Using Simulations to Define the Product Development Strategy Expected to Achieve the Shortest Time to Profitability

Jeffrey R. Boyer and John F. Elter

Plug Power Inc.
968 Albany Shaker Road
Latham, New York, USA 12309
(V) 518-782-7700
(F) 518-782-7961
jeff_boyer@plugpower.com
john_elter@plugpower.com

Abstract

Small entrepreneurial companies are challenged by the need to achieve the fastest path to profitability within the constraint of limited resources. Such companies often face a situation in which resources must be allocated among multiple products, or platforms, as the company engages new markets. These allocations must be made within the context of new and complex technologies and products and uncertainty in market adoption rates. In this paper, a system model is proposed that will identify a product development strategy that minimizes the time to profitability given the constraints of fixed resources and assumptions regarding key parameters such as product development time, market adoption rates, and cost learning curves. This model is used to compare a platform development strategy for products of varying newness, complexity, and potential profitability with one of developing the same products independently. By accounting for product lifecycles, the model considers parallel and serial product development.

Keywords

Product development; time to profitability; time to market; newness; complexity; small business; platform; architecture.

1.0 Introduction

There is constant pressure on companies by investors to shorten the time to reach profitability. Management literature is filled with methods to reduce the time to market for new products without sacrificing product quality and performance (Cooper et al. 1998; Cooper 2001; Gawer and Cusumano 2002; Leifer et al. 2000; McGrath 2001; O'Grady 1999; Patterson 1993; Rautianinen et al. 2000; Shane and Ulrich 2004; Smith and Reinertsen 1998; Thakker et al. 1998; Ulrich and Eppinger 2000; and Wheelwright and Clark 1992); the benefits of being first to market or a fast follower continue to be debated. However, the time to profitability is particularly problematic for small start-up companies, especially those pursuing disruptive technologies. These companies are exploring new and unknown opportunities with limited resources.

Time to profitability is a consequence of a company's product development strategy and how it allocates available resources to develop and produce those products. Product development strategies may reflect a series of independent products or a set of products based on an integrated, architected platform. Work effort will depend upon the newness and complexity of the products to be commercialized. The combination of work effort and availability of resources in turn will drive the time to market for new products. Thus, it stands to reason that the development of platform products should reduce the overall work effort required to bring new products to market, making this approach more conducive to operation with limited resources, *cetera parabis*.

Unfortunately, for many start-up companies, the markets for their new products are uncertain. In addition to the possibility of poorly defined product requirements, market size and adoption rates will be unknown. Product development strategies involved in development of disruptive technology will be especially hampered by this uncertainty. Opportunities may be lost during the time required to develop architected platform products; conversely, commercialization of independent products may accelerate sales and revenue generation while resulting in higher development costs that cannot be recovered. Confounding this is the fact that different products may have different price points and different profit margins. Net income will be the penultimate reflection of the success of the product development strategy.

In this paper, we examine the impact of product strategy on the time to profitability for a small entrepreneurial company. Although much work has been done on this subject, as already cited, we are the first to model the dynamics of parallel product development efforts and different development strategies. We examine the results of different strategies within the context of a small company with opportunities in related, but distinct, market segments. This company is pursuing new-to-the-world products; however, our model applies equally well to companies developing products that are not very new. Work effort, resource allocation, and time to market are determined for a number of product strategies, along with the corresponding development costs. Upon product launch, revenues are determined for each product according to the market adoption rate. The resulting combination of development costs, product revenues, and profits is a cumulative net income for the company. Using the results of this dynamic model, we identify the strategy that shortens the time for the company's cumulative net income to become positive.

2.0 Platforms, Architecture, and Products

The motivation behind this work is the demonstration of the influence of product development strategy on the time to profitability. Two types of strategies are considered in the analysis. The first is development of architected platforms delivering multiple products. The second strategy is independent development of the same stream of products.

A platform is best described as "an evolving system made of interdependent pieces that can each be innovated upon" (Gawer and Cusumano 2002). Platforms are defined by a set of architectural rules and a set of technologies (McGrath 2001). The combination of Microsoft's Windows operating system with Intel's processors, and Chrysler's series of K-cars are two notable examples of platforms.

Platform or system architecture represents the high-level arrangement of functions, technology, and interconnections within a system. System architecture thus provides structure by defining how subsystems and components will interact. Within the system, related functions may be grouped together into modules, each with its own set of technologies and well-defined functional and interface requirements. For example, automakers divide cars into modules such as the drive train, the electrical system, and the cockpit.

Modularity enables the production of a variety of products from one platform (McGrath 2001; O'Grady 1999). Different combinations of modules result in products with different feature sets meeting distinct application and market requirements. By changing the technology within certain modules, additional product differentiation and new market opportunities are possible. Ford Motor Company's Lincoln LS, Thunderbird, and Jaguar S-type are all based on the same platform and have some common components (Connelly 2002); however, by varying the engines, suspensions, interiors, and other components, each car can be tailored to offer different value propositions.

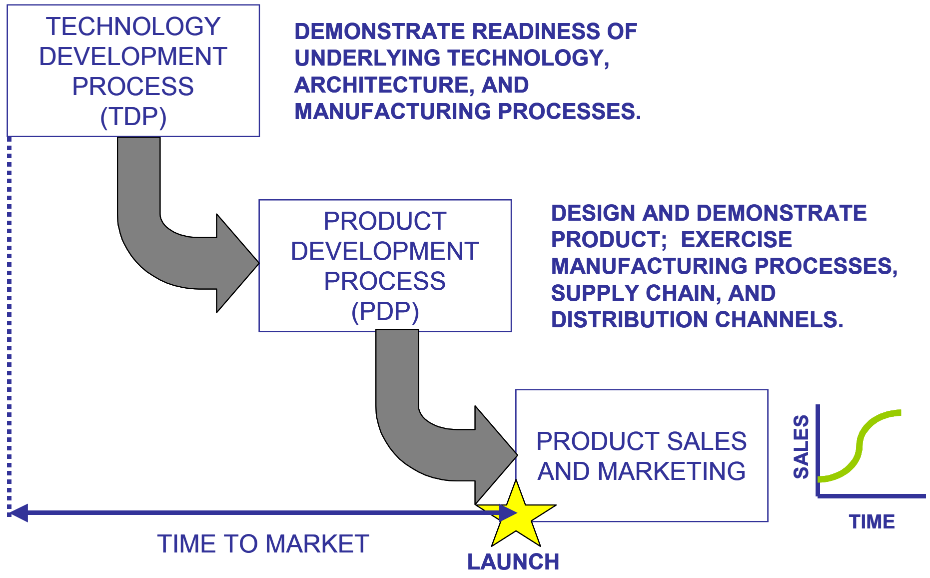
The second strategy often pursued is independent development of point products. Point products, unlike platform products, are developed with little or no commonality of design, technology, or components. They are generally limited in their scalability and extensibility over some key performance metrics. This strategy may shorten the time to market for a given point product aimed at a particular market segment, but may require more resources to cover the same overall market space. Since different products may have different adoption rates and command different profit margins, time to profitability may therefore be longer with this strategy. It is this balance of product development strategy and market adoption that is necessary to ensure continued viability of the company.

