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## UNIVERSAL PRODUCT FAMILY DESIGN VALUATION IN AN UNCERTAIN MARKET ENVIRONMENT

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## ABSTRACT
Strategic adaptability is essential in capitalizing on future investment opportunities and responding properly to market trends in an uncertain environment. Customized products or services are an important source of revenue for many companies, particularly those working with in a mass customization environment where customer satisfaction is of paramount important. In this paper, we extend methods from mass customization and product family design to create specific methods for universal product family design. The objective of this research is to propose a valuation financial model to facilitate universal design strategies that will maximize the expected profit under uncertain constrains. Real options analysis is applied to estimate the valuation of options related to introducing new modules as a platform in a universal product family. We use customers' preferences based on performance utilities for universal design to reflect demand and demographic trends. To demonstrate implementation of the proposed model, we use a case study involving a family of light-duty trucks. We perform sensitivity analysis to investigate the behavior of the estimated option value against chaining system parameters.

## 1. INTRODUCTION
Design has been adapted to changing environments, such as customers' preferences, technologies, economic situations, company's strategies, and competitive moves. Strategic adaptability is essential in capitalizing on future investment opportunities and responding properly to market trends in a dynamic environment [1]. Customized products or services are an important source of revenue for many companies, particularly those working with in a mass customization environment where customer satisfaction is of paramount important. Mass customization depends on a company's ability to provide customized products or services based on economical and flexible development and production systems [2]. By sharing and reusing assets such as components, processes, information, and knowledge across a family of products and services, companies can efficiently develop a set of differentiated economic goods by improving flexibility and responsiveness of product and service development [3]. Product family design is a way to achieve cost-effective mass customization by allowing highly differentiated products to be developed from a common platform while targeting products to distinct market segments [4].

Persons with limitations due to age and disabilities are not a static population with static abilities. We will all likely be disabled at some point, be it temporarily through injury or permanently through injury or the effects of age. The number of people with a disability is between 40 and 50 million [5]. Based on current demographic trends, particularly the aging population, the numbers of people with disabilities is expected to increase, perhaps significantly, for the foreseeable future. Innovative companies that generate a variety of products and services for satisfying customers' specific needs are invoking and increasing research on mass-customized products, but the majority of their efforts are still focused on general consumers who are without disabilities [6, 7]. Universal design is a recently suggested term in designing products, systems, and environments for everyone as well as persons with a disability [8]. Universal design specifically suggests the concepts of

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equity and social justice. Also, in the context of separate is not equal, universal design suggests the design of solutions that simultaneously and equally serve both the fully able and not fully able.

In uncertain market environments, the valuation of a product increases flexibility in decision-making for developing new products or redesigning existing products and affects product life cycles [9, 10]. Real options valuation is a rigorous analysis that can be applied to developing a financial model for valuing, managing, and optimally exercising options [11, 12]. Real option analysis offers a natural framework to evaluate the valuation of product design by utilizing managerial flexibility in the valuation process [13, 14].

In this paper, we extend methods from mass customization and product family design to create specific methods for universal product family design. We use a module-based platform design approach by introducing common modules, variety modules, and typical modules for universal product family design. The objective of this research is to propose a valuation financial model to evaluate universal design value based on market mechanisms in an uncertain market environment. The proposed model is to facilitate universal design strategies that will maximize the expected profit under uncertain constrains, such as demand, demographic trends, and regulations. Real options analysis is applied to value options related to introducing new modules as a platform in a product family. In the proposed model, we use customers' preferences and performance utilities for universal design to reflect demand and demographic trends.

The remainder of this paper is organized as follows. Section 2 reviews related literature and background for universal design, product family design, and market based design approaches. Section 3 describes the proposed framework valuing universal product family design. Section 4 gives numerical analysis for design valuation and a case study involving a family of light-duty trucks. Closing remarks and future work are presented in Section 5.

## 2. LITERATURE REVIEW AND BACKGROUND

### 2.1 Universal Design

A team of researchers organized through The Center for Universal Design at North Carolina State University has created seven principles of universal design [15]. The seven principles are: 1) equitable use, 2) flexibility in use, 3) simple and intuitive use, 4) perceptible information, 5) tolerance for error, 6) low physical effort, and 7) size and space for approach and use. For each principle, several guidelines have been created. For example, principle 6 has a guideline of "minimize repetitive actions." These principles have been well received by designers in a range of disciplines. Though the seven principles of universal design provide high-level guidance, they provide more of an evaluation aid than a design or synthesis aid for product design. Vanderheiden [16] has developed a set of guidelines for the design of consumer products. Some of these guidelines are useful for evaluation but more challenging to use for product synthesis. Housed in the Center for Inclusive Design and Environmental Access at the University of Buffalo is an active group of researchers with focus on universal design [17, 18]. Though this group is focused on architectural design and comes from an architectural background, they have performed research on appliances and other applications that extend to product design. A team of researchers at the University of Cambridge has produced implementable results for universal design [19, 20]. The focus of this research group has been in modeling user groups, creating product assessment methods, and extending the needs of universal design to modern product design processes. The results of the Cambridge team are the most directly applicable to product design. Their effort has been primarily focused on the user and the design challenges of accommodating that user.

