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Advances in Product Family and Product Platform Design

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Preface

Increased product variety, decreased costs, faster time to market. The motives for designing product platforms and developing families of products have changed little these past three decades; however, never have companies had more imperative to pursue platform-based product development. The rise of the BRICs (Brazil, Russia, India, and China), the Great Recession, and the interconnected global economy are but a few of the many factors that are causing renewed and continued interest in product platforms and product family design. In our own teaching, we have observed this shift as well. Shortly after our first book came out, industry interest was primarily focused on what is a platform and what are its potential benefits to a company, and only a few companies were aggressively pursuing platform-based product development strategies. Now, particularly in the last 2–3 years, industry interest has noticeably shifted to the implementation and execution of platforms (e.g., how do we design platforms? what constitutes a good platform? how does our platform compare to what our competitors are doing?), and we find the majority of companies are investing significant time and resources to develop a product platform and corresponding product family.

So what is a product family? Most generally, it is a set of products that share one or more common “elements” (e.g., components, modules, subsystems, fabrication processes, assembly operations) yet target a variety of different market segments. The commonality in the family is intentional—not coincidental—and arises from the product platform around which the family is derived. The individual product variants can be derived from the platform by adding, substituting, or subtracting one or more modules from the family to create a module-based product family or by “scaling” or “stretching” the platform in one or more dimensions to realize a scale-based product family (Jiao et al. 2007). Of course, it is never that straightforward in practice, as different product families require different combinations of modularity and scaling to achieve sufficient variety for the marketplace while remaining cost-effective and competitive.

Making the case for platforming in a company remains a challenge. It requires a different mindset than one for a single product, and most companies are not prepared to think across multiple generations of products and long term about their product lines. The concept of a "market attack plan" remains foreign to many companies as they still have a single product mindset and overcoming the corporate inertia to change that takes time and energy—and lots of it. A successful platform is as much about the technical solution as it is about the financial benefits or the organizational roadmap needed to establish and follow through on a viable platform strategy. The traditional thinking and established practices to manage *product* development often do not readily translate to *platform* development—a company cannot simply substitute one word for another in an org chart or a gate review process and expect things to go smoothly.

Cross-functional product development teams, support from upper management, platform architecting, understanding the market, and financial planning are just as important now as they were when we analyzed industry trends seven years ago (Simpson et al. 2006). We have also seen that platforming in "nontraditional" areas (e.g., software, services) continues to grow and thinking globally about platforms has become the rule not the exception as companies seek to establish a presence in multiple markets around the world. The variability that this creates—in customer needs, regulations/standards, and the general business environment—can be overwhelming, and companies need to think seriously about what platform strategy is best for them, if any. In some cases, the added cost and complexity of platform-based product development may lead to undesirable products; however, careful planning and an honest assessment of the true benefits of platforming within a company often yield exciting results.

To help companies with their platform journey—and it truly is a journey that does not happen overnight—we present *Advances in Product Family and Product Platform Design: Methods and Applications*, a follow-up to our first edition, which is now 8 years old (Simpson et al. 2005). While the methods and tools from our first edition are still readily applicable, numerous advances have been made, and the applications are becoming dated and no longer reflect the variety of areas that are now being targeted by platforms (e.g., software, services). Chapter 1 in the present text reviews recent literature to bring the reader up to speed on the recent developments. The remainder of the book is organized into four parts based on the order of a typical platform development life cycle:

- Part I: Platform Planning and Strategy
- Part II: Platform Architecting and Design
- Part III: Product Family Development and Implementation
- Part IV: Applications and Case Studies

Highlights of the chapters in each part follow.

Part I: Platform Planning and Strategy

The first part of the book provides a collection of methods and tools to help plan the platform development with given benefits in mind. Chapter 2 explores the benefits and pitfalls of commonality and provides evidence from several in-depth case studies on the cost savings and commonality premiums that companies were able to achieve in a range of industries. Chapter 3 investigates the challenges of integrating customer diversity across multiple market segments and provides methods to coevolve market segments and product variants to realize novel product platforms for multiple domains. Chapter 4 provides an overview of Modular Functional Deployment, a popular method in industry to support module-based product family design and examines the impact of different module drivers on both product and platform architecting. Chapter 5 expands on the notion of parts reuse to the reuse of design information and other generic assets to leverage platforms to integrate product and production systems. Chapter 6 introduces data mining techniques to help designers quantify the relevance (or obsolescence) of product features when developing a platform and corresponding family of products. Finally, Chap. 7 discusses platform valuation tools and the use of options to support module development decisions in uncertain market environments.