3.0 Development and Commercialization Processes

For most new products, development and commercialization may be divided into three overarching phases – technology development, product development, and sales – as shown in Figure 1. This division greatly simplifies the actual activities that a company undertakes, but it does allow these three types of activities – research, engineering, and manufacturing – to be explicitly represented in the model without influencing the conclusions.

In the technology development process (TDP), new technologies are investigated, evaluated, and demonstrated. Technologies include components, designs, modules, software, and control methods. TDP results in an understanding of the critical parameters governing a technology, operating latitude of the system, and manufacturing process capability. The outcome of the TDP process is proof of the technical readiness of new technologies for use in new or existing products.

The product development process (PDP) represents the activities necessary for successful launch of a new product, and takes advantage of the output of the technology development process. PDP generally begins with a market attack plan and determination of customer requirements, and ends with the company ready to manufacture, distribute, and service the new product. During PDP, the product design is finalized, manufacturing processes are developed and implemented, the supply chain is fully engaged, and distribution and service channels are established. For the purposes of this work, prototype demonstrations and early customer acceptance testing are conducted during the PDP. In some organizations, the early phases of PDP may be done concurrently with TDP, further accelerating time to market.



<u>Figure 1</u> – A simplified view of the major steps in the development and commercialization of new products. In practice, each of the TDP and PDP processes may involve multiple stages.

Upon completion of PDP, the product is considered launched, or commercially available. Product adoption in this model is assumed to follow the Bass diffusion model. Revenue generation is assumed to occur only in this phase for each product. Revenues depend upon adoption rate; net income and profitability for the company depend upon the accumulation of profits from products sold.

4.0 Model Description

The model presented determines the dynamic allocation of resources, completion of work, and product sales for up to three parallel projects within a company. From these results, cumulative net income is generated, producing an estimate of the time to profitability. The data used in this model are representative of a small company ("Company X") attempting to commercialize several new products for a variety of markets.

4.1 Complexity, Newness, and Work Effort

For each new product, the work effort, *E*, required to complete the technology development and product development processes is a function of its complexity, *C*, and its newness, *N*. Product complexity is a quantification of the interactions and interrelationships within the product (Lebcir 2002). Complexity reflects the interconnectivity between components of the product. Newness compounds complexity because of the unknowns associated with innovation. For products of equal complexity, different degrees of newness will require different levels of work effort. We therefore segregate these two parameters in estimating total development work effort for a new product.

Complexity has been found to be dependent upon the number of lines of code for software (Boehm 1981), the number of parts in mechanical systems (Dean 1991), and the number of functions a product must perform (Bashir 2000). In each of the cases considered, the relationship between the work effort required to develop a new product and the complexity of the product was found to be of the general power law form

$$E \sim aC^{b} \tag{1.1}$$

with no consideration given to newness of the product. To obtain this relationship for Company X, we examined the company's past and current product development activities. Company X has commercialized or is actively developing five different products, all of which are considered highly new. We represent the relative complexity of these products on a relative scale of 1 to 9; *low*, *medium*, and *high* complexities are assigned values of 1, 3, and 9, respectively. The resulting relationship is shown in Equation 1.2 and is of the form expected.

$$E(man-weeks) = 1652C^{1.113} \tag{1.2}$$

The second dimension of work effort is the newness of the product or the underlying technology within it (Cooper 2001; Lebcir 2002). Newness is considered to comprise two contributors – market newness and technology (or company) newness (Cooper 2001). Although some authors (e.g., Jin 2000) suggest three factors – new to the company, new to the market, and new to technology – a two-factor model is deemed satisfactory for this model. The amount of work required to develop products of equal complexity will vary in proportion to the amount of new knowledge (technical or market) needed. Therefore, Equation 1.2 holds for products with high newness and must be modified to reflect other degrees of newness.

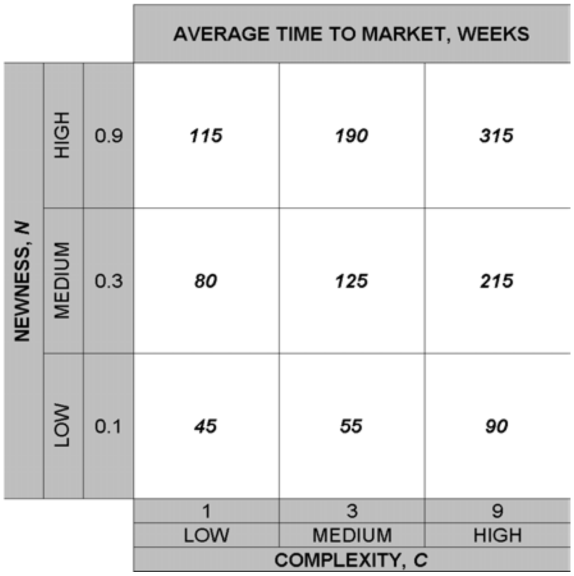
To determine the effect of newness on work effort, an overall newness reflecting the combination of market and company newness must be calculated. We derive such a relationship by first assuming that each newness factor reflects uncertainty. In the case of the two-factor model, these would be uncertainty of market acceptance and uncertainty of technology and product development, each of which is represented on a scale of 0 (not new at all) to 1 (completely new) such that the greater the uncertainty, the higher the value of newness.

Extending this further, we maintain that uncertainty represents risk. Thus, this is the risk of unsuccessful market acceptance or the risk of delayed technology readiness demonstration or slips in the product development schedule. Since risk is a probability, market newness and company newness may be combined into an overall risk of failure or overall newness, N_i, as

$$N_i = N_{m,i} + N_{t,i} - N_{m,i}N_{t,i} \tag{1.3}$$

for the combined probability of two independent probabilities (Hines and Montgomery 1990), where $N_{m,i}$ and $N_{t,i}$ are the market and technology (or company) newness factors, respectively, for product *i*.

The effort-complexity relationship shown in Equation 1.2 is for Company X products deemed to have an overall newness of 0.9. For products of equal complexity, differences in the time to market (TTM) reflect differences in work effort. To estimate the effect of newness on this relationship, data from a benchmark study of time-to-market for a number of commercial products (Elter 2001) were used (Figure 2) because insufficient data are available from Company X. The average time-to-market is shown in Figure 2 for nine combinations of newness and complexity; these parameters are represented in qualitative terms of low, medium, and high.