Universal design is an active research area. Nevertheless, fundamental work applicable to product design is still a sparsely populated space. Universal design is more of an objective than a systematic design approach. There is little in the way of a prescriptive approach to universal design in more detail than broad design objectives [21]. Additionally, though creating modular products that minimize modification to become universal is a recognized approach to universal design, specific knowledge and methods strategies to do it do not exist [20]. Methods that allow the design of universal products that offer value to the user and profitability to the producer have yet to be thoroughly developed.

### 2.2 Product Family Design

A product family is a group of related products based on a product platform, facilitating mass customization by providing a variety of products for different market segments cost-effectively [22]. A successful product family depends on how well the trade-offs between the economic benefits and performance losses incurred from having a platform are managed.

Simpson et al. [23] introduced a method to optimize a platform by minimizing performance loss and maximizing commonality based on a scale-based product family design approach. Gonzalez-Zugasti et al. [24] designed platform modules to minimize design risk and save costs related to develop a product family. Siddique and Rosen [25] described a method to design a platform from an existing group of products by comparing commonalities in assembly processes. Rai and Allada [26] used a two-step approach to determine a modular platform for a product family, which consists of an agent-based optimal technique and post-optimization analysis using the quality loss function. Johannesson and Claesson [27] proposed a configurable product platform design process and model using an operative product structure and a hierarchical function-mean tree to capture parameters describing design information such as rules, variants, requirements, and product configuration possibilities. Thevenot et al. [28] developed the design of commonality and diversity method (DCDM) to provide designers with recommendations for both the functional and component levels by the inherent tradeoff between commonality and diversity during product family and platform development. Moon et al. [29] introduced a market-based negotiation mechanism to support product family design by determining an appropriate platform level that represents the number of common modules using a dynamic multi-agent system in an electronic market environment. Zacharias and Yassine [30] proposed a mathematical model for developing and evaluating modular product families to provide maximum market coverage by integrating a conceptual design approach, a product development cost model, an economic model. Moon and McAdams [31] introduced a method for developing a universal product family through a game theoretic approach in a dynamic market environment by extending concepts from product family design to universal design.

## 2.3 Market based Design Approaches

Market based design approaches can provide the ability of investigating additional flexibility and strategic value in engineering design and product development. In engineering design, game theoretic approaches have been applied to model strategic relationships between designers for sharing design knowledge and solving design problems. Real options analysis is a decision-making method to evaluate design strategies that are affected by company's decision, competitors' action, and new technologies [1].

Xiao et al. [32] applied game theoretic approaches and design capability indices to model the relationships between engineering teams that were described as cooperative, non-cooperative, and leader/follower protocols, and facilitate collaborative decision making during a product realization process. Fernandez et al. [33] proposed a framework for establishing and managing collaborative design spaces by combining elements of cooperative and non-cooperative behavior, and formulating strategic and extensive games with utility theory. Kopin and Wilbur [34] introduced a Bayesian game to model cost sharing in uncertain and incomplete information that were related to producer and consumer attributes such as nature, production costs, players and information, and preferences. Correia [35] investigated the representation of incomplete and asymmetric information to model a strategic Bayesian game that was represented by the constraints of a transmission system and player's strategic reactions to estimate uncertainties. Lewis and Mistree [36] presented mathematical constructs for modeling a multidisciplinary optimization problem using game theoretic principles and the compromised Decision Support Problem (DSP) in a collaborative, sequential, and isolated design environment. Ford and Sobek [37] applied real options concepts to product development processes for managing uncertainty through flexibility impacts project behavior, performance, and value. Gamba and Fusari [13] proposed a stochastic dynamic framework for valuing the contribution of modularization process and modular operations in the design of systems using real options.

In a highly competitive market, universal design can be considered as appropriate marketing strategies by providing the broadest market segment [38]. A market-based design approach is one way to reflect dynamic and uncertain market environments in product design. In the next section, the proposed financial model for evaluating the valuation of universal family design is discussed in detail

## 3. UNIVERSAL PRODUCT FAMILY DESIGN VALUATION

To develop a financial model for evaluating design valuation, we propose relationships among a company, customers, and government in universal product development as shown in Figure 1. In the relationships, a company seeks to maximize profit based on product development cost, customers' purchase behavior, and government regulation. The customers' purchase behavior can be determined by maximizing performance measures that are represented as their needs and design quality. Government establishes policy and regulation related to products for maximize customers' welfare according to demographic trends and social issues. Demographic trends, social issues, and regulations can be critical constrains to determine design strategies for new products in uncertain market environments. To maximize the profit, the company tries to identify optimal investment time when universal design will be introduced into a product family with respect to customers' preferences, demographics, and regulations. We propose a financial model to investigate universal design strategies based on the value of the universal design using real option analysis in uncertain market environment.

