MODELING THE MARKET DYNAMICS OF WORKSTATION PLATFORM ADOPTION

by

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B.S. Electrical Engineering, University of Illinois -- Urbana, 1989

Submitted to the Sloan School of Management and the
Department of Electrical Engineering and Computer Science
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Master of Science in Management
and
Master of Science in Electrical Engineering

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Abstract

This thesis proposes a method for market analysis utilizing the modeling techniques of system dynamics.

In the 2nd quarter of 2000, Intel is expected to launch a 64-bit architecture (IA-64) into a market that already is supported by several existing 64-bit processors. This market scenario is a departure from Intel's historical microprocessor landscape in the following ways:

- The segment focus today is towards an established user population of high-end computing. This segment focus is a salient contrast to the relatively new desktop computer market that the 80386 processor targeted 15 years ago.
- The dramatic increase of market velocity as the result of intensifying competition and the insatiable demand for greater computing power.

Therefore, in introducing IA-64 into a market space that is as described above, Intel should expect greater complexity and uncertainty in the market dynamics of this product launch. It is therefore, more important than ever, for Intel to apply methods of market analysis that transcend the limitations of traditional methods tailored to the desktop segments.

Developing a market analysis that accounts for all the relevant drivers of user purchase decisions is a daunting task. Compounding this task with the complexity of a high velocity, time varying market environment, the analysis can rapidly become unwieldy. For this reason, the thesis proposes a framework for the development of a market model that attempts to address the complexity posed in a market system such as high-end computing.

The application of the market model to the workstation market has yielded a more concrete understanding of IA-64's launch delay ramifications. It is shown that by modeling the market with a system dynamics framework, a practitioner is able to rationally formulate the share of market and financial impact of a launch delay in numerical terms. In addition, for exploring the mitigating options of the delay, the model allowed for scenario analysis by the adjustments of relevant and tangible market drivers.

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I am also grateful to my thesis advisors, Steve Leeb and Roy Welsch, for their valuable insights in formulating an interesting and relevant research project.

I wish to also acknowledge my parents, Rev. Joseph & Ruth Tai, for instilling in me a vision for the pursuit of leadership and academic excellence. Your years of patience and prayers have paid off!

"Blessed is the man who fears the LORD, who finds great delight in his commands. His children will be mighty in the land; the generation of the upright will be blessed."

I would like to thank my daughter, Ruth Christianna, for helping Daddy maintain a sense of sensibility. Watching you grow from 0 to 2 through all my papers, cases, exams, and interviews has given me a more profound understanding of "living for the important things in life."

"What good will it be for a man if he gains the whole world, yet forfeits his soul?"

My deepest appreciation goes to my wife, Tzu-Ann, for being my best friend and most trusted confidant. This accomplishment is the fruit of your faith in my calling and unconditional love for who I am. These challenging times will be some of the sweetest years in our memories.

"A wife of noble character, who can find? She is worth far more than rubies...Many women do noble things, but you surpass them all. Charm is deceptive, and beauty is fleeting; but a woman who fears the LORD is to be praised."

Finally, I dedicate this work to my LORD and Savior, Jesus Christ, who is the Source of all knowledge and wisdom.

"For the foolishness of God is wiser than man's wisdom...The LORD gives wisdom and from his mouth come knowledge and understanding."

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1. Introduction

This thesis presents a proposal for market analysis utilizing the modeling techniques of system dynamics. The study of technology adoption in market analysis has never been more relevant to Intel Corporation than during its recent venture into 64-bit computing technology. During the year 2000, Intel will be introducing a 64-bit architecture (IA-64) into a market place that already is supported by several 64-bit processors. This scenario closely resembles the company's introduction of its first 32-bit microprocessor (80386) into a market already served by the Motorola 68020. So at first glance, one may expect the characteristics of IA-64 market diffusion to closely track its 32-bit predecessors. But it is important to recognize several key differences in today's market landscape that may dilute the accuracy of market forecasts based primarily on historical trend. First, the segment focus today is towards an established user population of high-end computing. This segment focus is a salient contrast to the relatively new desktop computer market that the 80386 processor targeted 15 years ago. The second key difference in today's market is the dramatic increase of market velocity as the result of intensifying competition and the insatiable market demand for greater computing power. Therefore, in introducing IA-64 into a market space that is characterized by a sophisticated user base and high industry velocity, Intel should expect greater complexity and uncertainty in the market dynamics of this product launch. It is therefore, more important than ever, for Intel to apply methods of market analysis that transcend the limitations of traditional methods tailored to the desktop segments.

Developing a market analysis that accounts for all the relevant drivers of user purchase decisions is a daunting task. Compounding this task with the complexity of a high velocity, time varying market environment, the analysis can rapidly become unwieldy. For this reason, the ensuing discussion of the thesis proposes a framework for the development of a market model that attempts to address the complexity posed in a market system such as high-end computing. Because a good portion of the groundwork for this effort was done at Intel's

Workstation Products Group (WPG), the system dynamics model developed is geared towards the mid- to high-end workstation market.

1.1. Industry Background

This section will contain a brief historical overview of the computing industry focused on Intel's business operations.

1.1.1. Intel's Historical Market and Position

Intel's participation in the computing industry came into true prominence during the mid 1980's. The semiconductor giant, at that time, ushered in a phase of tremendous growth in the market adoption of PC based microprocessors. In Intel's mission statement, it states that it is to be,"...the preeminent building block supplier to the computing industry worldwide." It is an undisputed fact that Intel today lives up to that mission by leading the industry with 80%+ market share.

Traditionally, Intel has maintained its market lead in the desktop and portable computing industry by maintaining its lead in performance and manufacturing. The company has steadily supported Moore's law by doubling computing capability every eighteen months for the last decade[1]. For the PC platform, Intel's strategy and capability of "first to market" has yielded huge dividends. Most notably, these competitive advantages are:

- Strong *platform equity*[2] which drives the network effects of user adoption;
- Significant horizontal market power over other rivals such as AMD and Cyrix;

[1] Erik Brynjolfsson and S. Yang, "Information Technology and Productivity: A Review of the Literature," *Advances in Computers*, 1996.
[2] *Platform equity* is a generalized description of complementary products that increase the utility of a computing platform These value added products may encompass software applications or operating systems from independent software vendors (ISV), peripheral hardware from independent hardware vendors (IHV), specialized architecture from OEMs (i.e. SGI's Visual Workstations).

- Significant vertical market power in the PC value chain that allows the microprocessor leader to drive architectural standards and the general technological direction of the industry[3].

Because Intel has always identified its core business competencies to be within the sphere of PC components such as microprocessors and chip sets, it has never pursued any significant portion of the board or system level markets. But given that the market value of Intel's components are highly dependent upon the down stream value added entities, the silicon giant has also adopted a strategy of mother board and system implementation to enable and accelerate early industry adoption[4]. This strategy has allowed Intel to more rapidly introduce technologies that provide much needed user benefits such as PCI and USB. By being in the forefront of technologies that directly address the needs of the market, Intel has also been able to significantly increase its brand equity as a component supplier.

1.1.2. The Workstation Market

Intel formed WPG in 1997 with the mission to enable and propagate the adoption of IA in workstation products. Around that time, the company recognized that a growing segment of workstation caliber users were shifting their demand on computing requirements. Those requirements fell right between the high-end traditional workstations and conventional desktop computers. It was also recognized by the chipmaker that the Pentium series of microprocessors are able to supply the computing power required for workstation level software and networking capabilities. The industry term for this user segment is dubbed the *Personal Workstation* Segment.

Since WPG's inception, IA-32 technology such as Pentium II and Pentium III processors has steadily narrowed its performance gap with the higher end RISC processors of traditional

[3] Robert D. Hof, Larry Armstrong, Gary McWilliams, "Intel Unbound," *Business Week*, October 9, 1995, p. 148-154.
[4] Robert D. Hof, Larry Armstrong, Gary McWilliams, "Intel Unbound," *Business Week*, October 9, 1995, p. 148-154.

workstations. The Merced microprocessor is designated as Intel's leading product for introducing the Intel Architecture into the 64-bit processing domain.