NEWNESS, *N*		AVERAGE TIME TO MARKET, WEEKS		
HIGH	0.9	*115*	*190*	*315*
MEDIUM	0.3	*80*	*125*	*215*
LOW	0.1	*45*	*55*	*90*
		1	3	9
		LOW	MEDIUM	HIGH
		COMPLEXITY, *C*		

***Figure 2** – Average time to market for commercial products as a function of product newness and complexity.*

Since it is assumed that the different times to market for products of a given complexity (Figure 3) result from differences in product newness, a newness factor, F_N, may be derived to reflect the underlying variation in work effort. The ratio of work effort relative to highly new products (N ~ 0.9) is shown in Figure 4; curve fitting leads to a newness factor of

$$F_N = 1.117 N^{0.5081} \tag{1.4}$$

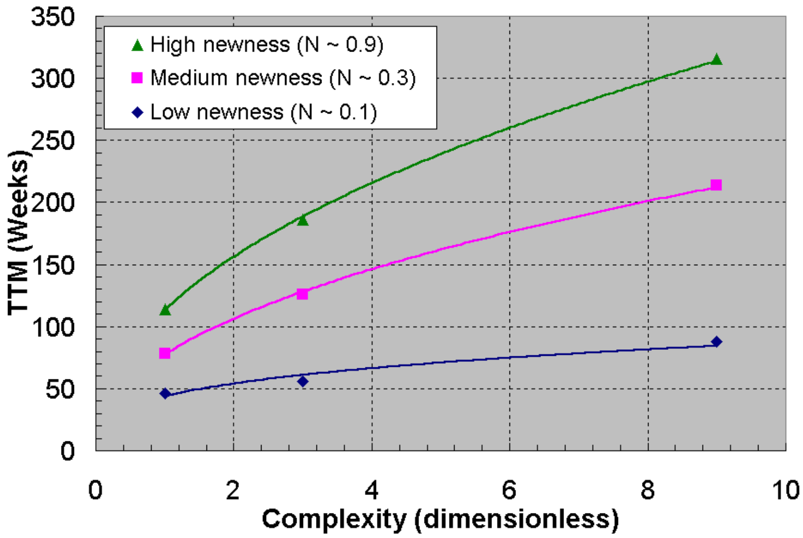


Figure 3 ***– The impact of product newness and complexity on the time-to-market for new products is shown. For a given complexity, TTM increases with newness because of the additional work required to address new technical or market requirements.***

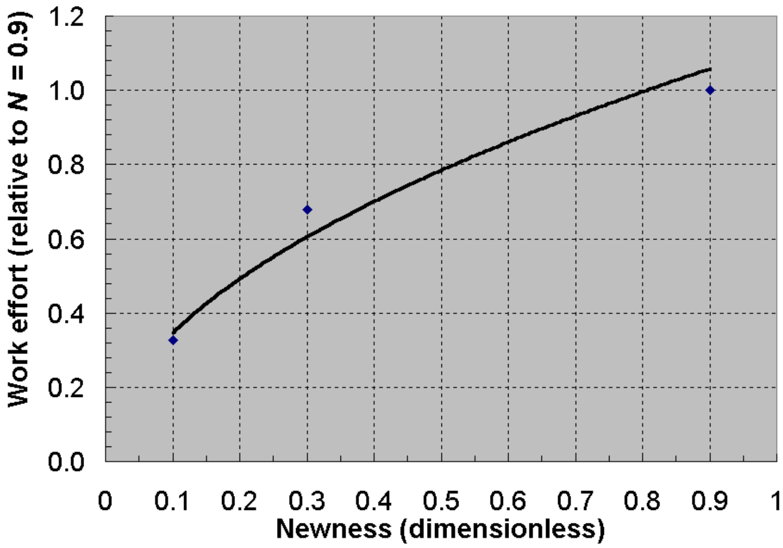


Figure 4 ***– The effect of newness on work effort is shown relative to the work effort required for highly new products (N ~ 0.9). These results may be used to generate a newness factor, F_N, for use in estimating total work effort required to launch a new product (see equation 1.5).***

Combining Equations 1.2 and 1.4 results in a relationship for estimating the product development work effort at Company X as a function of complexity (on a 1 to 9 scale) and newness (on a 0 to 1 scale). This relationship must be modified for other companies based on their experience or by using benchmark data as appropriate. For Company X, Equation 1.5 may not be accurate because it is not based on company newness data.

$$E(man-weeks) = 1845C^{1.113}N^{0.5078} \tag{1.5}$$

Because tasks are not all of the same duration nor do they require the same level of staffing, work effort is measured in man-weeks rather than tasks. The rate of work completion is therefore simply the number of resources (as full-time equivalents, FTEs) applied to the program (man-weeks/week is FTE).

4.2 Resource Management

Resources are assumed to be allocated to each development project based on a prioritization of products. We assume that small companies are limited in how many product development projects they can successfully manage (*n* projects). These projects are prioritized, with resources allocated to each project based on priority and the total number of resources available, *A*. For simplification, the model assumes that resources are generally fungible, with limited need for specialists for any of the product development projects. This enables free flow of resources from one project to another as work is completed. Further, only development resources are explicitly considered in the model; manufacturing resources, service personnel, and engineering support are assumed included in the revenue and net income calculations.

For each project, the required resources for each phase are defined. Thus, r_{ij} represents the required resources for phase *j* of product development project *i*, where *i* = 1, 2, …, *n* and *j* = 1, 2 (TDP and PDP, respectively). The applied resources, a_{ij}, for project *i* in phase *j* are then determined as follows:

$$\begin{aligned}
&a_{1j} = MIN\left(r_{1j}, MAX\left(A, 0\right)\right), j = 1,2 \\
&a_{2k} = MIN\left(r_{2k}, MAX\left(A - a_{1j}, 0\right)\right), j = 1,2, k = 1,2 \\
&a_{3l} = MIN\left(r_{3l}, MAX\left(A - a_{1j} - a_{2k}, 0\right)\right), j = 1,2, k = 1,2, l = 1,2 \\
&... \\
&a_{np} = MIN\left(r_{np}, MAX\left(A - a_{1j} - a_{2k} - ... - a_{(n-1)q}, 0\right)\right), j = 1,2, k = 1,2,..., q = 1,2
\end{aligned} \tag{1.6}$$

Note that the subscript *i* in equation 1.6 refers to product development activities in priority order: 1 = highest priority, *n* = lowest priority.

As priority decreases, so does the number of resources available for remaining projects. The *MIN* function limits the total number of FTEs applied to a particular program to only the number required, while the *MAX* function ensures that only non-negative values are used. Figure 5 shows the resource management module for the model. As work in each phase is completed, resource requirements and resource allocations are updated to reflect the needs of the remaining development projects. If the total number of resources applied to the n products is less than the number of available resources, the remainder is applied to a fourth project, which is assumed to represent long-term development activity.