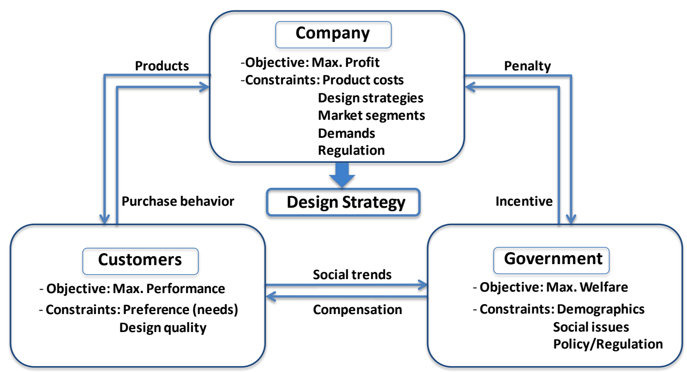


**Figure 1: Relationships among a Company, Customers, and Government in Universal Product Development**

## 3.1 Universal Product Family Architecture

The universal product platform framework is built on representing the product space in terms of five different modules: common modules, varietal modules, universal modules, accessible modules, and typical modules. The notion of common and varietal modules is generally a well understood concept in product family design. Common modules are those shared across the product family regardless of the module's characterization with respect to typical and accessible products. In general, these common modules are suitable candidates for establishing the product platform. Varietal modules refer to the differing elements used to introduce variety into a range of products in the family. The common elements plus the varietal elements combined create a product family. The framework used to design a product family here is modular, but the notions of common and varietal need not be limited to a modular framework.

A module based product family strategy allows for the design and production of economically viable universal product families. Specifically, modules for universal design can be categorized into: 1) universal; 2) accessible; and 3) typical modules. Universal modules are those that are the same in function and form for both typical and disabled users. Accessible modules provide specific functionality or form solutions for persons with limitations due to age and disabilities. Typical modules contain functional and form solutions, or both, that are not suitable for user with a disability.

The way in which the modules may interact to form different product families is illustrated in Figure 2. Approaching universal product family design with multiple notions of what constitutes common and varietal allows for the greater potential of leveraging economies of scale. Such thinking may be important when designers attempt to spread costs of an accessible module across as large a product family as possible.

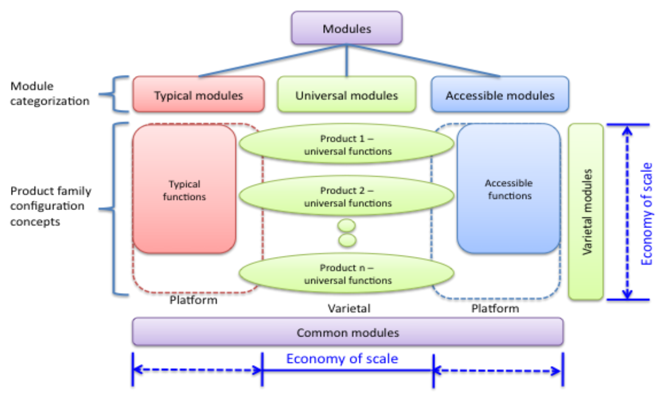


**Figure 2: Module categorization and platform based product configuration concepts**

### 3.1.1 A Module based Universal Product Family

The basic idea of modular design is to organize products as a set of distinct modules that can be designed independently and develop a variety of products through the combination and standardization of modules [39]. We assume that a product can be decomposed into modules that provide specific functions, and functions are achieved by the combination of the modules' design variables.

Suppose that a product family consists of $l$ products, $\mathrm{F} = (\mathrm{P}_1, \mathrm{P}_2, \dots, \mathrm{P}_l)$ and a product, $i$, consists of $m_i$ modules, $P_i = (x_{i,1}, x_{i,2}, \dots x_{i,m_i})$, where $\mathbf{x}_{i,j}$ is a module $j$ in product $i$ and consists of a vector of length $n_m$, $\mathbf{x}_{i,j} = (x_{i,j,1}, x_{i,j,2}, \dots, x_{i,j,n_m})$. The individual scalar components $x_{i,j,k}$ ($k$=1,2,…,$n_m$) of a module $\mathbf{x}_{i,j}$ are called design variables. Each module can be achieved by alternative instances. Let $b_j$ be an instance of module $j$ ($b_j$ = 1, 2, …, $B$) and $\mathbf{M}$ be a module instance matrix for the instances of modules in a product family. By introducing a module instance matrix $\mathbf{M}$, the product family is represented as:

$$\mathbf{PF} = \mathbf{MX} \quad (1)$$

where $\mathbf{M}$ is defined as:

$$\mathbf{M}_{i,j} = \begin{cases} b_j & \text{if module } j \text{ is used in a product } i \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

In the module instance matrix, if modules are designed by the same instance (i.e., common modules), then the number of $b_j$ is the same. And, the large number of $b_j$ indicates the number of alternatives in module $j$. Based on the proposed universal product family architecture, a module instance matrix can be represented as:

$$\mathbf{M} = \begin{bmatrix} \mathbf{M_{11}} & \mathbf{M_{12}} \\ \mathbf{M_{21}} & \mathbf{M_{22}} \end{bmatrix} \quad (3)$$

Where $\mathbf{M_{11}}$ and $\mathbf{M_{21}}$ are matrixes for universal modules, because the universal modules should be included in both typical products and accessible products. $\mathbf{M_{12}}$ is a matrix for typical modules, and $\mathbf{M_{22}}$ is a matrix for accessible modules in a product family.

