM, Playtex, Intel, and DuPont all have aligned their organizations to maximize the benefits of cross-functional teams and cross-organizational information sharing. Benefits include component reduction, common architectures, and a deep research pool to generate 'out-of-the-box' technology and ideas for innovative new products. Challenges, however, remain because the time constants involved in developing fundamentally new technologies, product platforms, and customized variants are often very different. Some firms are experimenting with layered organizational models where platform teams are acting as a connecting layer between the slower science-related organizational layer of basic R&D and the fast-paced market-related product development layer, where designers are primarily concerned with tailoring and assembling products from already existing and proven technologies and components to respond quickly to changing customer demands.

3.4. Architecture – Common Subsystems and Reduced Complexity

Developing cohesive and flexible product architectures is a necessity in successfully implementing a platform strategy. The platform should form the basis of an internal product roadmap that outlines future capabilities and functionality while serving as a pillar in the overall corporate vision [8]. Overall product strategy is derived from the platform, as the platform should be able to be tailored to meet different market segments and performance targets (see Figure 4). Platforms use supporting elements such as common subsystems and components. This allows platforms to be designed for a particular market segment and then be easily modified for different segments and/or higher-level tiers within the same segment.

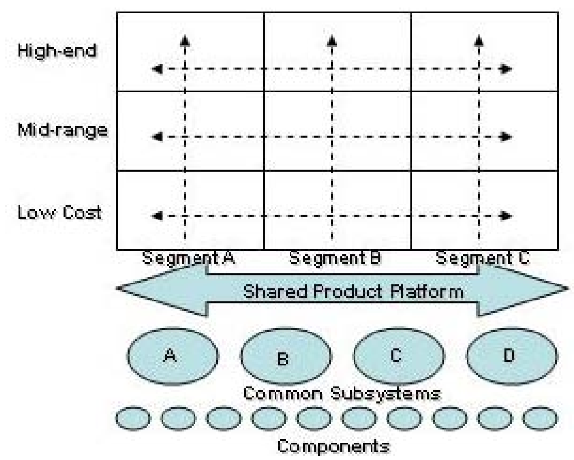

Figure 4. Market Segmentation Grid [5]

Lockheed Martin has implemented a successful platform strategy for its family of military transports [19]. With the next series of Block Upgrades (major aircraft and avionics revisions), software and avionics (major subsystems) will become common for Lockheed's three platforms, the C-130, C-5, and C-27. The common subsystems will form the basis for a new airframe platform eventually replacing the C-130, which will be similar to today's aircraft in that is can be easily reconfigured to fill a wide variety of different roles. Today's C-130 fills roles as diverse as Search and Rescue to Gunship applications, all leveraging a common airframe. Different software and weapons suites can be applied to the airframe to move up the Y-axis from 'Low-cost' to 'High-end' [19].

Modular platforming techniques are also finding new applications in telecommunications industries. Cingular Wireless is implementing a platform approach on Pre-paid and their 'Take Charge' cellular plans. These can leverage common technology subsystems such as wireless technology and be applied to different demographic segments. Additionally, service plans and customer service can be easily reconfigured to meet different market segment needs [20].

In terms of planning a product platform-based product portfolio, there is consensus that an abundance of product variants is undesirable, both from the product lifecycle management's (PLM's) and from end-user's/consumer's point of view. Therefore, complexity reduction constitutes a critical objective of the product family design process. Particularly, it is suggested that the number of product platforms is held to a minimum to maximize commonality benefits, and that they are modular so that new product variants can be derived with minimum effort and without having planned substantially for them. Moreover, it is recommended that existing product platforms are utilized to the maximum extent possible, since their development requires a significant amount of resources. This raises an interesting tension, since product platforms can clearly increase product variety and short-term innovation; however, because of the "sunk" investment into product platforms there is pressure to reuse them repeatedly. As pointed out by Pine, there may come a point where a platform acts as a barrier to future innovation at which point renewal of the platform and underlying product architecture may be required.