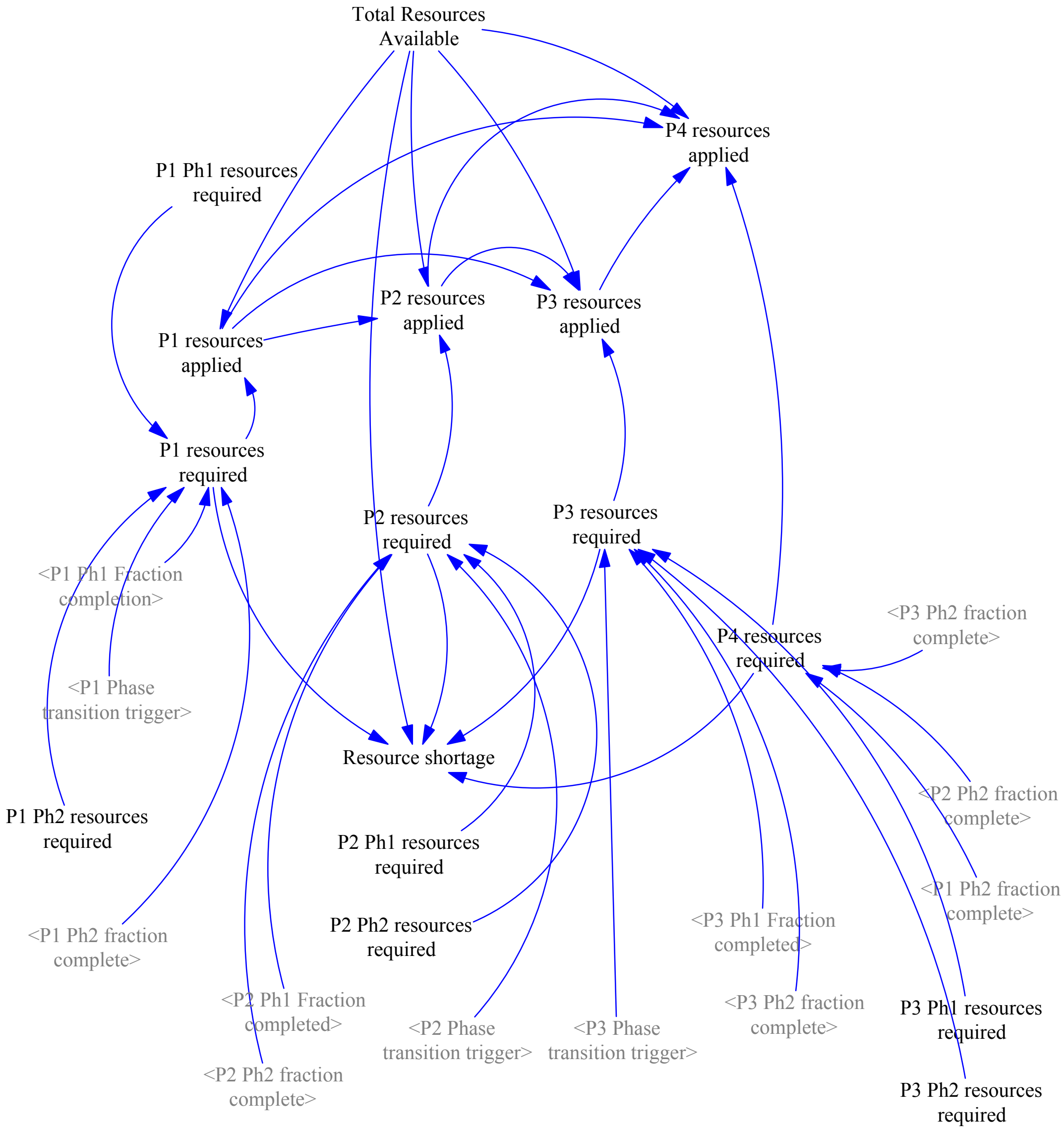
4.3 Schedule Slip

As previously discussed, newness represents a probability of failure. This probability is used to estimate delays in completing work. These delays represent unplanned activities associated with fire fighting, unforeseen technical hurdles, difficulties in conducting experiments, and other diversions from the development programs. Our model does not explicitly model all of these “distractions” from the planned work; we consider that these diversions of manpower and needs for rework ultimately result in accomplishment of less planned work than expected, which in turn increases the time to complete this required work.

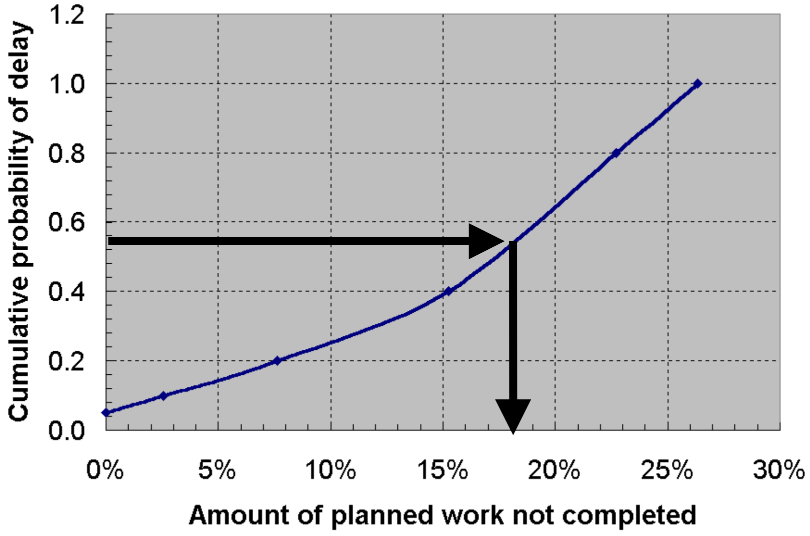
Schedule slip is assumed to occur randomly. During each time step, a random number is compared with the overall newness of the product. Slip is assumed to have occurred if the random number exceeds the overall newness. Thus, as newness increases, the likelihood of problems and associated delays increases.

Similarly, the magnitude of schedule slip is assumed to be random over a finite range representing a fraction of the time step. Figure 6 illustrates the probability of schedule slips that is considered representative of Company X’s past performance. In each time step, a random number between 0 and 1 is generated and used with the data in Figure 6 to determine the preliminary amount of schedule slip, D.

Because schedule slip is determined from the probability of delay resulting from uncertainty, as the amount of required work is completed, uncertainty decreases, so the probability of delay decreases. The preliminary magnitude of slip, D, is therefore reduced by the fraction of work completed within the appropriate phase, f_s. This approach is consistent with the results of others. For example, others have demonstrated the negative effects of resource limits and fire fighting on work quality and the amount of rework required within a single project (Ford and Sterman 1998; Joglekar and Ford in press; Repenning 2001; Repenning et al. 2001). These studied examined the causes of resource distraction in detail and their dynamic behavior. The results showed that the amount of rework necessary decreased as the project progressed. Since our model does not require a detailed understanding of the causes of schedule slip, but only that slip occurs and with some calculable magnitude, we can incorporate their results into our model implicitly as a schedule slip without loss of accuracy.