Part II: Platform Architecting and Design

The second part consists of eight chapters that introduce methods to help architect the platform, including methods for architecture decomposition as well as for both scalable and modular product platforms. Chapter 8 introduces a method to proactively create a platform based on assessment of market needs followed by identification of modules for individual product variants. Chapter 9 investigates the role of architecture decomposition and the impact that granularity has on modularity. Chapter 10 provides a comprehensive toolkit to support modular platform development along with an industry example to demonstrate its application. Chapter 11 explores the challenges of simultaneously designing a product platform and a product family and offers computational tools to optimize both at the same time. Chapter 12 provides a one-step approach to identify the platform and design the family of products simultaneously. Meanwhile, Chap. 13 identifies a tool chain to link disparate methods together to support product platform architecting. Chapter 14 describes a method for scale-based product family design using Quality Function Deployment (QFD) to optimize the engineering characteristics of the platform and the individual product variants. Finally, Chap. 15 offers a multi-platform approach to balance the trade-off between commonality and individual product performance that lies at the heart of product family design.

Part III: Product Family Development and Implementation

The third part continues to introduce methods for product platform development but with an emphasis on the implementation and execution of the platform strategy. Chapter 16 introduces methods and tools to support global platform design that integrates modularity and supply chain decisions. Chapter 17 presents three tools to support system architecting by linking functions, behaviors, and working principles to a variety of customer requirements. Chapter 18 discusses three methods to help identify potential common components in a product family and visualize the respective performance trade-offs. Chapter 19 describes several commonality indices and investigates their ability to capture the total cost savings within the product family. Chapter 20 investigates the implications of managing multiple design projects during product family development and introduces a process architecture to support modular design project planning. Chapter 21 discusses the challenges when architecting software platforms and codifies design principles to support software reuse. Chapter 22 explores the influences and impact of human variability on product design and identifies basic scenarios where platforming and modularity are advantageous. Finally, Chap. 23 concludes this part with a series of recommendations to align the product family with the manufacturing and supply chain while stressing the importance of aligning market variety with design versatility and supply chain responsiveness.

Part IV: Applications and Case Studies

The fourth part provides a series of practical examples from industry. In Chap. 24, a modular architecture is developed for a cordless handheld vacuum cleaner using Modular Function Deployment, which was introduced in Chap. 4. Chapter 25 investigates opportunities for commonality between different classes of ships for the US Coast Guard. Chapter 26 discusses heuristics for architecting software-intensive families, which are then used to develop a software platform for a family of industrial machines. Chapter 27 uses a sequence of design tools discussed in the book to analyze customer requirements and subsequently design a family of electric violins. Chapter 28 examines the implications of product family design and reuse on product life cycles with a smartphone case study. Chapter 29 describes the application of the Generational Variety Index (Martin and Ishii 2002) to analyze four generations of Apple's iPhone product line. A family of leaf blowers is designed using the proactive modular platform design method introduced in Chap. 8. Finally, the book concludes with an Epilogue that offers future research directions and discusses several trends shaping future applications of product platform and product family design and development.

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References

Jiao RJ, Simpson TW, Siddique Z (2007) Product family design and platform-based product development: a state-of-the-art review. J Intell Manuf 18(1):5–29

Martin MV, Ishii K (2002) Design for variety: developing standardized and modularized product platform architectures. Res Eng Des 13(4):213–235

Simpson TW, Marion TJ, de Weck O, Holtta-Otto K, Kokkolaras M, Shooter SB (2006) Platform-based design and development: current trends and needs in industry. In: ASME design engineering technical conferences – design automation conference ASME, Philadelphia, Pennsylvania, Paper No. DETC2006/DAC-99229

Simpson TW, Siddique Z, Jiao J (2005) Product platform and product family design: methods and applications. Springer, New York, NY

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Chapter 1
A Review of Recent Literature in Product Family Design and Platform-Based Product Development