3.5. Platform Strategies in "Non-Traditional" Applications

As noted with Cingular Wireless, platforming techniques are beginning to be used in other industries besides traditional product engineering firms. One of the consistent themes from both conferences is that after a decade of research and development in the consumer products (e.g., electronics and home tooling) and engineering (e.g., automotive and aerospace) sectors, platform-based product family design is now being adopted in "non-traditional" sectors such as software engineering, telecommunications, food and drugs industries, and service systems (e.g., entertainment, tourism, banking). Initially, this expansion occurs by marketing derivatives of existing products and services to fill current and readily exploited niches, but future product development will be conducted using product platform strategies. Of utmost importance for continued research and dialogue is having different industries use common terminology. As observed by many representatives from diverse sectors, establishing common terminology may seem simple but is integral ingredient to successful transfer of platform concepts to these non-traditional industries. The challenge of common terminology is discussed further in Section 4.

An interesting suggestion is that all of the following platform perspectives should be exploited to increase likelihood of successful product launch: industrial and artistic design-based platforms, technology-focused platforms, and brand recognition-based platforms [21]: the first type allows companies to effectively utilize, and re-utilize a set of distinguishing features, characteristics, attributes or elements. The second allows them to efficiently utilize and re-utilize a set of product and/or process technologies, and the third one allows for (hopefully positive) brand recognition.

3.6. Forecasting and Analysis – Understand the Market

In order to develop successful products and services, corporations must accurately listen to and identify the needs and expectations of each market segment and tier. In looking at this competitive landscape, each market niche needs to consider [8]:

- What is the significance of this segment?
- What are the key products?
- What are their volumes, revenue, and profits?
- What is the outlook for the next 5 years?
- What does the Company have to do to enter, sustain, and grow in the segment?

The company then develops a '360 degree' view of potential customers to understand their needs, requirements, and usage patterns. This 'Voice of the Customer' (VOC) approach has been effective in helping guide the product specifications and features of new product platforms.

A successful application of the VOC has occurred at Case-New Holland (CNH), a world leader in agricultural equipment such as tractors. In developing a new cross segment platform, CNH embarked on an extensive program of interviewing potential customers in each market. In person, one-on-one interviews were held to gauge customer feedback on issues ranging from cabin ergonomics to steering mechanisms. Responses were documented, analyzed, and used in the conceptual development process to formulate product solutions. This VOC process is integral to CNH's process of Customer-Driven Product Definition [22]. Playtex also gave an example of reorganizing a company in response to market needs [23].

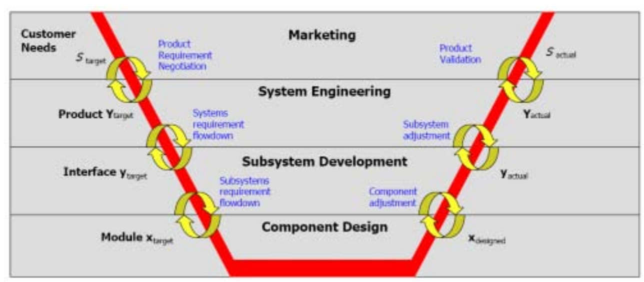

Figure 5. Requirements Allocation in Modern Systems Engineering [24]

Finally, it is becoming more widely accepted that product family design approaches must be analytical and quantitative, i.e., model-based (see Figure 5). One approach is to design product platforms for robustness, i.e., insensitive to variations. It has been suggested that this can be best accomplished by using hierarchical and modular product architectures with "clean" interfaces to enable sensitivity analysis, error tracking, statistical analysis of uncertainties and their propagation, and cascading of requirements and specifications that enable both subcontractor flexibility and accountability [24,25]. It is interesting to observe that hierarchical frameworks were suggested for both traditional (engineering) and "non-traditional" (e.g., software engineering) applications [26].