<u>Figure 5</u> – Resource management module for the model. P1, P2, and P3 refer to the prioritization of the product development projects. The **transition trigger** ***variables define what fraction of TDP work must be completed before PDP can start. The*** **Ph1 Fraction completed** ***variables indicate the fraction of TDP work that is completed in TDP (Phase 1). The initial value of*** **resources required** ***for each project is the number of resources required for TDP. When the*** **Ph1 Fraction completed** ***equals the corresponding transition trigger level, the corresponding*** **resources required** ***parameter is set equal to the number of resources required for PDP (Phase 2).***



<u>Figure 6</u> – Data representing preliminary magnitude of schedule slip,* D. *A random number representing the cumulative probability of schedule delay is generated in each time step; from this data, the amount of planned work that is not completed is determined, which represents an equivalent slip or delay in schedule.

The result of these assumptions is the calculation of work effectiveness, ε. Work effectiveness is the fraction of work done that is new work, as opposed to rework or unplanned work. Equation 1.7 therefore determines work effectiveness.

$$\varepsilon = 1 - D(1 - f_s) \tag{1.7}$$

We choose to use work effectiveness rather than productivity because we desire to reflect the amount of required work that is completed rather than the actual work effort that is expended. Productivity suggests a lack of any accomplishment may occur, which is a different issue and not one relevant to the purpose of the present work.

Work effectiveness is essentially the fraction of those resources that was working on new work. Since the work completion rate is the number of resources applied to the project, the real rate of work completion in each time step is therefore

$$\frac{dE_{ij}}{dt} = \rho_{ij} = \varepsilon_j a_{ij} \tag{1.8}$$

for the j^{th} phase of project i.

4.4 Development Costs, Revenue Generation, and Net Income

A study of Figure 1 shows that the first two phases of commercialization, TDP and PDP, represent development activities in which technologies, designs, and processes are conceived, implemented, and demonstrated. Revenue is not generated until completion of these development activities. For simplicity, development costs are tied directly to the number of resources working on product development. A constant cost per FTE per year is used. This average value represents direct labor, direct materials, and overhead.

Revenues result from product sales, which in turn are determined using the Bass diffusion model of product adoption (Bass 1969). The Bass model is extended by including price as a determinant of the population of potential adopters. From the total number of potential adopters, the fraction willing to buy at any given time is a function of the current product price. As the price decreases, more of this population will be considered active potential adopters for the Bass model calculations. The fraction of the total potential adopter population increases linearly with decreases in price, which is effectively a linear demand curve.

Decreases in price occur as more products are sold. This is represented by a learning curve, in which the product price is related to the cumulative production of the product by Equation 1.9,

$$P_i = P_0 V_i^a \tag{1.9}$$

where P_i is the price of the i^{th} unit, P_0 is the price of the first unit, V_i is the number of units produced up to the i^{th} unit, and a is a function of the learning rate (Teplitz 1991). The learning rate, *LR*, is the fixed fraction of price reduction that occurs with each doubling of production. Consequently,

$$a = \frac{\ln(1 - LR)}{\ln(2)} \tag{1.10}$$

A constant learning rate is assumed for the full lifecycle of each product. For each product, the initial price is associated with an initial number of units, which represent initial experience gained during the PDP phase with demonstration and early customer acceptance test units.

This approach greatly simplifies the overall adoption process. We assume that the products sold meet customer expectations for performance and features, and that price is the most significant, if not the sole, motivation for deciding to adopt a new product. The process model we use supports this assumption by ensuring that all of the work required for the TDP and PDP phases is complete (and therefore satisfactory) before product launch. This work includes ensuring that the products meet customer requirements. The adoption module is shown in Figure 7.

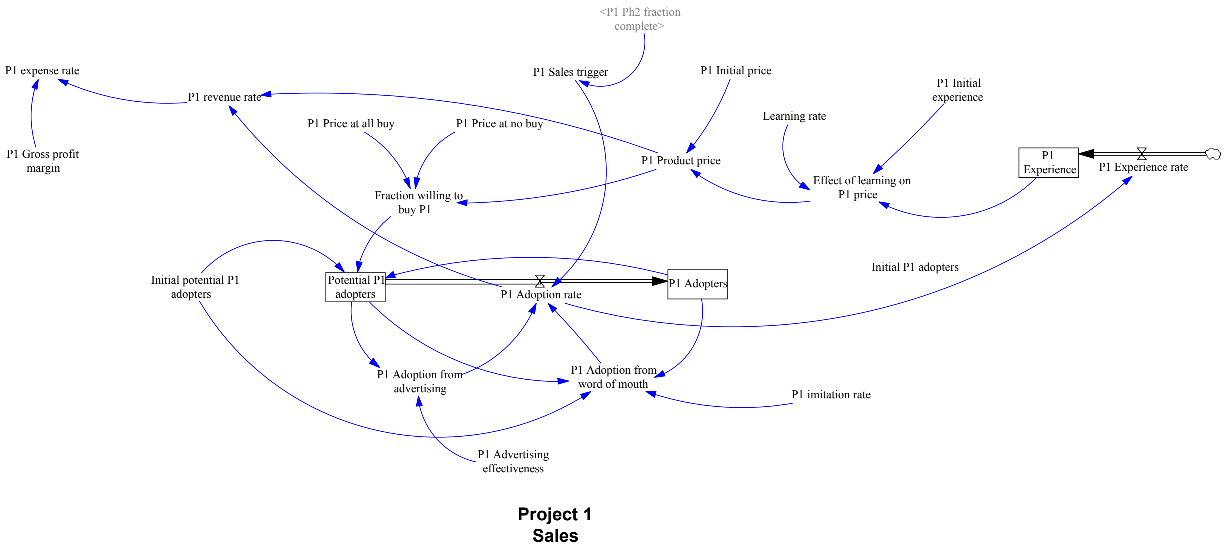


Figure 7 ***– The product adoption module used in the model. This module is based on the Bass diffusion model of product adoption (Bass 1969) and the dynamic model presented in Sterman (2000). The variable*** **Initial potential adopters** ***represents the full market size for the product based on its feature set and value proposition; the stock*** **Potential adopters** ***represents those buyers willing to purchase at the current price.***

Net income is derived from the revenues and gross profit margins of each product. As discussed earlier, the price is assumed to include all direct and indirect production costs, general and administrative expenses, current development expenses, and profit. Cumulative net income is represented in this model as the running total of gross profit less development costs; profitability is therefore defined as the point at which cumulative net income becomes non-negative.