Zhila Pirmoradi, G. Gary Wang, and Timothy W. Simpson

Abstract Increased demand for a greater variety of consumer products has forced many companies to rethink their strategies to offer more product variants. For manufacturers, producing a variety of products can satisfy this increasing demand and help companies gain more of market share; however, increased variety can lead to higher design and production costs as well as longer lead times for new variants. As a result, a trade-off arises between cost-effectiveness and satisfying diverse customer demand. Research has found that such a trade-off can be properly managed by exploiting product family design (PFD) and platform-based product development, an area that has been widely studied for the past two decades. New approaches have been proposed to address different issues related to PFD and platform development. Performance of these approaches has been assessed through case studies and applications to different industry sectors. This chapter focuses on reviewing the research in this field to classify recent advancements in PFD and platform development. We identify new achievements with regard to multiple aspects of PFD: customer involvement in design, market-driven studies, metrics for assessing platforms and families, indices for platform and family design, product family optimization issues, platform development issues, and, finally, issues relevant to supporting future platform design. Through a comparison with previous research studies, we identify ongoing challenges in this field along with potential directions for new research.

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1.1 Introduction

Customers' needs continually evolve and shift over time, and their demand for product variety and newer versions of products has increased rapidly in recent decades. Many companies have been attempting to provide more product variants to satisfy the increasing demand of niche segments in the market without sacrificing production efficiency (Berry and Pakes 2007; Jiao et al. 2007c). A trade-off quickly emerges: satisfying this wide array of customer needs leads to more sales, but producing this variety of products often increases costs and makes companies less profitable. In other words, using more common features and components in production (i.e., standardization of components) can reduce market share if products are not sufficiently differentiated. One way to manage this confliction is *mass customization*, which enables economies of scale and satisfaction of diverse expectations concurrently (Jiao and Zhang 2005). Mass customization emerged in the early 1990s with the objective of satisfying individual customers through increased product variety (Pine 1993). Product family design and platform-based product development are effective strategies to enable mass customization as they can effectively provide variety at reduced costs (Marion et al. 2007; Park and Simpson 2008). A product family can be considered as a set of products that share a number of common components and functions with each product having its unique specifications to meet demands of certain customers (Meyer and Lehnerd 1997). The common parts are usually defined as the product platform (Simpson et al. 2005). Design and development of families of products is challenging for many aspects. It involves selecting business strategies, considering multiple marketing issues, engineering customer needs, studying customer behavior and choice-related issues, as well as carefully considering engineering aspect of design, such as manufacturability, technological aspects, and design support issues (i.e., modeling and developing design information depository).

In general, the product family development process can be divided into three stages. The first stage is to translate identified customer needs (CN) into functional requirements (FR) for a product. The second stage deals with mapping those requirements into proper design variables (DV) subject to potential manufacturing constraints. The third stage is the process planning and determining process variables, which will be followed by the supply chain platform design, and determination of proper values for logistics variables (LV) (Jiao et al. 2007c). Figure 1.1 provides an illustration of the aforementioned issues and concepts.

According to this figure, an outline of this study can be provided as follows. As the front-end issues include customer involvement, product portfolio design, product family positioning, and transition or mapping from customer needs to functional requirements, these aspects will be discussed in the first section of this study. The product family design issues include the product family configuration, product architecture, design of families and platforms, variety in design, leveraging commonality and modularity, optimization of the family and platform design, and design decision support systems. The second section in the study will address

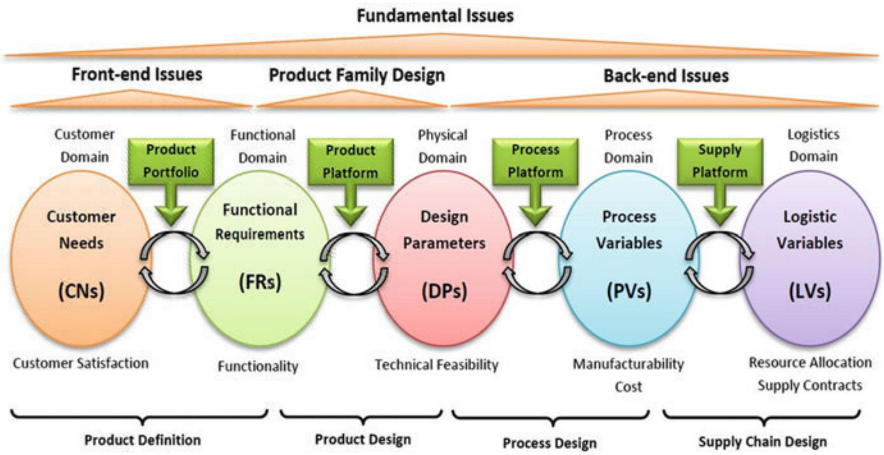

Fig. 1.1 A general view of product family design and development (Jiao et al. 2007c)