In an environment where all the traditional players of mid/high-end workstations and servers already have established 64-bit technology, Intel is considered a late comer into the market (a salient contrast to their desktop position as the technology leader). Because it is widely believed throughout the industry that the personal workstation and high-end server segments are still poised for strong growth[5], Intel has embarked on a strategy to participate in these segments by producing low cost workstation and server class CPUs. With the introduction of Merced, Intel will complete its portfolio of CPU products that range from the sub $1,000 PC, to the most high-end RISC-like computing machines.

It is the author's observation that Intel will have difficulty with IA-64's market penetration in the high-end computing arena. This belief is based on the observation that the incumbent participants such as Sun and HP have established market positions with very strong platform equity. This is evident from the breadth of software support that both platforms currently enjoy in engineering and design applications. Because the fundamental architecture of IA-64 is such a departure from IA-32, the marginal cost of transferring IA-32's existing platform equity to IA-64 would, in most cases, outweigh the marginal benefits. The new 64-bit architecture has to build its platform equity from almost ground zero. Therefore, unless Intel is able to induce a sizable number of downstream value added entities, such as ISVs and IHVs, to adopt the IA-64 platform, it will not have significant near term participation in the high-end computing market.

Most industry insiders believe that the competitive advantage of IA-64 would lie with its comparatively low price point. This position is plausible given the fact that Intel has one of the lowest industry cost structures for producing microprocessors.

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[5] Laura C. Segervall, "Updated Worldwide Workstation Forecast, 1997-2002," International Data Corporation.

1.2. *Intel's Dilemma*

The impetus for the WPG market modeling project came about in the public announcement that revealed a six-month launch delay for the Merced microprocessor (originally scheduled for third quarter 1999 deployment). In the wake of the announcement, opinions regarding the delay ramifications have formulated from all segments of the industry, both internal and external to Intel. The basic question that all interested parties are posing is, "what is the market and financial impact of the Merced delay on Intel?" A more pertinent question to Intel at this juncture of the IA-64 program is, "what are the options for mitigating the unfavorable ramifications and for assuring the long-term viability of IA-64 in the workstation and server markets?"

The answers to both questions require a market analysis technique that takes into consideration the processes that end users and other software and hardware developers undergo in determining a platform (or technology) of choice. Unfortunately, to accurately model the quantitative mechanisms of this determination process by a "gut feel" of the market is almost an impossible task. This is because such an analysis requires the accounting of highly interactive cause and effect relationships that are compounded in complexity by their time varying nature. It is a common understanding that most people are not wired to perform such thought processes on the basis of their intuition.

Figure 1 shows the causal loop diagram[6] developed to capture the key dynamics inherent in a workstation market. As the figure illustrates, the consideration of all key decision rules in the market system results in a web of non-intuitive, high order mathematical relationships, quite

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[6] Causal loop diagrams are used extensively in system dynamics modeling to illustrate the individual cause and effect relationships in the context of a larger system. These diagrams are typically developed through a collection of "localized" understanding of the system and may eventually be formulated into a quantitative model that can simulate the time varying dynamics of the system.

a daunting mess even for methodical analysis. But given this understanding, it is the intent of this thesis to show that the analysis of such complexity is both manageable and conclusive by employing a system dynamics approach.

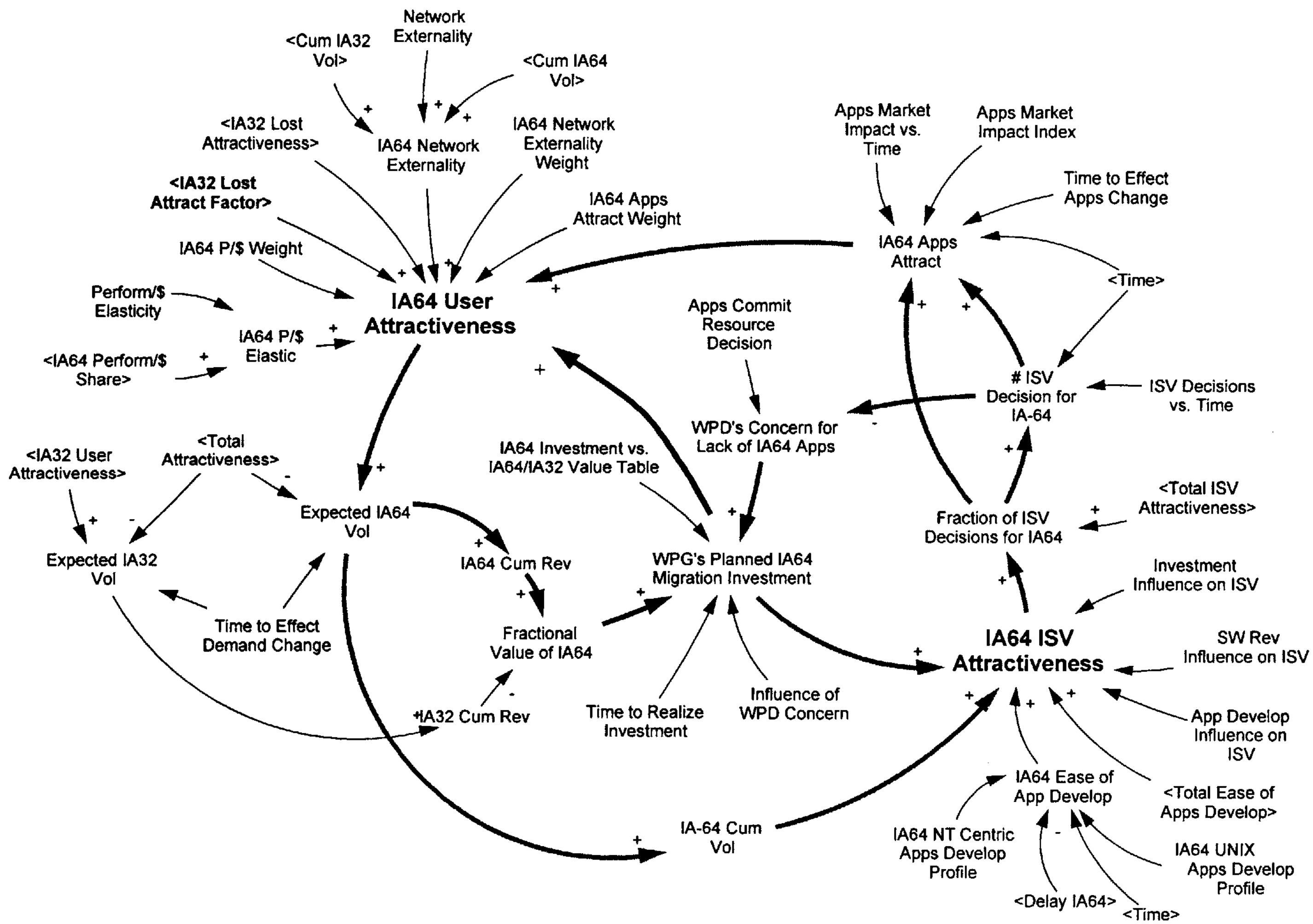

Figure 1. Causal Diagram That Shows the Complexities of the Workstation Market.

2. Analytical Approach

2.1. *Project Concept*

2.1.1. The Momentum Approach

The traditional approach to determining new technology adoption in the context of Intel's market space is to revert to historical trend extrapolation. Intel's general belief is that the IA-64 diffusion into the workstation and server markets will behave similarly to the historical performances of its 32-bit and 16-bit product lines. That is, a slow ramp up followed by a period of rapid growth in which the trend line resembles a hockey stick (**Figure 2**).