The work management module is provided in the Appendix to this paper.

5.0 Product Definitions and Development Strategy Options

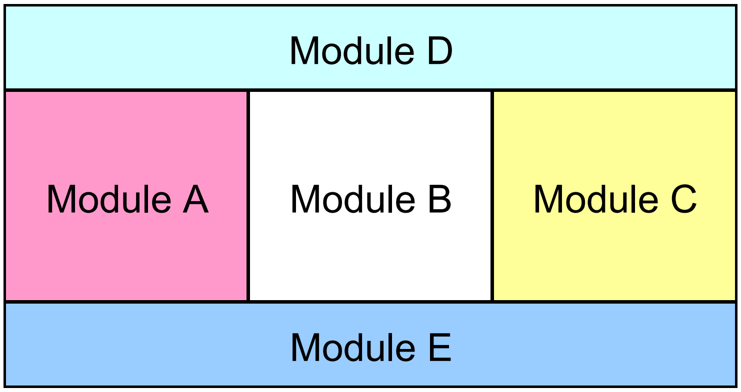
For this work, we postulate Company X is considering the development of several new products. Figure 8 represents the architecture of one of these products, consisting of five discrete modules. It is expected that Module A could be a separate product and the combination of Modules B and C could be yet another product. Each of these latter products would require their own versions of Modules D and E. There are then three separate products to be developed: Product 1 consists of Module A, Product 2 consists of Modules A and B, Product 3 consists of Modules A, B, and C. These products have varying newness and complexity and are for different markets, with different market sizes, adoption rates, price points, and profit margins (Table 1). Company X has three major options to consider:

1. Develop Products 1, 2, and 3 independently and in parallel, entering the market as each one is ready to launch.

2. Develop Product 3 as a platform. Priority is given to the subset products (Products 1 and 2) so that they may be sold as they are developed. (We refer to this strategy as a "building block" approach, wherein pieces of the whole are developed as separate products and then integrated into a full product.)

3. Develop Product 3 as a platform. Priority is given to completing this product before the subset products are launched. (We refer to this strategy as a "spin-off" approach, wherein the complete platform is demonstrated to be technically ready before smaller products are developed.)

Figure 9 illustrates the sequence of events and the architectural relationships in these three cases.

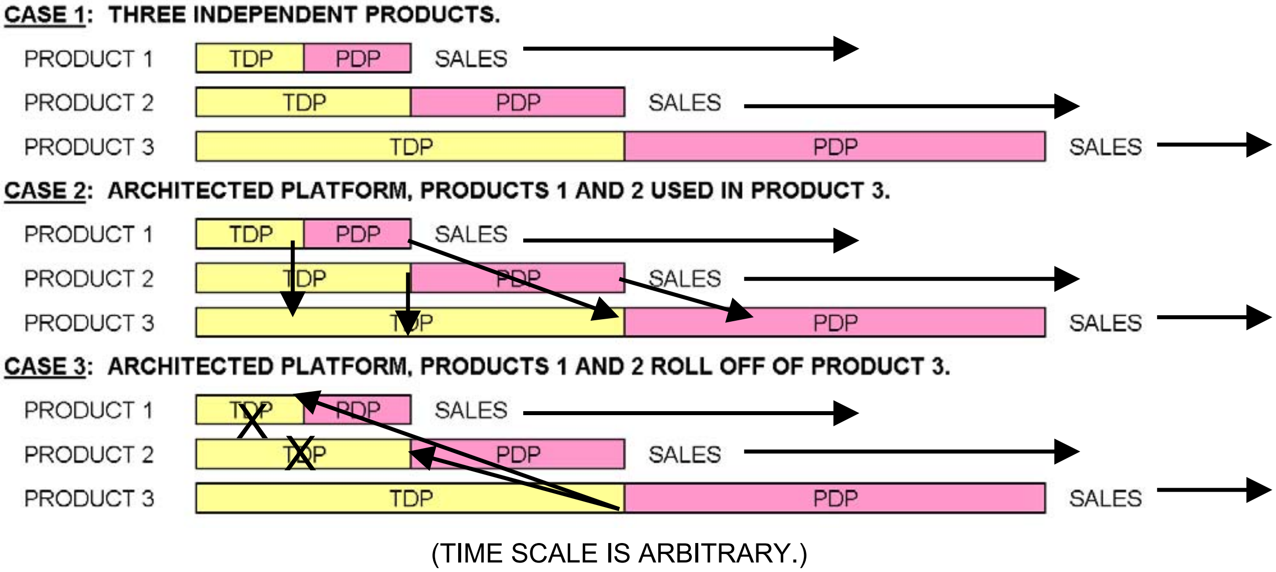


<u>Figure 8</u> – The architectural concept behind the products and cases simulated. Each module represents a distinct grouping of functionality and hardware.

<u>Table 1</u>
Qualitative description of market parameters for three potential new products.

Product	1	2	3
Modules	A	B, C	A, B, C
Sales – number of units	Low	Moderate	High
Sales – adoption rate	Moderate	Low	High
Price	High	Low	High
Profit margin	High	Moderate	Low

In Case 1, duplication of effort is maximized since the work required to develop the modules for Products 1 and 2 must also be done for the same modules in Product 3. However, it does have the potential advantage of entering the individual markets sooner than waiting to roll off Products 1 and 2 from Product 3 after it is launched. Case 2 reduces the overall work effort because TDP and PDP work for Products 1 and 2 represent subsets of the work in the same phases for the full product (Product 3); this option allows launching of products from a common platform as soon as they are ready. Conversely, Case 3 delays launching smaller products until the full plat form product is technically ready. In this option, the TDP work for the spin-off products is completed with the full product, but much of the PDP work remains.



<u>Figure 9</u> – Three product development strategies for products associated with the architecture and modules shown in Figure 9. Product 1 uses Module A, Product 2 uses Modules B and C, and Product 3 uses Modules A, B, and C. Each product requires unique Modules D and E. Case 1 represents parallel independent development of three products. Cases 2 and 3 are for the development of an architected platform of products, with Case 2 representing sequential development and launch and Case 3 representing demonstration of technical readiness of the full platform followed by spin-off product releases.

The values of the parameters used in the simulations are listed in Table 2. The price and market size data are based on Company X analyses, profit margins are estimated from Company X projections, and the Bass model parameters are estimated from the adoption of related products.

Table 2
Values of parameters used in the simulations.