### 3.1.2 Company's Profit Model

In this research, we use sales profits to evaluate company's profit. We assume that the price of a product is determined by the company based the product quality. The product quality can be represented as functions desired by customers. Then, the profit of product $i$, , $\pi_i$ can be formulated based on sales price, product cost, and demand as follows:

$$\pi_i = (S_i - C_i) D_i \quad (4)$$

where, $S_i$ is the sales price of product $i$, $C_i$ is the product cost of product $i$, and $D_i$ is the sales quantity of product $i$. In product family design, product cost depends on platform strategies and design quality. Generally, product cost can be determined by total expected product volume, material cost, direct labor, production resource usage, tooling and capitalization costs, system cost (overhead or indirect costs), and development costs [40]. Based on the proposed product architecture as mentioned in Section 3.1.1, product cost for product $i$ is represented by

$$C_i = \mathbf{M}_\mathrm{i} \mathbf{L}_\mathrm{i}' \mathbf{X}_\mathrm{i}' \quad (5)$$

where $\mathbf{M}_\mathrm{i}$ is a module instance matrix for product $i$, $\mathbf{L}_\mathrm{i}$ is a vector of module costs for product $i$, and $\mathbf{X}_\mathrm{i}$ is module design variables in product $i$. The module instance matrix is generated by a feasible set of products and includes a platform strategy to satisfy product requirements in a product family. In product family level, product cost using a platform strategy, $s_y$, can be represented as:

$$C(s_y) = \mathbf{M}(s_y)\mathbf{LX} \quad (6)$$

where $\mathbf{M}(s_y)$ is a module instance matrix when $s_y$ is used for product family design. The different platform strategies are constructed by combining the different typical, accessible, and universal modules into common and varietal modules as outlined above.

In product family design, problems related to determine a design strategy or the degree of commonality for a platform can be considered as an optimization problem with respect to design variables, production cost, company's revenue, and customers' satisfaction [29, 30, 41, 42]. For an example, the appropriate platform level for the universal product family can be represented as a mathematical programming model in which production costs are minimized, customer satisfaction is maintained, and profit is maximized [29]. The term platform level refers to the degree of commonality or the amount of common elements in the product family platform. A high platform level indicates more sharing than a low platform level. A well-defined platform reduces production costs by improving economies of scale and reducing the number of different components that are used [22, 29]. In the next section, we propose a financial model to evaluate the valuation of universal design in an uncertain market environment.

## 3.2 Financial Model for Universal Product Family Design Valuation

A company tries to maximize profit by identifying optimal investment time when universal design will be introduced into a product family with respect to customers' preferences, demographics, and regulations. We propose a financial model to evaluate the valuation of universal product family design using real options analysis in an uncertain market environment. In the proposed financial model, demand can be represented as the source of uncertainty and volatility in a market. We assume that the demand follows a Geometric Wiener Process and has drift, $\mu$, for the demand changing [43]. The drift is defined as:

$$\mu = r - \frac{\sigma^2}{2} \quad (7)$$

where $r$ is the riskless rate and $\sigma$ is the instantaneous volatility. Let $u$ be the rate of moving up, $d$ be the rate of moving down, and $ud$=1. The demand can move up, move down, or state constant at time $t$. The probabilities of movements for the demand at time $t$ can be obtained as follows [43]:

$$p_1 = \frac{1}{2\lambda^2} + \frac{\mu\sqrt{\Delta t}}{2\lambda\sigma} \quad (8)$$

$$p_2 = 1 - \frac{1}{\lambda^2} \quad (9)$$

$$p_3 = \frac{1}{2\lambda^2} - \frac{\mu\sqrt{\Delta t}}{2\lambda\sigma} \quad (10)$$

where $\Delta t$ is the length of each time interval and $\lambda \geq 1$. If $\lambda$ =1, $p_2$=0, and the movements of the demand become a binominal model [44].