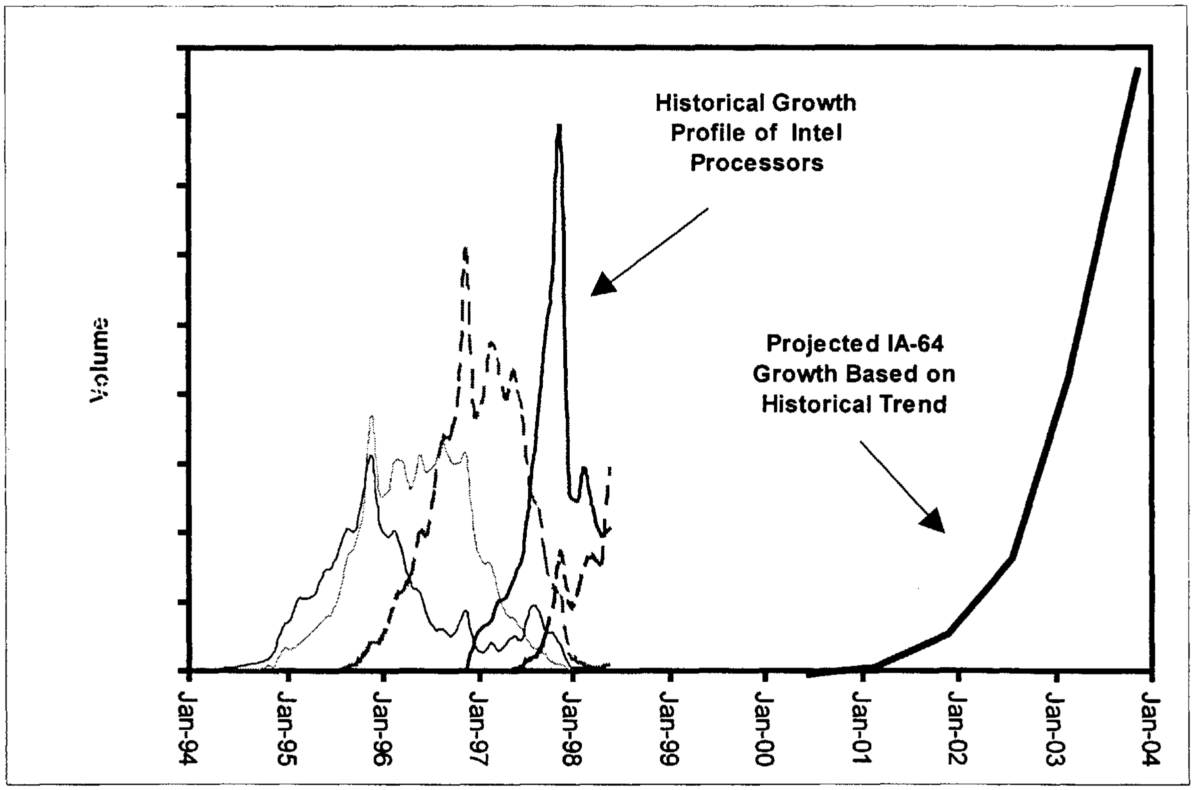

Figure 2. Historical and Proposed IA-64 Growth Profiles.

This approach to market analysis has an obvious advantage in that it reduces to a greatly simplified process. It is plausible that the forecasting method may predict reality if the 64-bit market behaves in a manner consistent with older IA technologies. But casual observation of the 64-bit market suggests a very different competitive landscape. Intel will be immersed in a highly competitive environment where it is not a player who has significant platform equity in the workstation market segment. Therefore, the momentum approach to this market analysis breaks down.

2.1.2. The Proposed Solution

The proposed approach to analyzing the 64-bit workstation market is to derive a model that encapsulates the collective behaviors of all relevant market drivers. This analytical approach does not establish any market presuppositions based on historical adoption profiles. The underlying premise is a belief that this high technology market is characterized by:

1. A high degree of uncertainty in market economics and technological standardization, therefore, one cannot confidently rely on historical information[7];

2. A complex maze of highly interactive cause and effect entities embedded with feedback mechanisms and time delays throughout the system **(Figure 1**).

The comprehensive nature of this analytical approach will ultimately produce more realistic market projections. But the obvious draw back is the complexity in managing such a market model.

2.1.3. Role of System Dynamics

One of the most effective techniques of managing the analysis of a highly complex system is the application of system dynamics. This modeling technique is established on the premise that many observable systems, e.g. ecological, physical, social, or economic, manifest behaviors that can be described by recursive, time delayed mechanisms of the system variables[8]. As **Figure 1** shows, that the workstation market can be modeled as a system of

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[7] Rowland T. Moriarty and Thomas J. Kosnik, "High-Tech Marketing: Concepts, Continuity, and Change," *Sloan Management Review*, Summer 1989, p. 7-17.
[8] John D. Sterman, "Business Dynamics: Systems Thinking and Modeling for a Complex World" (working title) Version 1.0, 1997, p 1(3).

dynamic variables interlocked by networking effects and non-zero time delays. Therefore, system dynamics presents a good fit for modeling the complex dynamics of the workstation market.

The ability of system dynamics modeling to manage problems of extreme complexity is manifested in several ways. First, it allows the modeler to build the system based on a simple understanding of microscopic relationships of the cause and effect variables. Second, one can incorporate quantitative relationships in all causal links. Third, the model considers the endogenous effects of system feedback so that the nonlinear time varying nature of the system variables are captured.

Numerous commercial software tools, such as Vensim, are designed for model formulation based on the theory of system dynamics. The tools will typically incorporate features that enable one to efficiently develop, manage, and analyze the system model. This is important because systems with feedback and propagation delay, by nature, exhibit non-linear and overshoot/undershoot characteristics. It is almost impossible to intuitively derive the behavior of such a system, especially if it contains many interactive variables. But the management of such an analysis, on a quantitative level, is feasible because tools like Vensim impose a discipline in the model development process, such that a trail of assumptions that dictate initial conditions or causal arithmetic can always be traced.

Applying the modeling methodology to the workstation market, the end result is an analytical tool that:

1. Considers the relevant variables of the workstation market system and their higher order interactions;

2. Simulates the time varying dynamics of the cause and effect relationships in the market system;

3. Carries out the transformation of qualitative data to quantitative output in terms of percentage share of market.

The end result would, at the minimum, manifest projected market share of the IA-64 platform with respect to time to market (or delay) and other key factors of the platform attributes. If this modeling approach provides an accurate projection of platform diffusion, then its analytical value would be enormous. The model will not only allow Intel to accurately evaluate the return on investment (ROI) impact of the launch delay, it will also provide an avenue for evaluating the effects of different market or operational strategies. Such analyses are possible through the manipulation of the various inputs or causal relationships in the market model.

2.1.4. Project Scope

The scope of this project is bounded to the analysis that encompasses the time varying dynamics of the mid/high-end workstation market. The development of model structure is limited to the most relevant drivers in the workstation market system. More specifically, the platforms that are considered as competitive entities are: high-end IA-32 (Intel's 32-bit technology), IA-64, Sun SPARC, Alpha, and other RISC's such as HP, SGI, & IBM (these have migration paths to IA-64).

The scope of the market analytical tool is also bounded by the fact that the market size (total available market of the proposed analysis space) is treated as an exogenous input. Strictly speaking, the market size is a variable that interacts with the share of market profile. But it was deemed that incorporating such a formulation would greatly compound the complexity of the analysis. Therefore, the analytical derivation of the market size is considered beyond the bounds of this project.

2.2. Analytical Framework

The framework for the system dynamics approach to the workstation market analysis is formulated around the following questions:

1. What would be the useful outputs? How do we want the results to be formulated such that they will provide useful decision support?

2. What are the available inputs and how do we distill the information into manageable driver elements?

3. Given that we know the inputs and have a notion of the desired outputs, how do we go about simulating the market system and process the data?

From the output perspective, it seems that a useful analysis would provide insights into the market competitive landscape and ultimately translate that into cash flow or rate of volume. Based on Intel's position in the workstation value chain, the company would be most interested in the expected volume of microprocessors over a specific production cycle under various market scenarios. Also, with the availability of cost and pricing profiles, one can readily calculate cash flows over time.

For a market system as complex as the workstation value chain, the available inputs are numerous. The process for simplifying and defining the input drivers follows a heuristic that assesses the following criteria: order of influence on the final output, level of accuracy with which the information may be obtained, and the ability to quantify the defined inputs. This subject will be discussed in greater detail in the subsequent sections.