Product	**1**	**2**	**3**
Maximum price	\$100,000	\$15,000	\$50,000
Minimum price	\$0	\$0	\$0
Initial price	\$80,000	\$14,995	\$49,995
Bass coefficient of innovation, p (1/week)	0.0001145	0.0006877	0.00007037
Bass coefficient of imitation, q (1/week)	0.08920	0.01945	0.05862
Market potential (units)	5,000	20,000	250,000
Net profit margin	40%	30%	20%
Required resources (FTEs)			
TDP	15	30	60
PDP	15	30	60
Newness			
Market	0.9	0.9	0.9
Company	0.1	0.3	0.3
Overall	0.91	0.93	0.93
Complexity	1	3	9

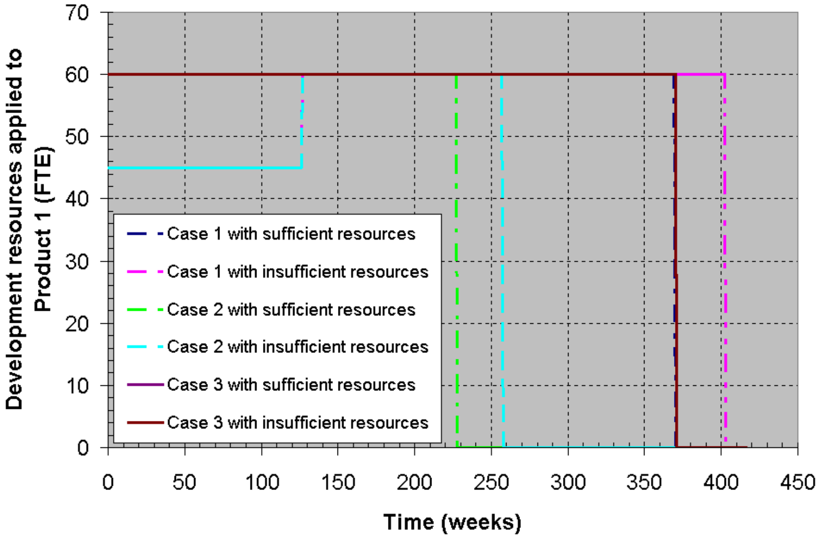
For Company X, development costs were estimated at \$100,000 per FTE for all products. A learning rate of 15% (price decreases by 15% for every doubling of production) was used, which is within typical ranges for new products (Dutton 1984). The model also assumed PDP started when 90% of TDP work was completed; the remainder of the TDP work effort is completed during PDP.

Small companies often do not have sufficient resources to develop all the products they have in mind in the time desired. This may be simulated by varying the number of available resources, *A*, in the model. The maximum number of resources required to complete the work for the three projects listed in Table 2 is 105 FTEs. For each case illustrated in Figure 8, two simulations were run – one with more resources than required to develop Products 1, 2, and 3 (120 FTEs available), and one with insufficient resources to meet the total resource requirements at the outset (90 FTEs available). The model does not allow "resource stealing" or reprioritization of development products if insufficient resources are available, so some products will experience slower rates of work completion due to the lack of resources.

6.0 Simulation Results

The six scenarios (three cases with two resource limits) were evaluated for the effect of product development strategy on time-to-market and time-to-profitability. Product 1 provides the benchmark for rapid entry into the market, while Product 3 is the most limiting product; together, the launches of these extremes of the products considered provide insight into the influence of the product development strategy.

Figure 10 illustrates the time-to-market (TTM) for Product 3, representing the complete platform in Figure 8. Placing a higher priority on developing the smaller subset products (Products 1 and 2) reduces the total work effort required for Product 3 and accelerates its development, thereby reducing its time to market. By developing a product in the context of an initial application followed by other applications, the overall work effort is reduced relative to developing the overarching product and then modifying it to support roll-off products. This is substantiated by comparison of the TTM for Products 1 and 3 provided in Table 3. A stepwise development process of architected products enables short TTM for the smaller products and decreased TTM for the larger product. Completing the technology development of the full product before developing and rolling off smaller products increases the TTM for all products. In this case, there is no significant benefit of system architecture and platform products relative to development of independent products.



<u>Figure 10</u> – The time-to-market for Product 3 for six scenarios. Development resources are those people working on the TDP and PDP phases of product development. At product launch, development resources are zero.

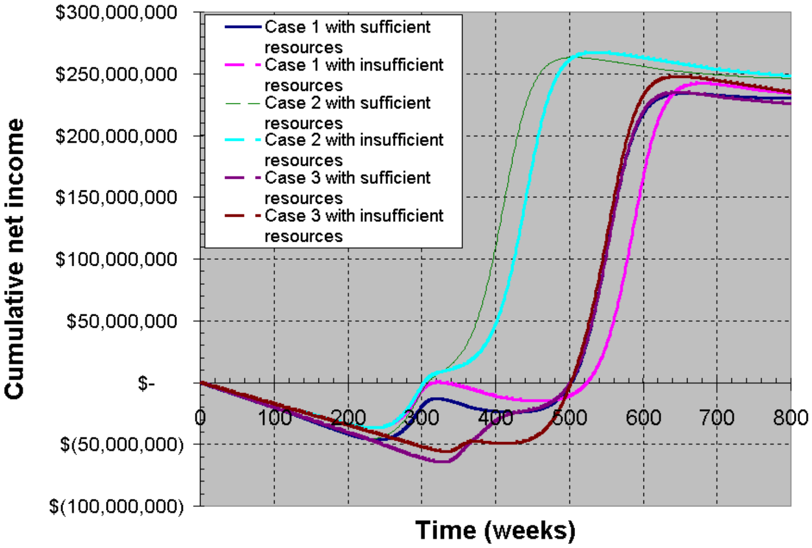
Table 3
Time-to-market for Products 1 and 3 for different product development strategies and resource availabilities.

	Development resources (FTE)		TTM (weeks)	
	Available	Required	Product 1	Product 3
Case 1 - Independent products	90	105	126	402
Case 1 - Independent products	120	105	126	369
Case 2 - Architected platform, Products 1 and 2 used in Product 3	90	105	126	257
Case 2 - Architected platform, Products 1 and 2 used in Product 3	120	105	126	227
Case 3 - Architected platform, Products 1 and 2 roll off of Product 3	90	105	340	370
Case 3 - Architected platform, Products 1 and 2 roll off of Product 3	120	105	230	370

A comparison of the model results in Table 3 and the average industry TTM data in Figure 2 is instructive. For Product 1, with a high newness and low complexity, the industry data suggests a nominal TTM of 115 weeks. The model shows a TTM of 126 weeks for the first two cases; the agreement is good, with the difference due to the addition of schedule slip in the model. In the third option, the model predicts a 2- to 3-fold increase in TTM for Product 1, which is attributable to delaying start of Product 1 development until the completion of the TDP phase of Product 3 plus schedule slip.

Product 3, when architected along with the contributory products (Products 1 and 2), was shown to have a TTM of between 220 and 260 weeks, which is approximately 75% of the industry average TTM of 315 weeks for highly complex, highly new products. When architecture is neglected or if smaller products are not used to accelerate development, the model TTM results are in-line with the industry average plus additional time for schedule slip.