We consider a profit model for a typical product. We assume that the demand, $D_t$, during time interval, $t$, is a variable in company's profit function. Let $S$, be the sales price and $C$ be the production cost. We assume that the sales price and the production cost are determined by the company. The production cost is represented as row materials, labors, logistics, assemblies, financial issues, and regulation. Profit, $V_{ty}$, for a typical product in time interval $t$ can be defined as:

$$V_{ty}(t) = (S - C)D(t) \quad (11)$$

Otherwise, we consider an accessible module that is applied to a universal product. Let $d_i$ be the rate of extra demand related to design quality for the universal product (refer to Section 3.3) and $v$ be the rate of variable production cost savings if accessible modules are applied to a product family. The demand of the universal product is affected by design quality related to customers' preferences for accessibility and usability. Let $U$ be the additional cost of introducing an accessible module per time interval. The additional cost is represented as the research and implementation costs of the new design. The profit per time interval $t$ for a universal product can be calculated as:

$$V_{un}(t) = S(1 + d_i)D(t) - (1 - v)(1 + d_i)CD(t) - U \quad (12)$$

Then, the net benefit from the universal design, $N_t$, for introducing an accessible module during time interval t can be represented as the maximum of the difference between two profit functions (11) and (12), and 0:

$$N_t = max(0, d_i SD_t + (v - d_i + vd_i)CD_t - U) \quad (13)$$

Interpreting Equation (13), positive values of the net benefit represent an advantage of universal design over typical design. If the net benefit is zero, the company selects a typical product to maximize the profit. The net benefit is affected by the volatility rate, the increasing demand rate, the saving cost of family design, and the additional cost. To evaluate the valuation of universal design with respect to customers' preferences and family design, sensitive analysis will be performed in Section 4. In this paper, we use a Lattice approach to solve the problem [14].

When $\lambda$=1, the valuation of an accessible module can be calculated by the value of call option based on the net benefit as follows:

$$F(t, N_t) = \frac{pN_t^u + (1-p)N_t^d}{(1+r_f^t)^{\Delta t}} \quad (14)$$

Where $p$ is a risk natural probability that is calculated by Equation (8) and $r_f^t$ is a risk-free interest rate at time $t$, $N_t^u$ is the net benefit of achieving the best case scenario with probability $p$ at time $t$, and $N_t^d$ is the net benefit of achieving the worst case scenario with probability (1-$p$) at time $t$. Figure 3 shows the binomial tree for assessing the call option. The next section introduces a design quality model for evaluating design performance in a universal product.

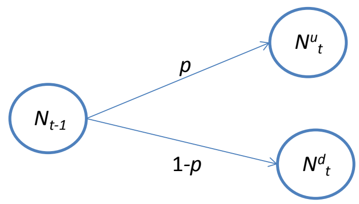


**Figure 3: Call Option Valuation in the Binomial Tree**

## 3.3 Universal Design Quality

Designers can evaluate design characteristics and functional needs for universal products using a usability testing and a participatory design model during the conceptual design phase [6, 45]. To evaluate and measure performance of a product, we propose a quality metric that is positively related to product quality, customer preference, and price. In this paper, we introduce two quality levels to determine the performance of a product: (1) marginal quality and (2) full quality. The marginal quality is defined as the level of quality that customers want to buy a product with their preference. Customers have zero preference if the quality of the product is below the marginal quality. Full quality is represented as the level of quality that customers are willing to pay the price for purchasing a product. The full quality is defined as full typical quality or full accessible quality depending on customers' group. In between marginal and full qualities, customers have various preferences related to product's quality as shown in Figure 4.

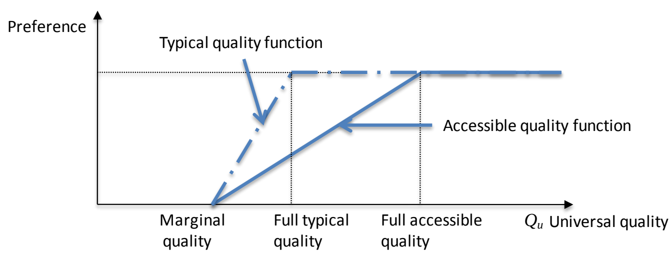


**Figure 4: Relationship between Preference and Quality for a Universal Product**

We assume that the quality of a universal product consists of typical and accessible qualities. To determine the value of customers' reference related to the universal quality, $Q_u$, we assume that customers in the market are categorized into two homogenous customers, typical and accessible groups. The value of the preference, $U(Q_u)$), can be represented by a utility function as follows:

$$U(Q_u) = \begin{cases} 0\,, & if\ Q_u \le Q_M \\ \frac{f_{t,q}(Q_u)+f_{u,q}(Q_u)}{2}\,, & if\ Q_M < Q_u \le Q_F^T \\ \frac{1+f_{u,q}(Q_u)}{2}\,, & if\ Q_F^T < Q_u \le Q_F^A \\ 1\,, & if\ Q_F^A < Q_u \end{cases} \qquad (15)$$

where $Q_M$ is the marginal quality of a product, $Q_F^T$ is the full quality of a product for a typical customer group, $Q_F^A$ is the full quality of a product for an accessible customer group, $f_{t,q}$ is a typical quality function and $f_{u,q}$ is a accessible quality function. The accessible quality represents the interaction of product features and product accessibility: it is a measure that indicates what product features are needed to make a product accessible to individuals who have a functional limitation as defined in the World Health Organization's International Classification of Functioning, Disability, and Health (ICF) [46]. To determine the accessible quality, we can use the Feature-Universal Principles Matrix (FUPM) proposed by Moon and McAdams [31]. This matrix is based on impairment and usability measures developed in the ICF [46] and the seven principles of universal design [15, 47]. The FUPM is used to evaluate a design with respect to a specific functional limitation is defined by the ICF [46]. In terms of product family design, this measure allows us to explore how a particular product platform can best be used to develop a family that provides high accessibility to a large set of users.