At the heart of the analysis is the time stepped numerical transformation of inputs to outputs. For a system dynamics market analysis, one can envision this transfer function as a collective network of cause and effect relationships. These relationships capture the behavioral mechanisms of all participants identified in the system on a microscopic basis. Furthermore, software tools like Vensim allow one to incorporate explicit mathematical definitions for the causal relationships. The following sections will describe in greater detail the steps taken to develop the transfer function of the workstation market model.

2.3. Steps to Developing the Dynamic Market Model

This section outlines the high level view of the market dynamics model structure. The general process of formulating the workstation market model will first be described from a qualitative perspective. Then the treatment will focus on the quantitative basis of the model.

2.3.1. Developing the Qualitative Model

The approach to the qualitative, or behavioral model, involves several basic steps. These steps are:

1. Identify the relevant variables on a high level;
2. Establish causal relationships;
3. Establish feedback relationships; and finally,
4. Incorporate any time delays inherent in the causal relationships.

Figure 3 shows the high level qualitative model that captures the general dynamics of the workstation market. The subsequent sections will detail the development of this model based on the steps described above.

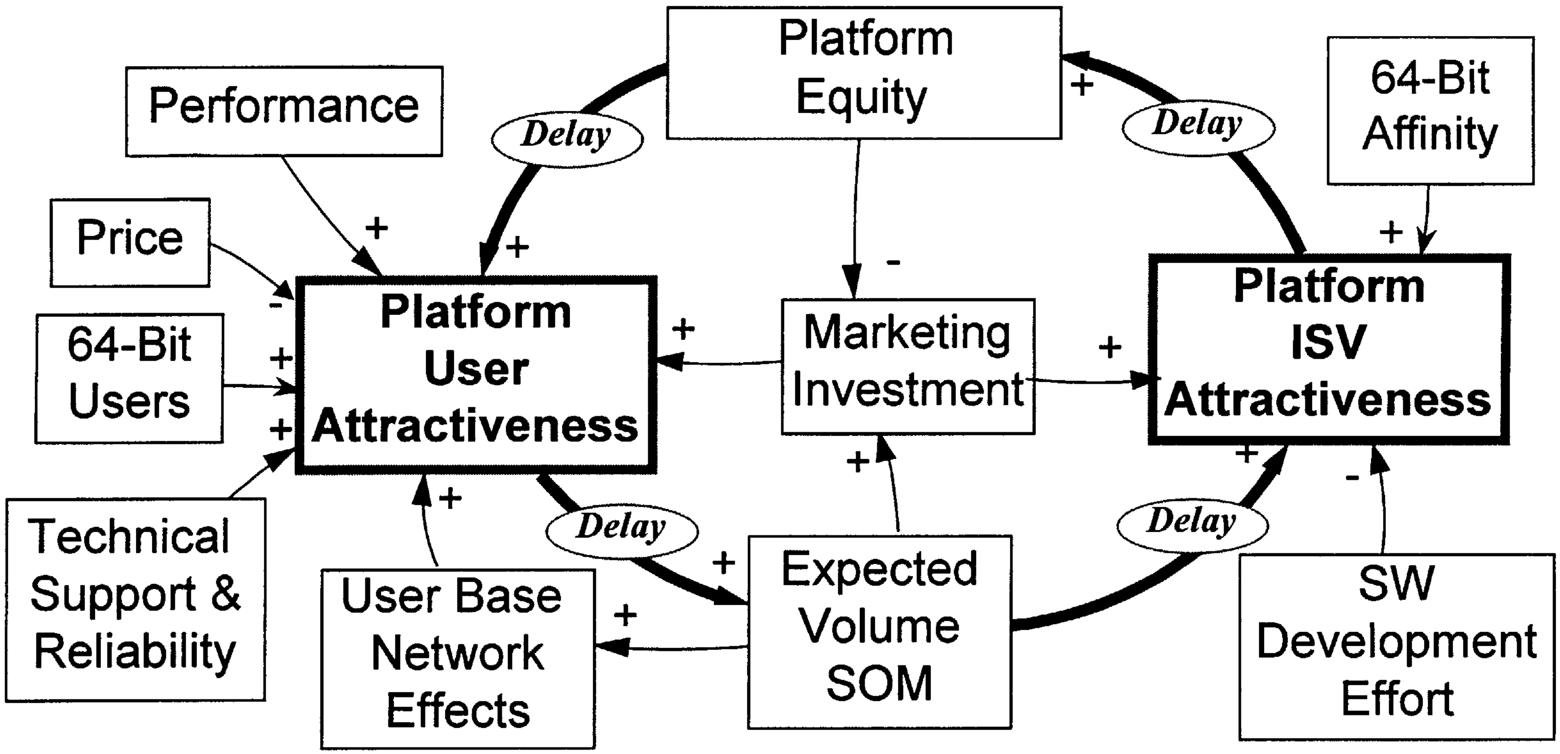

Figure 3. High Level Qualitative Model of the Workstation Market.

2.3.1.1. Relevant Variables

The analysis of this system is anchored on two key variables identified as ***Platform User Attractiveness (PUA)*** and ***Platform ISV Attractiveness (PIA)***. The drivers for these "anchor" variables were identified through interviews within Intel group and empirical market observations. The ***PUA*** serves as a point of consolidation for all the key drivers that influence the end user purchase decision. In the quantitative analysis, this variable also encompasses the decision rules employed by the end user for platform determination (to be discussed in section 2.4). Based on the research carried out for ***PUA*** formulation, the market drivers with first order influence on a platform's attractiveness to the end user were identified to be: ***Performance***, ***Price***, ***Platform Equity***, ***Marketing Investment***, ***Technical Support and Reliability***, ***64-Bit User*** requiring 64-bit technology, and ***User Base Network Effects***. By formulating ***PUA*** for all the competitive platforms in the market, one may be able to derive the expected share of market (**SOM**) for each workstation platform.

The ***PIA*** variable serves as another important anchor because it represents point of consolidation for drivers that influence the independent software vendors. By careful observation of the market, one can again identify key drivers that determine the attractiveness of a workstation platform to a software developer. The formulation of the ***PIA*** variable was based predominately on interviews with WPG's Industry Marketing Group. The model asserts that application developers are generally concerned with the potential user penetration of their products, which is driven by ***Expected Volume SOM***. They are also concerned with the cost of developing and maintaining the software, which are comprehended by the ***SW Development Effort*** variable in the model.

2.3.1.2. Causal Relationships

With the completion of variable identification, the cause and effect relationships can now be established. This process rationalizes the behavioral premises behind the model's causal links. The recognition of system interactions is done on a pair-wise basis at a level of abstraction where the causal relationships are appropriately discernable[9]. Single variables can drive and be driven by multiple entities. The end result is a diagram of causal networks.

From a qualitative perspective, it is sufficient to just recognize the causal link and the relative correlation between the variable entities. For example, **Figure 3** shows that both ***Performance*** and ***Price*** are causal factors of ***PUA*** because they significantly influence the end user's decision rule. But ***Performance*** is positively correlated to ***PUA*** in that as platform performance increases, all other drivers remaining constant, the platform will become more attractive to the end user. On the other hand, the contrary is true for ***Price***. As the price of the platform increases, the platform loses its attractiveness to the end user, and visa-versa. The relative variable correlation is designated with a + or – polarity symbol.

2.3.1.3. Feedback

In the process of building the model through pair-wise relational links of the system variables, a network of causal relationships that captures the system behavior on a macroscopic level would eventually emerge. At this level, variable drivers can be identified to be either exogenous or endogenous to the system. Exogenous drivers are considered as inputs into the model. Endogenous drivers, on the other hand, originate from within the system and represent feedback relationships in the causal links.