concerns directly related to design. Finally, the back-end issues will be discussed in the third section, including manufacturability, cost considerations, supply chain design and management, metrics for product family and platform design, resource allocation, redesign and flexible platform design issues, processes design, and process platforms. Eventually, the areas of improvement and potential areas for future research, as well as summary remarks, will be presented at the end of this study.

Researchers have developed techniques to address these stages individually and as a whole, and they have assessed efficiency of their developments through case studies. Among the developments with regard to PFD, two are well known: the top-down and the bottom-up approaches. The top-down approach focuses on developing a family in order to fulfill a variety of customer needs. The bottom-up approach attempts to increase production efficiency through providing solutions for reuse of components in multiple products and redesign to develop a family based on available products (Alizon et al. 2007).

1.2 Fundamental Concepts

The fundamental issues and concepts regarding design and development of product families are summarized in Table 1.1. For ease of reading, they are categorized into three sections, namely, the front-end, design and development, and back-end issues. A novel state-of-the-art review was implemented by Jiao et al. (2007c) for research activities before 2006. Therefore, this study focuses on published research since that time.

Table 1.1 (a) Front-end issues, (b) design and development issues, (c) back-end issues

Concept/issue	Definition	Examples and approaches
(a)		
Product architecture	A concept for describing relations among components and connecting the functions to the components in a product. Platform architecture describes the logical relations between common and unique elements for enabling highly customized products based on customer preferences (Xu et al. 2008)	*Modular architecture*: functions-components mapping for minimizing inter-module interactions *Integral architecture*: performance-driven or cost-based architectures, enabling variety, product change, and engineering standards (Cutherell 1996)
Product family and platform configuration	Approaches for selection of platform variables versus non-platform variables and platform configuration and selection	*Parametric platforms*: finding optimal platform parameters through algorithms such as genetic algorithm *Configurational platforms*: module identification through data mining techniques, reasoning systems, clustering approaches, etc.
Product family modeling and knowledge-based systems	Approaches for knowledge integration about product families and platforms	Unified modeling approach, graph grammar approach, architecture modeling, set-based models, parametric modeling, functional models, configuration information modeling, etc.
Product portfolio positioning	Strategies to give the customers the exact number of variants that they need	Factor analysis, discriminant analysis, perception scaling techniques, choice set determination, discrete choice analysis, probabilistic choice modeling
(b)		
Platform	Sets of components, technologies, subsystems, processes, and interfaces that form a structure to develop a number of products to maximize commonality and minimize individual performance deviations (Li et al. 2007)	*Scalable platforms*: variants can be produced through shrinkage or extension of scalable variables *Modular platforms*: enabling product differentiation through adding/removing/substituting different modules
	Product platform design deals with determination of the variables to be shared, as well as optimal values for both shared and unique variables among variants	*Generational platforms*: enabling consideration of possible requirements for changing the design over a period of time, to allow variation of next generations (Jiao et al. 2007c)
Variety versus commonality	The diversity that a production system can provide for the market. Two main concepts are	Functional variation: driven by customer requirements and it

(continued)

Table 1.1 (continued)