In general, market demands can be affected by the quality and price of a product [48]. To determine the expected demands for introducing universal design at a specific time, we can use the expected preference value and demographics (potential customers) in market segmentation grids that are covered by a product [31]. The demands of product *i* at time interval *t*, $\alpha_i(t)$, is formulated as follows:

$$\alpha_i(t) = \sum_{i \in M_i} (U_i \times \beta_i(t)) \qquad (16)$$

where $M_i$ is the set of the market segmentation grids for product *i*, $U_i$ is the expected preference value of product *i* in $M_i$, and $\beta_i(t)$ is the demographic in the market segmentation grids for product *i* at time interval *t*. Based on the expected demand, we can estimate the expected increasing demand rate of a specific product for applying to the proposed financial model. The next section discusses government regulations related to universal products.

## 3.4 Government Regulation

Regulations can influence companies' decisions for product design and production planning by imposing penalties and incentives. The US government has encouraged reducing barriers in using technologies for persons with disabilities through regulations [7]. Since the 1964 passage of the Civil Rights Act, significant advances have been made with respect to the rights of persons with disabilities. As the Civil Rights Act fostered the Rehabilitation Act of 1973 and more recently 1990's American with Disabilities Act (ADA), activists working with government have legislated the inclusion of persons with disabilities fully into all facets of living [49]. For an example, The American with Disabilities Act of 1990 has stipulated that environments accommodate persons with disabilities. Since many persons with disabilities need specific equipments for their motor vehicles, three of the major U.S. automotive manufacturers, General Motors, Ford, and Chrysler, support vehicle owners by offering “rebates” or reimbursements for a portion of the cost of the specific equipments [50]. As a regulation method, a tax can be imposed on manufacturers based on evaluating the safety and accommodation of vehicles for persons with disabilities and used to force more universal products into the market. We introduce three regulation methods that can be used to define penalties and incentives for companies as follows.

- Incentives: Government offers incentives to a company or reduces tax when the company provides customers with universal products subject to government regulations.
- Tax (Penalties): A company pays tax to government when the company produces products that do not meet government regulations.
- Rebates: A company gives rebates to a customer. A company produces products that do not meet government regulations, but supports a portion of the expense of specific equipments to the customer.

Government regulations can affect to design strategies and customers’ purchase behaviors. In this research, we consider the effect of the regulations as an additional cost for introducing an accessible module in the proposed financial model. In next section, the proposed financial model is applied to determine the valuation of a platform strategy using a case study involving a family of light-duty trucks.

## 4. CASE STUDY

To demonstrate and validate the proposed model, we performed a case study involving the family of automobiles. Automobile companies provide adjustable features in seats, steering wheel, mirrors, dashboard light level, and floor pedal placements (brakes and accelerator) for adapting to a much wider spectrum of people [51]. We consider a following scenario for the case study. As the demand of light-duty trucks such as sport utility vehicles, vans, and pickups with high floor levels is continuous increasing, an automotive company is planning to develop a new product platform that can provide with significant benefits to customers with a disability or older persons. The new platform will be applied to the light-duty trucks for older customers who have difficulty getting in and out of these vehicles. Because the high floor level is barriers to enter and exit the vehicles, a swivel seat is considered a platform for the family of light-duty trucks. The swivel seat offers the opportunity to create a universal product family with the common feature that constitutes the product platform.

The objective in this case study is to determine the valuation of a new platform strategy in uncertain market environments. The platform design strategy is represented by accessible modules to support persons with limitations due to ageing and disabilities. This case study focuses on introducing a new product platform through the addition of accessible modules. Benefit of the proposed product platform is based on the maximum valuation of the proposed additional module. We also perform sensitivity analysis for the valuation of the platform design strategy with respect to different parameters that reflect the proposed financial model.

### 4.1 Market Analysis and Design Quality

In this paper, we selected Ford’s light-duty trucks for the case study as shown in Table 1. Table 1 shows current market segmentation for the light-duty trucks and MSRP in 2009. The company wants to maximize profits by developing a platform as an accessible module for the family of light-duty trucks.