Referring again to **Figure 3**, it can be seen that the pair-wise identification of causal links yielded several feedback loops. One such loop captures the feedback interaction between the two "attractiveness" entities. This loop is drawn with bold arrows in the diagram. To gain an intuitive understanding, one can step through the causal structure by starting at any point on the loop, say ***PUA***. The endogenous driver for ***PUA*** is ***Platform Equity***, which in turn is determined largely by ***PIA***. One strong driver for ***PIA*** though is the potential revenue that can be generated by the platform, which is determined by ***Expected Volume SOM***. The

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[9] In the spirit of maintaining simplicity, the causal links should be recognized at the highest level of aggregation. It is only when the model fails to capture the full dynamics of the system behavior should one consider breaking the causal links into more specific relationships.

platform volume of course is driven by the ***PUA***, which comes back in a full circle. This feedback relationship, if stepped through time, will generate a reinforcing dynamic that manifests exponential growth[10]. So as volume for a platform grows, the reinforcing dynamics produced by the network effects will further drive the growth in volume, limited only by the size of the market (which is an exogenous input in our analysis).

It should be noted that as the bounds of the system of interest expand, the system would naturally incorporate more endogenous drivers. If, in fact, one considers the universe to be the system of interest, then all drivers would be considered endogenous. One must, however, use common sense in setting the bounds of the system so that its analysis produces manageable and meaningful outputs.

For the workstation market model, one can reasonably argue that inputs considered exogenous can also be driven by other variables in the system. For example, ***Performance*** and ***Price*** of the platform, in an environment characterized by game theory, should be considered as dependent variables driven by the factors of market size and competitors. For the sake of simplification, these inputs are treated as exogenous to the system and justified by two reasons. First, the ability to accurately capture the heuristics of competitive response requires a level of modeling sophistication beyond the scope of this project. Second, the software tool Vensim allows the user to play out gaming scenarios on an ad hoc basis, which more accurately portray the complex intuitions of competitive response.

As for ***Platform Equity***, one may wonder why the endogenous bound has been set to incorporate just the ***PIA*** feedback relationship. What about the value added OEM's and other third party hardware vendors (IHVs). This is rationalized by the notion that software products, compared with hardware, have a greater level of differentiation, thus, exhibit greater influence on platform equity. The implicit belief is that value added functions from

[10] In a reinforcing loop, the product of all the correlative polarities in the loop should, in principle, net a positive sign. Conversely, a balancing loop (such as exponential decay) will yield a negative sign from the product of its correlative polarities.

hardware are typically duplicable from multiple manufacturers, and therefore, the impact on the end user's perception of platform equity is significantly less severe.

2.3.1.4. System Time Delays

Inherent to every system is embedded transfer delays of information or objects between variable entities. The workstations market model shown on **Figure 3** considers these delays for the causal relationships of ***PUA*** and ***PIA*** feedback loops. Observing the real life interactions between ***PUA*** and expected volume, for example, can lead one to see that there exists a non-zero time delay in the interaction. The delay accounted for may encompass the time between when a user makes a purchase decision, to the moment when the actual transaction takes place. Such a delay may involve the processes of platform evaluation, capital expenditure approval, and procurement. Based on observations in the field, this time lag can range from 12 to 24 months for a brand new platform and 2 to 8 months for an established platform. With a high velocity industry like workstations, delays of such lengths effect significant ramifications in the market system dynamics.

Now that the modeler has considered the relevant variables, causal relationships, and time delays, he should examine the model for its behavioral consistency with the real world and determine how quantifiable the variables are. If the result is unsatisfactory, the modeler should further disaggregate the variables and reiterate the evaluative process. Repeat this process until one formulates a quantifiable model that satisfactorily captures the key market mechanisms. **Figure 1** is a more detailed qualitative market dynamics model as a result of the refinement iterations.

At this stage of model development, one should solicit inputs from experts of the field and incorporate their understanding into the model structure. Involving future model users during this iterative process will not only enhance the accuracy of the model, but will also strengthen their understanding and acceptance of the final analysis.

2.3.2. Developing the Quantitative Model

When a satisfactory behavioral model has been developed, the final step is to incorporate mathematical relationships to the causal links. The quantitative model developed from this process is an order of magnitude more complex than the qualitative. This is because the model must comprehend initial conditions, unit transformations, look up relationships, and exponential smoothing functions for representing time delays. The model for the workstation market also must quantitatively integrate the interactions between all five competitive platforms. The quantitative workstations market model, shown in, **Figure 4** well illustrates the increased complexity of realizing the mathematics for the behavioral model[11]. Section 2.4 will discuss the quantitative basis of the model in greater depth.

[11] The purpose of this diagram is simply to illustrate the increased order of complexity in the qualitative to quantitative transformation. The figure is not meant to provide specific information of the quantitative model. For directions on obtaining the source code for this Vensim model, please refer to Appendix section 5.2.

Figure 4. Quantitative Model of the Workstations Market Model.

2.4. Basis of the Quantitative Model

This section will detail the framework for developing a quantitative model that is applicable to markets similar to the workstation market. The discussion is intended to illustrate the quantitative methodologies by leveraging the IA-64 case[12]. The first portion will cover the structure of the model in terms of its inputs, outputs, and mathematical causal relationships on a microscopic level. The quantitative implementation of system time delays and their significance will also be described.

The second portion will provide a perspective for assessing the model's correlation to real world dynamics and its applicability for strategic analysis. A philosophical case for determining the validity of such a forward-looking model will also be presented.

2.4.1. Expected Share of Market

Figure 5 illustrates the structure that drives the derivation of the share of market (SOM) for the IA-64 platform. The SOM value is simply the fraction of the calculated value for user attractiveness to a platform divided by the total sum of the platform attractiveness values for all competitive entities. Referring to **Figure 5**, let

$SOM_{IA64}(t)$ = ***IA64 SOM*** *at time t*

$A^{User}_{IA64}(t)$ = ***IA64 User Attractiveness (PUA*** *for IA-64) at time t*

$A^{User}_{Total}(t)$ = ***Total Attractiveness of All Platforms*** *at time t*

the expression for IA-64 SOM would be:

$$SOM_{IA64}(t) = \frac{A^{User}_{IA64}(t)}{A^{User}_{Total}(t)} \qquad \text{Eq. 1}$$

[12] Since the analysis presented in this thesis employed contrived input quantities, the author will not attempt to present any comparative analysis on the model's correlation with actual industry data. Moreover, at the time of writing, significant amounts of industry data were still not readily available.

The implication of the quantitative definition in the equation above is to interpret ***IA64 User Attractiveness*** as the probability of a user choosing the platform, at an instant in time. This means that every causal driver for ***IA64 User Attractiveness*** must be expressed in a manner that is mathematically consistent with this definition.

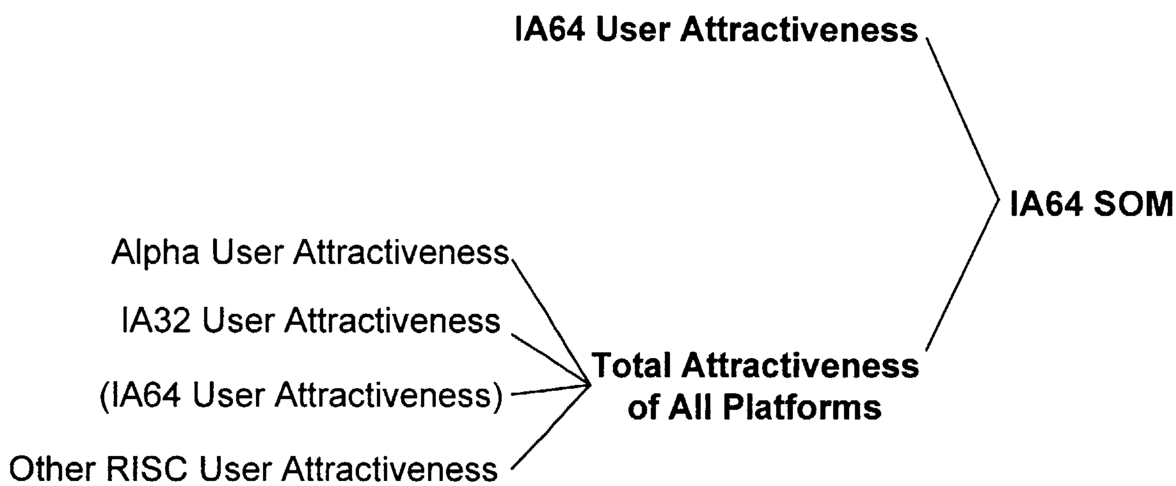

Figure 5. Structure of SOM Quantitative Drivers.