Concept/issue	Definition	Examples and approaches
	modularity and commonality. Modularity decomposes components and functions into independent groups, while commonality clusters the components and functions based on similarity or other criteria	attempts to increase variation in functions Technical variation: addresses issues such as manufacturability and costs and it tries to decrease diversity in functions and processes
	Functional variation can be traced in research studies focusing on product line structuring, product portfolio positioning, product pricing, and portfolio optimization. Technical variation strategy, however, can be found in areas such as design for variety, variety reduction schemes, and modularization (Jiao et al. 2007b)	Functional commonality/ modularity: paying attention to the relation between customer needs and functional requirements Technical commonality/modularity: based on technical design solutions or physical, based on mapping of functional requirements into design parameters (Jiao et al. 2007b)
Design optimization	Techniques and algorithms for determining the optimal design variable values, for specific objectives subject to constraints	Search approaches, multi-attribute utility analysis, preference-based design, MDO methods, product line design through cost modeling, engineering design considerations, etc.
Design support systems	Tools for facilitating information management and creating design information repository	Configuration reasoning systems, agent-based knowledge management systems, knowledge-intensive evaluation models, advisory systems, web-based customization systems, etc.
(c)		
Manufacturability	All concerns related to manufacturing part of PFD, including standardization and commonalization of the processes, facilities, and technologies and controlling manufacturing costs and process variations that result from customization development risks reduction techniques	Exploiting process families/ platforms Developing generic bill of materials (GBOMs) Integrating mass customization with product life cycle management Design for reuse Flexible platform design Reconfigurable system design (Mehrabi et al. 2000)
Metrics and indices	Tools that provide information about the cost savings resulted from commonalization compared to quantitative benefits of commonality	CMC, DCI, TCCI, PCI, %C, TCM, etc. (see Sect. 1.4.1 for more detail)
Supply chain management	Consideration of issues related to different PFD stages, including	Developing robust approaches to maximize profit of the supply

(continued)

Table 1.1 (continued)

Concept/issue	Definition	Examples and approaches
	first stages of supply chain management to the other end, which is delivery to customers	chain, along with minimizing delivery time, procurement costs, logistic and assembly costs, etc.
Postponement	Enabling late differentiation and allowing reduced inventory and delaying the resources commitment to the final configuration of a product as long as possible	Redesigning the family architecture or rescheduling the master production plan can facilitate postponement

While many approaches have been developed in the past decade to address PFD and platform development issues, many challenges remain. Necessity of handling many variables and simultaneous consideration of interdependencies among different elements of design make PFD problems complex in nature. Research continues in this field, and many opportunities exist for improvement. Based on the categories and concepts introduced in this section, new developments and recent achievements of this area are reviewed in this chapter. The literature review of each issue is presented in subsequent sections, and identified opportunities for future research are addressed in the closing section.

1.3 Front-End Issues in Product Family Design

As mentioned in the introduction, in the front-end of product family development, the following issues are of interest: involving customers into product characterization, product family positioning and market segmentation, product portfolio design, realizing the customer needs and the required functions to meet those needs, and eventually tools or techniques for facilitating information standardization and leveraging the product family knowledge.

1.3.1 Product Portfolio and Product Family Positioning

While different variants in a family may call for similar technical and manufacturing requirements, research has shown that they might not be equally preferred by the customers (Thevenot and Simpson 2007b). Therefore, product family positioning is vital for properly balancing the diverse customer tastes and manufacturing costs of variation (Olewnik and Lewis 2006). The product family positioning problem is a front-end issue that can be facilitated through market segmentation that segments the market into different clusters, providing specific variants for each, and identifying opportunities for adjusting products in order to attract more customers (Hisrich and Peters 1991). The family positioning problem focuses on increasing variation and diversity in the offered products. Clustering is required for this target so that the minimum possible number of variants which cover the maximum possible customer preferences can be determined. As a result, attention has been paid to clustering techniques such as data mining, fuzzy clustering, conjoint analysis, and heuristic search algorithms for finding matches between customer groups and product variants.

The summary of research done in area of positioning is as follows:

- Review of fuzzy logic applications for product family development (Barajas and Agard 2009).
- Use of engineering characteristics as segmentation variables for market segmentation and product line positioning (Zhang et al. 2007).
- Use of conjoint analysis for identifying customer needs and clustering method for segmenting customers (Kazemzadeh et al. 2009).
- Development of three indices: cost reduction, commonality percentage, and satisfaction percentage for comparing a generic product for the whole market with a customized product for each segment.
- Consideration of different market leveraging strategies and product line extension (Doraszelski and Draganska 2006).
- *Product mix selection* (Chung et al. 2008) assuming varying demand and different priorities for customer orders.
- Use of *real options* (Jiao et al. 2006; Jiao 2012) to assess values of different design options for flexible and intime action against market volatilities.