**Table 1: Models of Light-duty trucks and MSRP (2009)[1]**

| Model | Market segmentation | MSRP |
|---|---|---|
| F-150 | Pickup | \$21,380 - \$39,010 |
| Edge | Cross-over | \$26,920 - \$35,770 |
| E-150 | Minivan | \$25,250 - \$30,165 |
| Explorer | Midsize SUV | \$28,880 - \$38,200 |
| Escape | Small SUV | \$20,550 - \$27,055 |

The trucks’ high level floors cause difficulties in ingress and egress for persons with aging and disabilities. We assume that the company develops a swivel seat for applying to the high-duty trucks as a platform. For evaluating the preference of comparing to a typical seat and a swivel seat, we use the expected design quality for the easy of ingress and egress. Table 2 shows the accessible quality of the swivel seat based on the Feature-Universal Principles Matrix (FUPM) [31]. In FUPM, a represents the degree of importance for function in terms of accessibility and λ is the important weight of universal principles in terms of function. We assume that the values of usability levels for a typical seat and a swivel seat are 2 and 4, respectively. Therefore, the quality of the typical seat design is 66 and the quality of the swivel seat design is 360. Figure 5 shows the function of design quality for the seats based on FUPM. Preference values of the typical seat and the swivel seat can be calculated by Equation (15) and the preference values are 0.108 and 0.78, respectively. Applying the swivel seat, the preference of light-duty truck was increased as 0.78 based on the expected universal design quality.

**Table 2: Functions-Universal Principles Matrix for Seats**

| Function | *a* | Equitable use | Flexibility in use | Simple and intuitive use | Perceptiable information | Tolerance for error | Low physical effort | Size and space for use | Functional accessibility level value | Usability level value |
|---|---|---|---|---|---|---|---|---|---|---|
| Typical seat | 2 | 10 | 10 | 0 | 0 | 0 | 10 | 3 | 33 | 2 |
| Swivel seat | 5 | 25 | 25 | 0 | 0 | 0 | 25 | 15 | 90 | 4 |
| λ | - | 5 | 5 | 4 | 2 | 2 | 5 | 3 | - | |

[1] www.ford.com

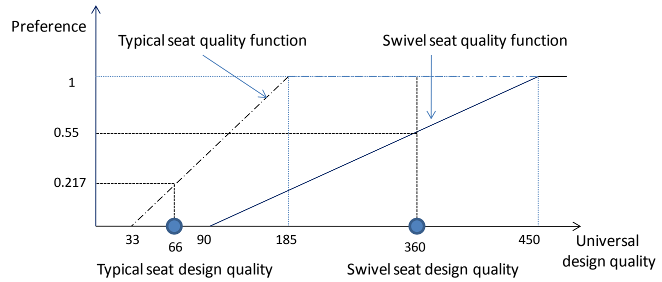

**Figure 5: Preference and Universal Design Quality for Seats**

## 4.2 Numerical Analysis

To evaluate the valuation of a swivel seat for the family of light-duty trucks, Escape was selected for applying to numerical analysis based on the proposed financial model. In 2009, the sale volume of Escape[2] was 173,044. We assume that the total time horizon for the problem is ten years and the time interval is one year. Suppose that the problem parameters at the current time ($t$=0) in the case study are as follows:

$S$ = \$30,000 (Sales price)
$C$ = \$24,000 (Production cost)
$D_0$ = 173044 (Demand at $t$=0)
$U$ = \$10,000,000 (Additional cost for introducing a swivel seat)
$\mu$ = 5% (Riskless rate)
$\sigma$ = 10% (Volatility)
$u$ = 1.0226 (the rate of move up)
$d$ = 0.9729 (the rate of move down)
$d_i$ = 3% (the rate of the expected increasing demand rate)
$v$ = 2% (the rate of cost saving for product family)
$r_f^t$ = 5% (the rate of a risk-free interest at time $t$)

We assume that $\lambda$=1. Then, the probabilities of movements for the demand can be calculated by Equations (8) and (10). Therefore, $p_1$=0.5712 (move up) and $p_3$ =0.4288 (move down). Using use a Lattice approach, the valuation of real option for a swivel seat is estimated to be \$106,579,935. This value is represented as the expected worth of introducing an accessible module as a platform for the family of the light-duty trucks for 10 years. A binomial lattice with ten time steps and 66 nodes is generated to estimate the valuation of the module as shown in Figure 6.

We performed sensitivity analysis to investigate the behavior of the estimated option value against chaining system parameters such as the volatility of demand, the rate of the expected increasing demand, and the rate of cost saving for product family. Figure 7 shows the estimated option value against the volatility of demand. The estimated option value is dropped with an increasing rate while the volatility increases. Figure 8 presents the estimated option value versus the rate of the increasing demand that occurs with customers' preferences and demographic trend. Design quality gives positive effects on the option value. Figure 9 shows the effect of the rate of cost saving for product family on the estimated option value. While the rate of the cost saving increases, the option value increase linearly.