2.4.2. Platform Attractiveness to Users

Moving up a level from ***IA64 SOM***, the focus now will be on ***IA64 User Attractiveness***. **Figure 6** shows the drivers that determines a platform's attractiveness to the end user. This quantity is a probabilistic indicator of user preference given a large user population. There are two important points to be discussed concerning the derivation of this variable. The first point of discussion will deal with how ***IA64 User Attractiveness*** accounts for market segmentation. Then, the attention will focus on the mechanism of deriving the platform attractiveness value for a particular segment.

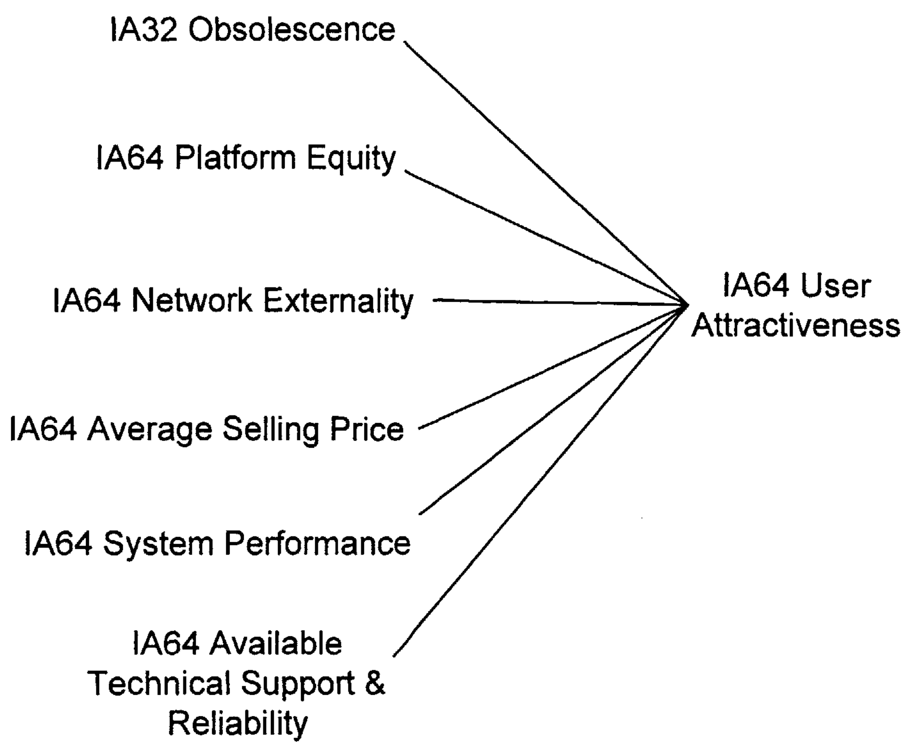

Figure 6. Structure of User Platform Attractiveness Quantivative Drivers.

2.4.2.1. Market Segmentation

The ***IA64 User Attractiveness*** variable is an aggregated indicator of how probable an end user will adopt the IA-64 platform over another competitor. The variable is an aggregate of "user attractiveness" quantities for various user segmentations in the market. As **Figure 7** illustrates for the workstation market, the end users are segmented into three different groups. Each group exercises different relative weightings for platform features in its purchasing decision. In examining the workstation market, it was noted that general segmentations of the market can be broken down to user populations who are highly performance sensitive, highly price sensitive, or optimizers of cost to performance ratio. The relative fractions of the market segments are designated W_1-W_3 in **Figure 7**.

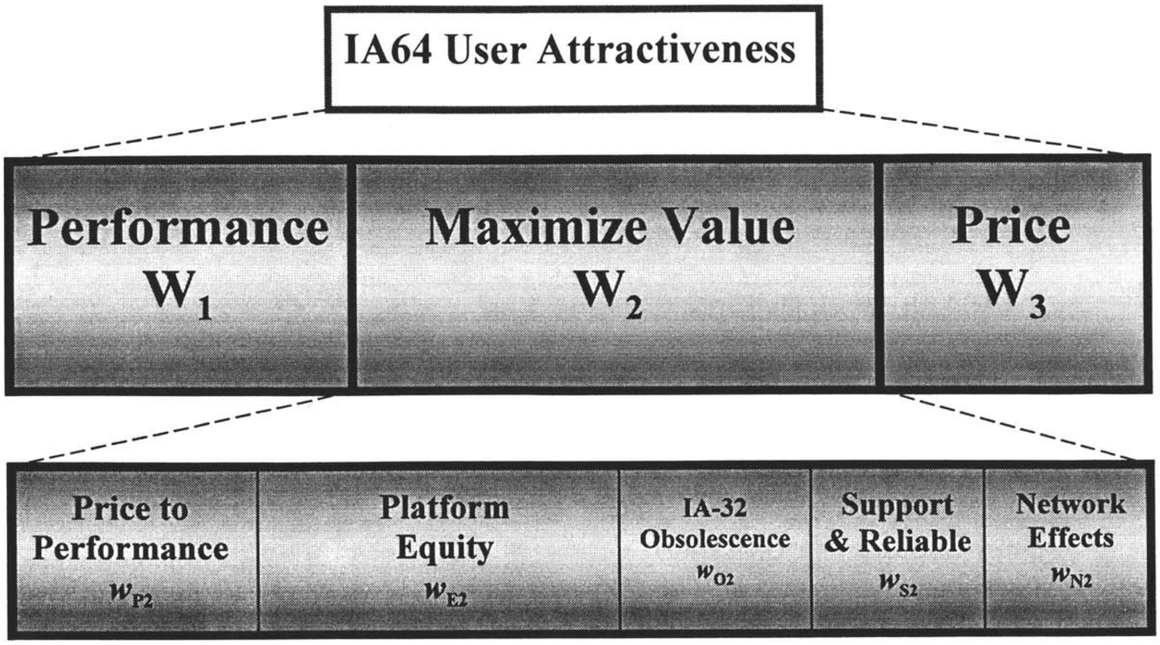

Figure 7. Structure of Workstation User Segmentation and Relative Weightings.

One begins the calculation of ***IA64 User Attractiveness*** by first identifying the relative proportions that each user segment occupies in the market. Let,

$a_x(t)$ *= Platform attractiveness for market segment x at time t*

W_x *= Relative weightings for market segment x in the market*

Then,

$$A_{IA64}^{User}(t) = W_1 a_1(t) + W_2 a_2(t) + W_3 a_3(t) \qquad \textit{Eq. 2}$$

2.4.2.2. Derivation of Attractiveness for One Market Segment

In calculating $a_x(t)$, it is useful to note that its causal variables are derived to express the modeler's best understanding of a user's decision making. The quantitative expression of the drivers reflects how a user assesses the platform features compared to all the available platforms, and how to ultimately incorporate the information into platform choice.

From the workstation model example (**Figure 6**), observe that users will typically consider their purchasing decisions based on the following platform features: price, performance, platform equity, technology obsolescence, technical support and reliability, and user network effects. The manner in which the model accounts for a user's level of attractiveness to each feature is based on two dimensions. The dimensions are platform features' attractiveness relative to competition, and the relative importance of each feature to the user.

With a large population in the user pool, one can derive an expression that numerically represents the probability of a user segment choosing a particular platform. To achieve this in the workstation market analysis, the model first establishes or calculates the quantitative profiles of each platform feature[13]. Then, the values of the feature profiles from all competitors in the analysis are totaled and a fractional value for each platform is calculated. The value indicates the user population's level of preference for a specific platform feature relative to the competitors at a specific instance in time. This percentage value is then subjected to a transfer function, called a *perception function*, which accounts for non-linearity inherent in the user's decision rules. The perception functions for the model were derived based on data gathered through interviews and research. Finally, this output is incorporated into the ***PUA***. After the derivation of perception outputs for each feature, the values are weighted according to the modeler's belief of how a user perceives each feature's importance. The weighting is determined from data gathered in the marketing organization.