Sharman and Yassine (2007) showed that serious difficulties can arise when using the real options for clustering, especially when the product architecture is complex and it lacks a truly hierarchical structure. However, market conditions play an essential role in product family and platform design decisions, and many other factors affect the market, which affect planning and decision-making in turn. For example, markets are affected by government policies, demographics, and personal characteristics of customers as well as customer purchasing behaviors and preferences, which may vary under different circumstances. Therefore, prior assessment of all such issues is necessary for making the most reliable decisions before development of any product family. This makes PFD even more challenging, as it exacerbates development time and information gathering. Meanwhile, value creation for customers and successful development of product families/platforms depend on agile action for capturing such changing trends. Therefore, the demand for further research and more scrutiny in this filed continues to grow.

1.3.2 Market-Driven Product Family Design

The involvement of customer preferences into engineering design decisions has received remarkable attention recently. Mapping the customer needs into functional requirements of products, mapping the customer requirements into different market segments (Farrell and Simpson 2008), leveraging tools such as choice modeling for predicting customer reactions in different situations, using *quality function deployment* (*QFD*) for translating customer requirements into design requirements (Li et al. 2006), and other similar techniques have been helpful in product attributes selection, family/platform configuration, and portfolio optimization to fulfill the market demands.

A market-driven product family design approach was proposed by Kumar et al. (2006), known as *MPFD* to integrate market considerations with family design concerns in order to enable product family positioning. This approach examines the impact of variety on different market niches and employs a demand modeling through which the impacts of competition in different segments on market share of each competition can be identified. Similarly, in another study the same researchers integrated market share considerations and demand modeling for simultaneously optimizing decisions related to platform leveraging and product line positioning (Kumar et al. 2009). Their purpose was to overcome limitations of past market-driven PFD studies, which have only considered production line positioning in lieu of how a product competes with other products by the same supplier as well as competitive products. They concluded that including performance considerations and market considerations results in obtaining more economic decisions.

The list of other works done with consideration of market is as follows:

- Providing suggestions for overcoming the shortcomings of previous product line optimization models (Michalek et al. 2011).
- Exploring the strengths and limitations of discrete choice models for understanding market demand and supporting mass customization (Ferguson et al. 2011).
- Using the hierarchical mixed logit model for continuous representation of preference heterogeneities and the latent multinomial logit model for the discrete representation (Sullivan et al. 2011).
- Simultaneously considering important factors from both marketing and engineering domains (Luo 2011) considering the strategic reactions of incumbent manufacturers and retailers.

Among the works done for optimizing the product portfolio, few take the advantage of customer-perceived value; the work (Farrell and Simpson 2008) is an example that focuses on the set of components with the highest potential for cost savings, rather than redesigning the entire product line. More development potential for preserving customer-perceived variety exists, as it will help in offering the optimum number of products that is not necessarily equal to the number of market segments as the results of the study (Michalek et al. 2011) show.

Also, most of the studies that have included market systems into product development apply only to a single product, and there are numerous opportunities to cover in product family design. For example, Shiau and Michalek (2009b) studied two factors that affect design stemming from market systems: (1) the interaction structure between manufacturer and retailer and (2) the heterogeneity of consumer preferences in modeling. Such considerations can be applied to product family design as well.

1.3.3 Product Family Modeling

Modeling product families and platforms can serve as a basis for prior analysis of design, and it can play a significant role in the early stages of product family design and platform development prior to any redesigns or design implementations. The purpose of studies about family modeling can be identification of modules and unique components as Zhang et al. (2006c) have proposed to decrease the effect of module's internal behaviors on external interactions among them to decrease complexity of the modularized design. The applied approaches and their objectives can be summarized as follows.

An important yet not widely addressed issue in PFD is the end-of-life assessments for families. As the variants in a family will be taken out of the production cycle after their life, there might be plenty of opportunities for taking advantage of these designs and enabling economic recovery of the design for new generations. One study tackling this issue is Kwak and Kim (2011), which assesses the family design through a quantitative model from this perspective. Also, integration of life cycle management issues into mass customization (Zhang and Fan 2006) is to provide a multi-domain modeling of the product family architecture. There are some other important works that are listed below:

- Integration of product family data and process family data into a framework for product life cycle management (PLM) (Zhang et al. 2006b) to capture and reflect diverse relationships among model components and entities.
- Knowledge management framework development (Nanda et al. 2007) for capturing and translating the design information into a unified network, called *networked bill of material* (NBOM), for searching, reusing, aggregating, and analyzing design knowledge in a product family.
- Managing product variety and enabling efficient reuse of validated design and manufacturing data through a systematic modeling approach (Brière-Côté et al. 2010).
- Sharing of design data definitions through an extended generic product structure (Callahan 2006).
- Developing an assembly sequence model (Siddique and Wilmes 2007) to find the optimal assembly sequence which required the minimum modification of current assembly plant for adding new variants to the family based on the fact that adding a new variant needs prior considerations of cost and feasibility.