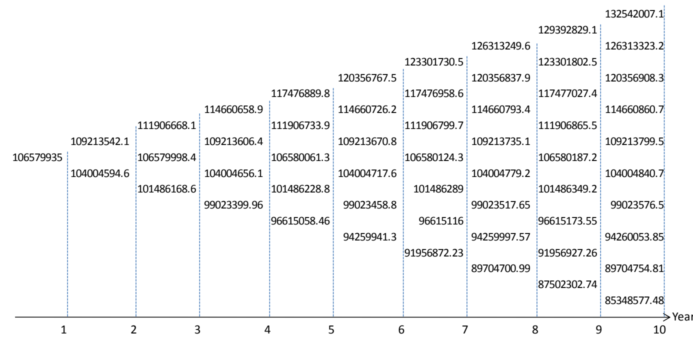

**Figure 6: Option Value for Universal Design in the Binomial Lattice**

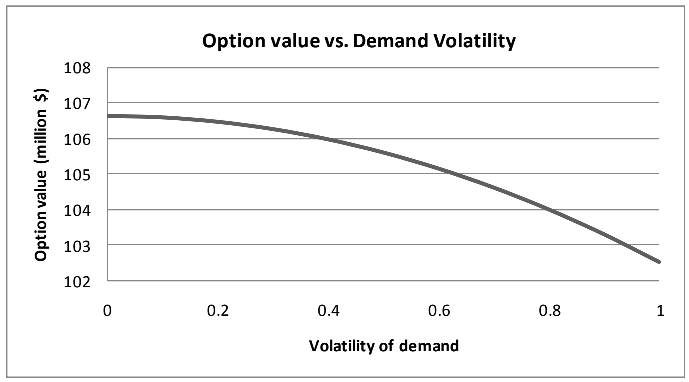

**Figure 7: The Estimated Option Value versus Volatility of Demand**

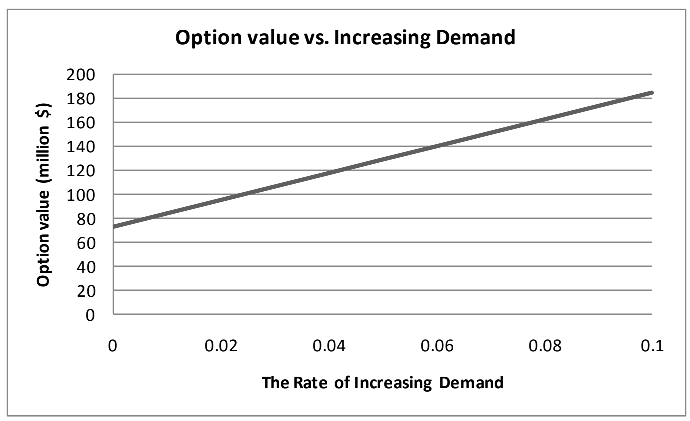

**Figure 8: The Estimated Option Value versus the Rate of Increasing Demand**

[2]http://online.wsj.com

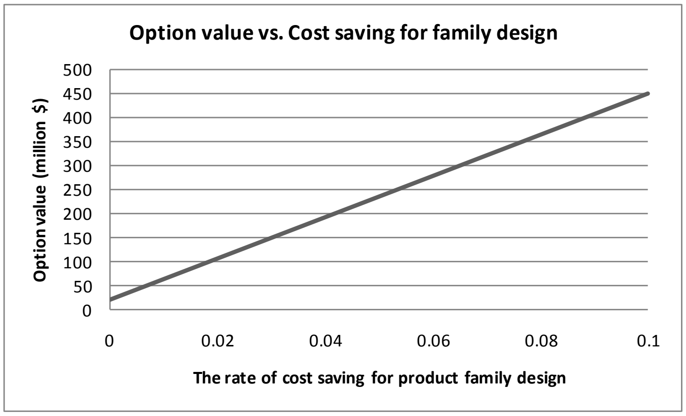


**Figure 9: The Estimated Option Value versus the Rate of Cost Saving for Family Design**

Through the case study, we demonstrate that the proposed valuation model for a module could be used to determine a design strategy for maximizing profits by valuing the module in the family of universal products. The proposed model can provide a quantitative method to facilitate universal family design in an uncertain market environment.

## 5. CLOSING REMARKS AND FUTURE WORK

In this research, we presented a valuation financial model to evaluate universal design value based on real options analysis in an uncertain market environment. Real options analysis is applied to evaluate the expected worth of introducing new modules as a platform in a product family. Modular product architecture was used to allow a range of trade-offs in determining the specific configuration for a platform at a conceptual design phase. Additionally, modular product architecture may be used to better leverage accessible and universal modules across multiple economies of scale. To evaluate and measure design quality of a universal product, we proposed a preference function using a well-established and thorough representation and rating method from the ICF. We have discussed regulation methods that affect product design and development using penalties and incentives.

The proposed financial model can facilitate design strategies that will maximize the expected profit under uncertain constrains, such as demand, demographic trends, and regulations. Via a case study, we have applied the proposed model to determine the valuation of an accessible module for a platform in a family of light-duty trucks in an uncertain market environment. We also performed sensitivity analysis to investigate the behavior of the estimated option value against chaining system parameters.

To improve the proposed model, we need to develop a method to better reflect the benefit of family design, social issues and government regulation. Additionally, since the production cost are sensitive to the valuation of options, future research efforts will be focused on improving production cost models in an uncertain market environment. Also, the proposed method will be compared to other decision-making methods for determining a design strategy in a universal product family.

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