3.7. Financial Planning

Appropriate planning and architecture configuration for product family development requires estimating expected financial benefits both in terms of savings due to commonality (manufacturing, inventory, training, maintenance) and revenues due to successful product performance in the market. With only a few exceptions, most existing methodologies for product family design and development lack a rigorous cost-benefit analysis: cost models and data are either not available or proprietary, while expected product performance and revenues are estimated using elementary net present value methods. Most methodologies are based on the implicit assumption that maximized commonality is equivalent to maximized cost benefits. Even when cost models are included, they are used to quantify cost savings and to translate commonality to monetary units. Therefore, product commonality and differentiation is decided upon functional performance penalty (relative to products that do not share common parts or manufacturing processes) considerations without taking into account losses or profits due to market performance. Attempts to quantify the market impact of commonality in terms of demand and revenue effects and to "close-the-loop" with the manufacturing savings (both fixed and variable costs) achieved through commonality are being made in both industry and academia. Figure 6 shows an end-to-end product modeling framework that maps key platform commonality decisions through both the product architecture – engineering performance – product value-market-revenue path (upper) as well as the product architecture – manufacturing cost – investment finance path (lower).

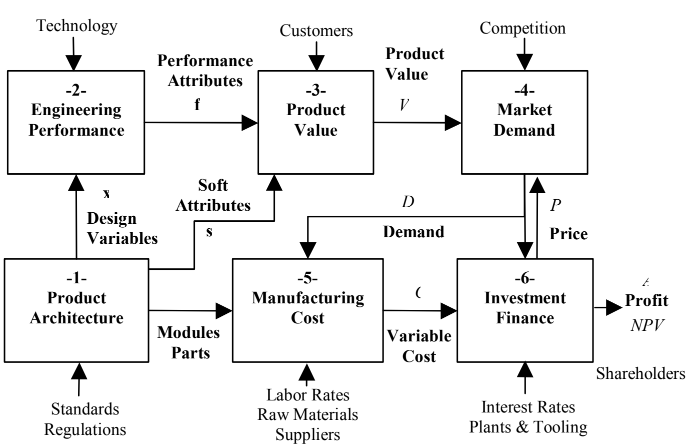

Figure 6. Interdisciplinary Product Modeling Framework [27]

While the general causal relationships between key quantities such as commonality, product performance, market demand, revenue, and manufacturing costs are generally well understood, their detailed quantitative modeling remains elusive. The main reason is that as models of product performance, market demand, and manufacturing costs are concatenated, so are the modeling errors and uncertainties inherent in them. To make matters worse, these errors are not typically additive but multiplicative. It is thus imperative to develop credible interdisciplinary product family development frameworks. Along with these, formal methods of model validation and verification against engineering, market and cost data are needed. As many speakers at the two conferences indicated, the engineering part of the framework already exists and/or may not be the hardest one to achieve; the rest, such as integrated financial planning, is a challenge.

3.8. Globalization and Product Platforms

Finally, globalization not only offers opportunities for product families but actually implies them. Consumers worldwide are increasingly wearing the same type of clothes, driving the same type of cars, working on the same type of computers using the same type of software. Additionally, people are using the same type of appliances and telecommunication means, enjoying the same type of home entertainment, and playing the same type of electronic games. As highlighted by many industry speakers, many of whom represent global companies, product families are the only way for international companies to market their products efficiently and stay in business, as product families drive the competition. Figure 7 depicts an example of how DuPont took a global perspective while developing their platform strategy. In today's global market, different regulations and cultural differences (not only customer, but also within the firms and their various regional divisions) must be taken into account. As such, product lines must be even more robust and flexible to such variations.

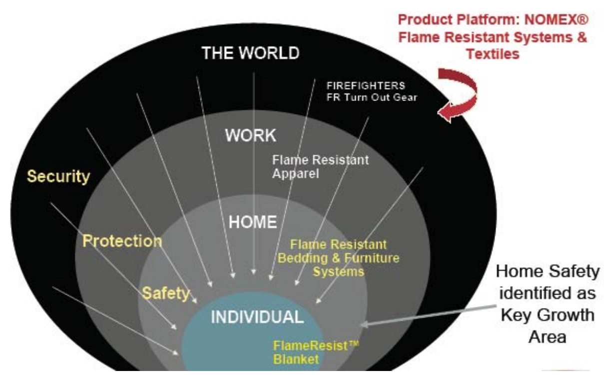

Figure 7. Thinking Globally Offers New Opportunities to Exploit Platforms [28]

4. CHALLENGES AND FUTURE DIRECTIONS

A review of the common themes and trends leads directly to identification of challenges industries face in deploying platform strategies. Identification of these challenges creates opportunities for future research as discussed next.