The goal of this model is to demonstrate the effect of product development strategies on time-to-profitability (TTP). As shown in Figure 11, there is a strong dependence of TTP on the strategy pursued, as expected. It is clear that a fully architected product platform with gradual release of building-block products (Case 2) reduces the TTP significantly for Company X and the assumptions used. Company X would be expected to reach profitability about 4 years sooner following this product development strategy than with the other two strategies considered.



<u>Figure 11</u> – The time-to-profitability for Company X for three product development strategies and two different resource limits. Cumulative net income is the sum of all product net income (profits) less the sum of all development costs over the course of time. Development costs are defined as a set quantity per FTE per year and apply to the TDP and PDP phases of product commercialization. Profitability is defined as the point at which the cumulative net income for the company becomes non-negative.

The results in Figure 11 suggest that this company will become profitable in 6 to 10 years depending upon the product development strategy. This is consistent with the results of a study of new business ventures conducted in the late 1970's. Biggadike examined 68 ventures launched by 35 companies in the top 200 of the Fortune 500 companies. The businesses studied were new products or services for the parent company and that required the parent company to acquire new resources or knowledge to develop them. This study demonstrated that, for these types of new businesses, the average time to profitability was approximately 8 years. Although there are some differences between the companies and new ventures considered in the corporate study and Company X, the data provide a benchmark for calibrating the model and demonstrate that the model provides reasonable estimates.

It is interesting to note that pursuing a strategy of three independent products almost results in a TTP comparable to that of the architected, building block approach. However, because the former strategy requires some duplication of effort, the additional development costs ultimately outweigh the profits from sales of the early products, and the company does not maintain profitability for another 4 years or so. This suggests that if Product 1, and then Product 2, had higher revenue generation rates, the independent product strategy would be comparable to that of the fully architected strategy. This is the core of this analysis – the shortest time to profitability depends on market parameters as well as product development strategy. Uncertainty in the former is expected to be mitigated by a coherent product development strategy that maximizes use of product architecture and platform products.

7.0 Conclusions

We have developed a dynamic model of product development processes that enables estimation of the time-to-market for new products and the time-to-profitability for a new business. The results compare favorably with estimates of these parameters in the literature.

The simulations demonstrate that the use of product architecture has the potential to accelerate the time-to-profitability. While this is consistent with much product development literature, the results also indicate that following a building block approach to product development within the context of a given architecture is preferable to following a spin-off approach. Delaying release of smaller products until the full architected product is technically ready serves to delay revenues, and may not be any more profitable than developing independent products.

The model does not fully nor adequately represent corporate reality. Limitations and constraints on resource allocation and launch timing do not afford the user the opportunity to explore the impacts of different actions that management might take. A primary example is the application of a constant number of resources to each product development project. In the event of schedule delays associated with high priority projects, management might respond by shifting resources from lower priority to higher priority products. The resulting time-to-market and time-to-profitability may be significantly different when resources are shifted at will. The benefits of near-term launch may be negated by long-term delays, especially when a strategy of independent products is pursued. It is expected that shifting resources from long-term product development efforts to short-term projects will have an effect on time-to-profitability similar to that observed with the independent development strategy – TTP will be increased because of delays in com pleting the long-term work.

A related limitation is the assumption of fungible resources. The needs of different products, with different innovation requirements, may not be met by the same types of employees. It is possible that an early product requires a significant number of mechanical engineers who cannot help with the development of a later new product requiring substantial electrical engineering expertise; in this event, the company is faced with the potential cost of underutilized employees and the possible delay of product revenues.

From a revenue perspective, the model is greatly simplified by assuming that product adoption is driven solely by price and that all other customer requirements are satisfied before product launch. In reality, management may accelerate the development schedule by launching products that do not fully meet customer requirements; this most likely will shorten time-to-market but adversely impact the price that can be commanded and the number of potential adopters.

Lastly, while the model produces results consistent with those of industry studies, it is not intuitive in its structure and presentation. The model requires restructuring to allow users to better understand the underlying structure and to apply it to their own situations. As presented in the Appendix, the model reflects the authors' newness to the complexity of system dynamics modeling.

8.0 Future Work

The model has not been fully exercised to understand the relative importance of the input parameters on its dynamic behavior. Once the model has been revised for clarity and ease of use, a sensitivity analysis will be performed to ascertain the limitations of the model and to provide further elucidation of the impacts of strategy, resource allocation, complexity, newness, and market adoption rates. In mechanical engineering, certain dimensionless constants may be used to illustrate physical phenomena; in finance, certain ratios may be used to explain corporate performance. The sensitivity analysis may reveal characteristic quantities that can be used to rank the time-to-profitability of different strategies. It will also provide insight into the benefits of and the approach to be taken to implement the possible modifications discussed below.

The proposed future work reflects an expectation that broader capabilities and added realism are necessary to fully characterize the dynamics of product development strategies. The limitations outlined above will be addressed, allowing exploration of additional dimensions in product development. Further, the quantitative relationships incorporated into the model will be explored and better defined.

One of the first improvements will be flexibility in resource allocations among active development projects. The model will be modified to include such "resource stealing" from one project to another. Since doubling the number of people working on a project does not necessarily result in a halving of the time to complete the required work, this change will contain limits to the effectiveness of applying additional resources.

From a decision-making perspective, the model will be modified to allow comparison of quality-driven and schedule-driven management strategies on time-to-profitability. One way to do this is to allow a fixed development period; at launch, product sales will be influenced by the level of customer requirements that are met by the product, which are in turn related to the amount of TDP and PDP work completed prior to launch.

Along with capability at launch, the product adoption module may be modified to include the effects of external influences. Network externalities, the regulatory environment, and competitive technology will influence the decision to buy any new product to some extent. For some products, these will be non-existent, while, for others, these will be strong considerations. Overall, these are most likely secondary to customer requirements, but inclusion of these effects will be considered.

Other improvements to the realism of the model are under consideration. These improvements address the limitations associated with quantifying newness, complexity, schedule slip, and work effort. A better mathematical definition of newness is expected to be difficult to achieve; however, detailed analyses of past project performance will be conducted to develop a better relationship between the probability of schedule slip (failure) and the magnitude of schedule slip (failure). Likewise, complexity will be related to quantifiable metrics such as number of parts and lines of code. Past product development data will be used to correlate work effort to complexity. In addition, complexity should, in reality, contribute to schedule slip because of the compounding effect of the number of interactions between parts, lines of code, and so on. Thus, schedule slip predictions will be related to both newness and complexity just as work effect is a function of both parameters.

Lastly, time-to-market and time-to-profitability benchmark data are limited in the literature. Additional research is required to broaden the available set of comparative data. This work will be undertaken as appropriate to improve analysis of simulation results, but is not considered necessary to calibrate the model further.

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10.0 Appendix: The Work Management Module