- Introducing a product family master structure (Yu and Cai 2009) to provide a basis for information reuse in product reconfiguration, using the component-based *design structure matrix* (DSM) to illustrate the hierarchical dependencies among structures and design processes.
- Developing *part relationship model* (Liu and Qi 2006; Fan and Qi 2007) for forecasting the component increase based on product proliferation through considering the evolving nature of part relations.
- Multi-agent approach for product family modeling in conceptual design (Ostrosi et al. 2011).
- Using a mathematical structure to serve as a basis for a product family algebra in features modeling (Höfner et al. 2011).

According to the literature, several attempts have been made to cover different aspects of product family design knowledge management; however, less attention has been paid to the data on the back-end stages of PFD, for example, knowledge and information about the supply chain (i.e., relations of different suppliers to efficiency of the product family and developed platform) or other examinations such as interdependencies and correlations of different stages of product family development to each other. Such issues can contribute significantly to efficiency of design solutions in the sense that they allow for more comprehensive considerations prior to decision-making and they provide the possibility of wider assessments in regard to the different stages involved in platform and family design and development.

1.3.4 Platform and Product Family Configuration

For configuration of product family and platforms, it is necessary to decide on which components or modules or features to be shared among the variants, and this requires consideration of different levels of commonality/customization. A comprehensive framework for platform planning is proposed (Chowdhury et al. 2011), which enables satisfying different market niches through a mathematical modeling in designing platforms. Their framework is called Comprehensive Product Platform Planning (CP^3). Key concepts and existing approaches for configuration design such as frame-based models, case-based reasoning, variable-oriented structure configuration, and process-oriented assembly configuration are discussed in Zhao et al. (2010), which proposes an approach called *Product Family Extension Configuration Design* (PFECD). *Extension theory* is used in their study, which allows analysis of adding elements/material/relations to existing products based on existing constraints and enables managing the trade-off between mass production and individual customization.

Appearance customization of the products has been considered as an industrial design issue in Liu et al. (2009), which proposed a *PFD DNA* method to develop new families inheriting characteristics of existing families, while creating unique style characteristics of their own.

Since variation in the product design information can adversely affect the efficiency of design and redesign of product families, finding ways to reduce such variation can be helpful. Thevenot and Simpson (2007b) investigated sources of variation when using the product line commonality index (PCI) for estimating commonality among family members. They provide guidelines for reducing the variation resulting from product dissection. Technology changes and changing market opportunities can also impact the efficiency of the developed platforms; and Rojas and Esterman (2008) developed an *impact assessment process* and presented remedial suggestions for cases in which varying conditions after developing platforms might result in efficiency loss. In a reverse case, the application and impact of platform strategy on marketing strategies, brand, and business processes have been studied (Thomas 2012), and it has been concluded that application of platform-based planning is important for product design.

Service family design is another application derived from PFD as defined in Moon et al. (2007) on the basis of platform-based design principles. Their study used the game theory to analyze different options in module selection based on different cost strategies and under conditions with uncertain and incomplete information. This new application can be a choice for future development of service families. Service families can result in efficiency improvements in service sectors due to standardization of processes, and cost savings resulted from unification of different service activities.

1.4 Product Family Design and Development Issues

The middle stages that connect the back-end to the front-end in product family design include all the approaches, techniques, and developments regarding the design and realization of the chosen functionality in a family of products. In order to facilitate design of a product family, concepts such as commonality versus modularity or variety and approaches for optimization of the family/platform design are fundamental. The research improvements and developments regarding such concepts are discussed in this section.

1.4.1 Commonality Versus Variety

Leveraging commonality can lead to remarkable cost savings and higher standardization of the product line. On the other hand, variety is desired because more variation results in more customer groups' coverage and satisfying specific needs of more customers. However, variety is in conflict with commonality. Jiao et al. (2007b) considered ten outstanding papers that have presented a view of the cutting-edge research studies in the area of commonality and modularity management. Among their reviewed papers, the work by Fixson can be highlighted, as it provides a comprehensive literature review on the approaches and techniques for