4.1. Formulation of Effective Industrial Partnerships

The companies that participated in the workshop were mostly the believers; that is, they had already embraced the concept of product platforms. However, they experienced challenges implementing the approach greater than anticipated from the relatively straight-forward concept of "shared assets for leveraged benefit". It is also clear that there is a disconnect between academia and industry. From the academic side, the low level of application can be seen, for example, in how papers on platforms tend to revert to the same, already dated, examples of platforms in industry. Similarly, many of the techniques and tools from academia are not being applied in industry because they often do not scale well to complex or "messy" situations. This disconnect could be remedied in several ways. The first is simply for academia to work more closely with industry on the research, and obviously more cooperative workshops bringing together both parties would help this. Another way to increase the relevance and impact of academic platform research is to have students spend more time at host companies and for host companies to make greater efforts in the area of data availability and release. Other approaches could involve research consortia where non-competing firms from various industries who would freely share data to jointly develop generalizable methods and tools to support platform-based design, development, and decision-making. Another approach is to view this disconnect as a research opportunity. Is there a reason why certain platform design techniques and tools have been adopted in some industries while others have not? What can we learn from this for developing future techniques and tools?

Another cause for disconnect identified was language, even with the meaning of the term "platform". The many different definitions of platforms create challenges for platform design. Different definitions among organizations can lead to tensions in common goals. For example, management may use the word platform for product lines and marketing may refer to customer options as product modules, while engineering might call the core technology of the company their platform. It is important for these multiple views to contribute to the same goal of platform benefits in sync with the company strategy. The challenge becomes how to define a platform, or how to combine the different definitions in a way that the entire organization can be on the same page. Govindarajan from Hewlett-Packard emphasized the need to explore how to generalize some of the core ideas of platforms along key dimensions such as portfolio, stakeholder, geography, and lifecycle so that they are more applicable to "non-traditional" areas such as service systems [29]. There is an opportunity to establish a richer semantic description for platforms to help identify these nuances.

4.2. Recognizing a Holistic Platform Strategy

Considerable research has been conducted on techniques and strategies on formulating platforms based on physical features, components or modules of products [11]. There has also been considerable research on utilizing platforms for production processes [30]. It may be that effective platform strategies must recognize all of the elements described by Robertson and Ulrich rather than focusing on just the physical aspects of components and processes. So, effective sharing of knowledge and relationships are integral elements for realizing an effective holistic platform strategy.

While technologies such as Enterprise Resource Planning (ERP) and Product Lifecycle Management (PLM) have made inroads to supporting product development, there are currently no tools available to facilitate the sharing of knowledge directed to product platforms [31,32]. Opportunities abound for enhanced techniques for effectively capturing, storing, retrieving and delivering information in support of product platform strategies. Govindarajan from Hewlett-Packard acknowledged a need to explore how documents can become primary vehicles for manipulating an information model in support of platforms [29]. This is just one facet of the broader opportunities for knowledge management to support platforms.

A common theme among industry representatives reflected the need for approaches in transforming the organization to support platform strategies thereby highlighting the relationships aspect. Nidamarthi from ABB highlighted the importance of an organization aligned to implement and sustain the platform [33,34]. If the purpose of a company is to produce products to generate profit (based on platforms), then perhaps the organization should be designed around the platform rather than the other way around. This organizational change can be difficult, possibly the biggest challenge as argued by Meyer during the conference. Organization culture is not easy to change. Especially in the engineering literature, the organization that will develop the platform is often ignored. The challenge is in how to get support and involvement from the entire organization to this major change. There are industry examples of success, such as IBM [15]; however, there are clearly ample opportunities for research into organizations, operations, and human factors to support product platform strategies. Can diffusion of technology theories facilitate user adoption of platform techniques and tools?