An example drawn from the ***Performance*** feature of the platform will provide a clear illustration of the process described above. **Figure 8** shows a contrived performance profile projected for the workstation market for a five-year time horizon. Note that all players in the market for this example have the same performance roadmap. The acronym **SpecFP** refers to an industry standard benchmark for measuring system level performance with floating point computations.

[13] Exogenous inputs must be established while endogenous drivers are calculated.

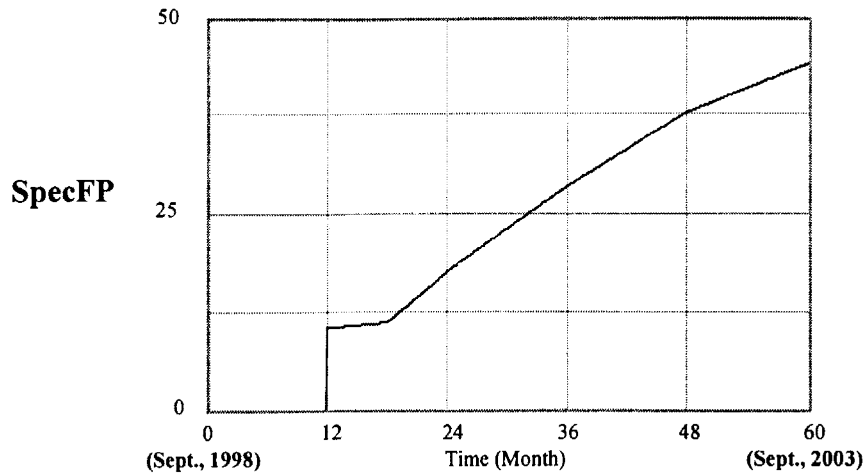

Figure 8. Projected Performance Profile for Workstation Market (5 Competitive Entities).

In calculating the ***Performance*** contribution to user population's preference for IA-64, the fractional value of IA-64's performance level is first determined. Let,

$P_{IA64}(36)$ = *SpecFP for IA-64 at time 36 = 27*

$P_{total}(36)$ = *Total SpecFP for all platforms at time 36 = 135*

Then,

$$P^{f}_{IA64}(t) = \frac{P_{IA64}(t)}{P_{total}(t)} = \frac{27}{135} = 0.2 \qquad \textit{Eq. 3}$$

Where $P^{f}_{IA64}(t)$ is the "performance share of market" for IA-64 at time instant t in the analysis. $P^{f}_{IA64}(t)$ is then subjected to a perception function (**Figure 9**), resulting in the output $P^{f*}_{IA64}(t) = 0.15$. The perception function is derived based on data from market research that describe the user population's nonlinear response to various levels of $P^{f}_{IA64}(t)$. Such non-linearity takes into account factors such as network effects of user perception on performance. Network effects in the market tend to reinforce user preference if a particular platform exhibit features that are strong relative to competitors. So, as shown on **Figure 9**, if $P^{f}_{IA64}(t)$ is small (performance of IA-64 is considerably less than the performance of its competitors), then users will attribute significantly less attractiveness to IA-64 based on performance. But as $P^{f}_{IA64}(t)$ increases above the threshold of 30% (for 5 competitive entities in the market environment), its performance based attractiveness increases at an increasing marginal rate. But at high $P^{f}_{IA64}(t)$, the marginal benefit that platform performance contributes to user attractiveness decreases due to the nature of diminishing returns.

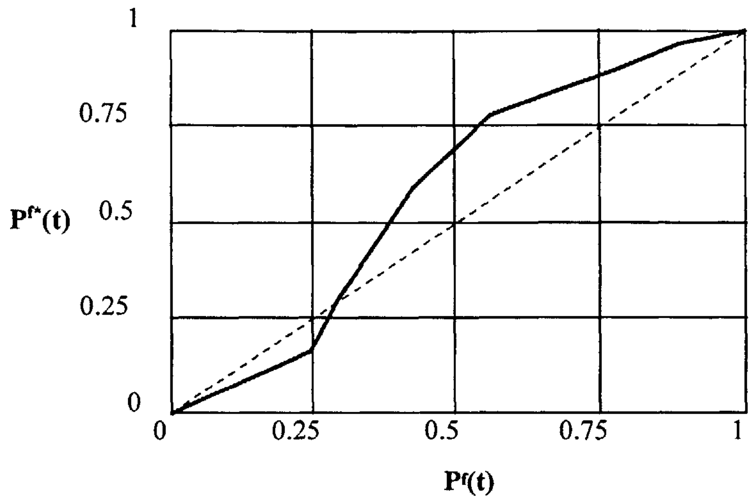

Figure 9. $P^{f}(t)$ **Perception Function.**

To derive the ***IA64 User Attractiveness*** for one market segment, the modeler would identify the relative weighting that each feature, on average, figures into the user purchase decision. If, for example, the market segment of interest is "Maximize Value" (segment 2) as shown in **Figure** 7, and let,

$a_2(t)$ = *Platform attractiveness for market segment 2*

$C^{f*}_{IA64}(t)$ = *Attractiveness contributor of price*

$P^{f*}_{IA64}(t)$ = *Attractiveness contributor of performance*

$E^{f*}_{IA64}(t)$ = *Attractiveness contributor of platform equity*

$S^{f*}_{IA64}(t)$ = *Attractiveness contributor of support & reliability*

$O^{f*}_{IA64}(t)$ = *Attractiveness contributor of IA-32 obsolescence*

$N_{IA64}^{f*}(t)$ = *Attractiveness contributor of network effects*

Where each one of the above 6 terms represents a platform feature that has been subjected to its own unique perception function. In addition, let,

$$w_{C2}, w_{P2}, w_{E2}, w_{F2}, w_{O2}, w_{N2} = \textit{weighting of attributes for segment 2}$$

Where,

$$w_{C2}, + w_{P2}, + w_{E2} + w_{F2}, + w_{O2}, + w_{N2} = 1 \qquad \textit{Eq. 4}$$

Then,

$$a_2(t) = w_{C2}C_{IA64}^{f*}(t) + w_{P2}P_{IA64}^{f*}(t) + w_{C2}E_{IA64}^{f*}(t) + w_{E2}S_{IA64}^{f*}(t) + w_{C2}O_{IA64}^{f*}(t) + w_{E2}N_{IA64}^{f*}(t) \qquad \textit{Eq. 5}$$

2.4.2.3. Launch Delay

Reflecting back on the original motivation for the IA-64 project, the primary goal was to understand the implications of Merced's six-month launch delay. This section will detail the effects of delay on ***IA64 User Attractiveness***, $A_{IA64}^{User}(t)$, through the example of the ***Performance*** feature.

From Eq. 2, recall that $A_{IA64}^{User}(t)$ is driven by the aggregate user attractiveness, $a_x(t)$. Also recall from Eq. 5 that $a_x(t)$ is dependent on $P_{IA64}^{f*}(t)$, which ultimately is derived from $P_{IA64}^{f}(t)$. In the event of a delayed product launch, as shown in **Figure 10**, the performance profile shifts to the right. If all other competitive platforms remain on schedule for their performance road maps, then, IA-64 performance will have a lower $P_{IA64}^{f}(t)$ for every instance of time. This idea can be applied to the time profile of every platform feature for IA-64. The end result of a time delay is effectively a degradation of $a_x(t)$ and ultimately, $A_{IA64}^{User}(t)$.