4.3. Flexible Platform Design for Multiple Generations

As the lifetime of a platform is long with multiple product generations, one of the key challenges is to be able to predict the future or to design the platforms so that the expected and unexpected changes can be accounted for during the original design of the platform. This calls for methods for designing flexible product platforms. There is already work in the area [35-37], but much more is needed. Key questions include: Where to design platform flexibility? When to design a flexible platforms and when to choose a platform update? How to prepare for new applications, new product lines, and new radical technologies? How to properly value any flexibility investments into platforms? When to initiate a complete platform redesign before it reaches stagnation and decline?

A related problem is determining the "extent" of the platform; see Ref. [27] and references therein. This refers to the question of how diverse the set of variants can be that is derived from a common platform. The diversity can be quantified in terms of physical attributes such as geometry or in terms of functional performance. As a product platform is leveraged more-and-more over time, the capabilities (bandwidth) of the platform is constantly challenged with each new variant derived from it [36]. One may choose to keep "extending" the platform or one may choose to strictly enforce its current configuration and impose boundary conditions on new variants, in which case the variants may be overly constrained. If on the other hand one continues to continuously "stretch" the platform, it may eventually become overburdened, and it may be more efficient to split the platform into two (or more) platforms. Thus, in some cases deploying multiple platforms may actually be optimal [37]. If the variety of functional requirements becomes too large, the platform may become too demanding to develop, too expensive to build and too complex to operate reliably. In that case it might be better to "descope" the platform and revert back to a collection of less ambitious, and simpler "special purpose systems". This is not purely an engineering or financial question, but one of systems architecture and strategy.

4.4. Corporate Platform Strategy and Tradeoffs

Platforms are related to the product architecture, supply chain, manufacturing, design reuse, etc. The platform strategy should be considered not only as a part of a product strategy but also as a corporate strategy. Platform design can be the tool to use to achieve the goals aligned in the company strategy. The challenge is how to consider the full strategy in the development i.e. how to take into account the multiple demands of the entire strategy while designing the platform. In order to implement a broad and effective platform strategy, substantial management involvement is needed. But since the engineers are typically the ones designing the platform, it is important also to involve them to ensure that the crated platforms strategy guidelines will also be followed. Effective platform design requires a truly company-wide effort.

Once the platform strategy is created and the platform(s) designed, the company faces a new problem – how to stick with the strategy and how to manage the platforms? A single platform should carry over through multiple product generations, but how many, and how often should a single platform, or the entire platform strategy be updated? Should a platform be adapted to changes when needed, or does that make the platform just a regular component that is redesigned as needed? Some researchers have addressed generational issues such as these [3,38,39], but considerably more work is needed. Also, the phenomenon of platform discipline is related to this. There is anecdotal evidence that the Joint Strike Fighter (JSF) program started out with a relatively clean platform and a high degree of commonality between the carrier (U.S. Navy), vertical-take-off (USMC), and USAF (long range) versions of the aircraft, but that the amount of commonality between the variants has gradually eroded. This erosion might happen for legitimate engineering reasons – because the variants are more different than initially thought based on prototype tests – or for reasons of policy or lack of enforcement of common standards. We feel that the area of platform discipline represents a rich area for further research at the intersection of organizational behavior and engineering design.

A common challenge in platform design is the management of multiple tradeoffs. The possible benefits from a platform depend on the starting point for the platform strategy (e.g., maximize commonality with minimal performance loss [40], minimize cost, maximize variety). Surprisingly many methods claim a multitude of benefits but most only handle the tradeoff between two goals: performance and commonality [41]. This can result in abandoning the platform strategy, even though the real problem lies in the misalignment of the goals and the methods used to attain them. Ideally, a method would consider cost, performance, variety, flexibility, etc. all at once, but this is often unrealistic and intractable. Instead, typically a method handles a tradeoff or two, leaving the remainder as separate decisions. Trying to choose the best platform for a company is difficult. Learning about why different organizations strive for commonality reveals that the motivations can be quite varied. In the oil industry, for example, the main reasons for increased standardization in oil platforms are not primarily capital expense savings from commonality but faster speed to "first oil" and higher levels of production reliability with fewer interruptions due to diverse hardware [42].

As in single product development, in platform development too, the profits from the design take years to realize. The true success of a design can be objectively judged only at the end of the product's lifecycle. In platform development this problem is even more pronounced as a platform is designed to last for several product generations. The question becomes how to evaluate the "goodness" of a platform sooner, rather during the development process already.

During the MIT conference, PRTM showed an example, where a medical device company applied a platform strategy and saw positive results by reducing the total number of platforms being developed to lower the overall cost of development and speed up development [7]. In the automotive industry, the success of a platform strategy is often described as a decrease in the number of different platforms and decrease in time-to-market. Oh [43] described how LG has benefited from their platform approach through cost reductions in manufacturing and development. Similarly, Marion discussed how Innovation Factory reduced the cost of development and manufacturing as well as increased variety using a platform approach [44]. It seems that the "goodness" of a platform can be measured, but are these few measures enough to capture the financial success of the platform?

Two companies, United Technologies [45] and PRTM [7], addressed this issue in the MIT conference: both called for a multi-criteria approach to platform screening during platform development. Otto and Hölttä-Otto [46] suggest that companies can use multiple metrics such as commonality, complexity, flexibility and reliability to evaluate which platform, among a set of alternatives, a company should pursue. More work is needed to define suitable metrics for specific cases and validation of how these metrics best reflect the future platform success or failure. More research is needed to identify proper metrics for measuring platform success during the platform evaluation phase as well as modeling platform and variant performance. Rigorous models could be used to improve platform design and aid in selecting platform alternatives.

4.5. Expanding Views for Platforms

Platform concepts are expanding into new domains. Peter McGrory [21] from the University of Art and Design Helsinki discussed the importance of the relationship of the customer to the product from an industrial design perspective. He stressed the importance of considering factors beyond the technology as part of the platform strategy. While technology-related intellectual property involves only patents, it is important to consider other intellectual property such as trademarks, copyrights, and registered designs. An industrial design platform can be used to create brand image for products while still benefiting from the common elements. Examining opportunities in this domain requires interdisciplinary collaboration among industrial art, design and engineering and carry with it cross cultural and language challenges.

It is also clear that there is a need to recognize products beyond physical artifacts. There is a need to explore the nuances of platform strategies applied to such areas as software and services. Kathryn Weiss described her efforts to employ the product family approach to software development for spacecraft control [26]. She stressed that success of software families is contingent on developing and selecting an appropriate software architecture to support the various products in the line; a similar approach was advocated by Harris [47]. There are clearly opportunities for exploring appropriate techniques from physical product family planning in software architecture. Govindarajan [29] described HP's approach to enabling mass customized services based on platform strategies. He identified many of the same challenges in the service domain as in physical products; however, there clearly are opportunities for research into the service sector that can be well received by our advancing service economy.

5. CLOSING REMARKS

Market pressures are forcing companies to rethink their product development organization, develop new technologies, infuse these into platforms and derive customized variants from them. This encompasses the entire development process, from market and customer research to supply chain management. Integral to this change in a wide variety of industries is the adoption of a platform management architecture. Successful traits among industry leaders are the formation of cross functional development teams, strong management support, common platform architectures that maximize the sharing of subsystems and components, and the ability to apply lessons learned over time for continuous improvement.

The most common themes resulting from the two conferences are the need to think strategically about developing families of products or services and platforms based on scalable, modular architectures with "clean", standardized interfaces. In reality, however, "complete" modularity is not always fully achievable due to packaging, weight, power and volume constraints, among others. Quantifying both the benefits *and costs* of platforming and standardization is necessary, but difficult due to inherent model and market uncertainties. It is these uncertainties that also require platforms to be designed with robustness or flexibility to respond to future needs better. These future needs could include new functional requirements demanded by customers, new technologies, adherence to new regulations or the expansion into new geographical and demographic markets. Product platforms tend to have lifetimes that exceed the lifetime of the variants that are derived from them and this makes the problem both challenging and relevant.

Finally, we are seeing expansion of platform concepts into new areas such as the service industry, software, large-scale infrastructures, and military and other government systems. The starting point for success of platform concepts in these new areas is an understandable and – generally – agreed upon nomenclature. We are encouraged by the interactions between industry and academia during past conferences and are invigorated and confident that much research and implementation work remains to be undertaken in this interdisciplinary and fascinating research field.

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