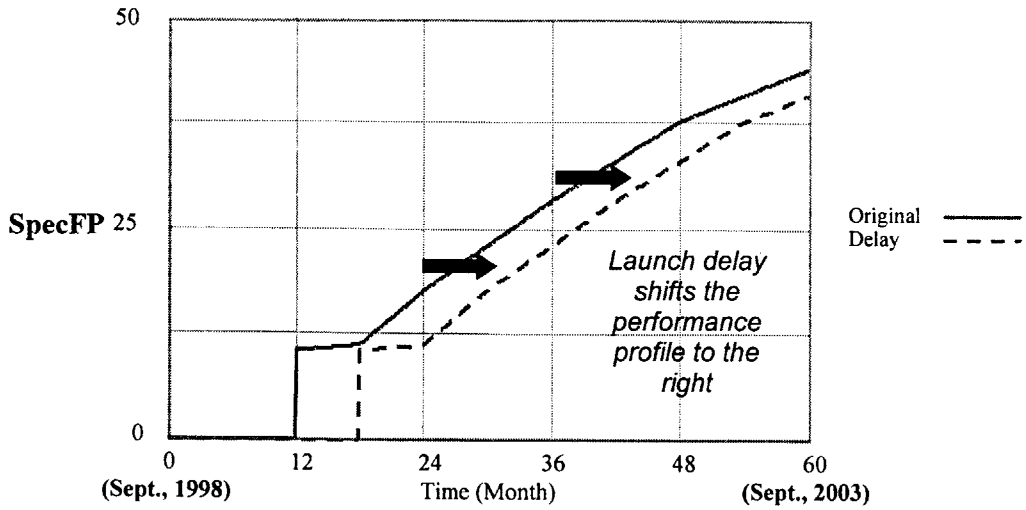

Figure 10. IA-64 *Performance* Implications of Launch Delay.

At this juncture, it is worth noting the market ramification of the nonlinear nature of $A_{IA64}^{User}(t)$. Recall from Eq. 1, that IA-64's potential SOM is determined by $A_{IA64}^{User}(t)$. Also by referring back to **Figure 3**, it can be seen that IA-64 SOM (volume) drives ISVs who, in turn, are high determinants of IA-64 platform equity. The effect of this feedback behavior on a Merced schedule slip is very similar to that of compound interest (also a nonlinear system). The initial loss of $A_{IA64}^{User}(t)$ will reinforce itself and propagate greater loss of market share as time progresses.

2.4.3. Platform Attractiveness to ISVs

The mechanism for deriving ***PIA*** is very similar to user attractiveness as described in the previous sections. The only differences in the case here are the drivers and perception functions unique to ISVs. In the workstation market model (**Figure 3**), the ISV drivers considered are: potential volume, support from workstation vendors such as Sun or microprocessor manufacturers like Intel, the effort required to develop software, and the affinity to 64 bit technology (versus IA-32).

2.4.4. Market System Time Delays

The inherent time delays in the market system are important elements to consider in the analysis. Accounting for delays, especially within the context of a feedback system, can greatly influence the accuracy of the quantitative outcome. The workstation market model accounts for two distinctive types of delays. The first type is information delays and the second type is material delays.

2.4.4.1. Information Delays

Information delays exist between just about every causal relationship in the market system. These delays simulate the discernable time gap between information's dissemination and the recipient's incorporation of that information into his decision rule.

Some of the informational delays implemented in the market model are meant to capture time lags in the processes of diffusing new information on platform features and price, ISVs support for bolstering platform equity, and the visible benefits of word of mouth promotions. The model also incorporated similar informational time delays for ISVs.

System dynamics implements time delays in the form of a stock and flow relationship[14] as shown in **Figure 11**. This diagram, from a mathematical perspective, represents a first order exponential-smoothing function. This type of time dependent function is employed for several reasons. First, its time averaging effect models a user population's smoothing reaction to high frequency informational fluctuations. Second, the delay output exhibits a high variance about the average time delay, which well depicts the market behavior of a high user population system.

[14] John D. Sterman, "Business Dynamics: Systems Thinking and Modeling for a Complex World" (working title) Version 1.0, 1997, p 6-1.

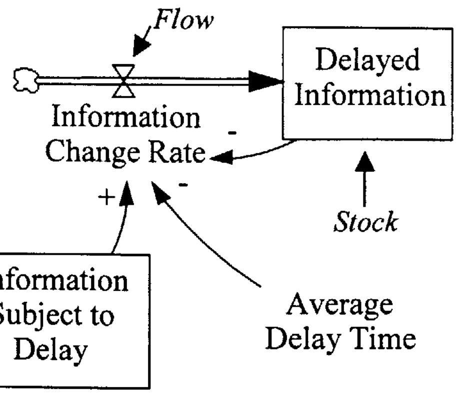

Figure 11. The Stock and Flow Structure of a First Order Informational Delay.

The stock, depicted by the block, is analogous to a tank. The flow, depicted by the arrow, is analogous to a faucet that determines the rate and the direction of flow to and from the tank. From a mathematical standpoint, let

I_{in} = *Information subjected to delay*

T_D = *Time constant (the average time for adjusting to new information)*

I_D = *Delayed information (stock)*

r = *Rate of change for* I_D *at a specific time interval (dt)*

Based on the diagram of **Figure 11**, if the flow determines the rate of change in the stock, then a relationship can be derived such that,

$$r = \frac{\Delta I_D}{\Delta t} = \frac{I_{in} - I_D}{T_D} \qquad \textit{Eq. 6}$$

From which can result in the following first order linear differential equation:

$$\frac{dI_D}{dt} = \frac{I_{in} - I_D}{T_D} \qquad \textit{Eq. 7}$$

Solving the differential equation will yield I_D for a specific time interval,

$$I_D = I_{in} - (I_{in}^o - I_D^o)e^{-t/T_D} \qquad \textit{Eq. 8}$$

Where I_{in}^{o} and I_{D}^{o} are initial values of I_{in} and I_D, respectively, at $t=0^+$ for a given time step interval in the analysis. Intuitively, if T_D is large, it will require a much longer time period for I_D to catch up to I_{in}. Alternatively, one can depict the stock as a capacitor that dampens the effects of the incoming signal with a time constant T_D.

A simple case of the dynamic mentioned above is illustrated in **Figure 12** where the delay structure is subjected to a step function at time step 10. The level change of this step function could represent the expected percentage of user population who will receive new product information, perhaps a reduction in price. If the information is disseminated at time step 10, the user population's adoption (100%) of this new information will not be immediate. The market population will tend to exponentially converge to the 100% goal with an average time delay of 12 time steps (22 time steps into the analysis). This is a typical market behavior of a sales curve or user adoption profile, except in this particular case, the market is adopting new information.

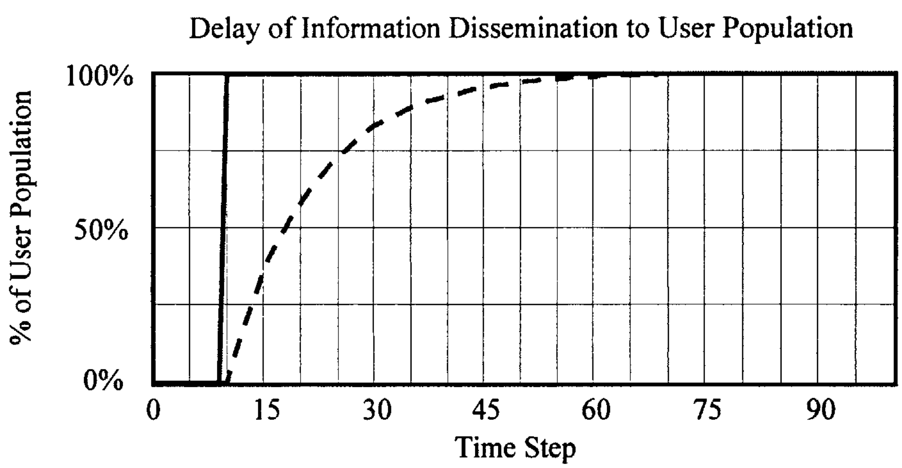

Figure 12. The Time Adjustment Behavior of First Order Informational Delay.

The first order information delay is incorporated for all relevant causal relationships in the model. The reason for this is that first order information delays represent the worst case in terms of delay variance (greatest level of smoothing). Therefore, unless more information can be obtained to justify a higher order delay, the model will establish its information delays with more conservative assumptions.

2.4.4.2. Material Delays

Material delays differ from the informational delays in that the stock is considered a physical entity. As drawn in **Figure 13**, the delay system consists of a positive inflow, positive outflow, and a material stock that by definition can never be negative. The net inflow of the system, or rate of change of the stock, is inflow minus outflow. Note that the rate of outflow is a function of the stock and the average time delay of outflow, so if the stock depletes to zero, the outflow will also be zero. Let,

r_{in} = *Rate of material inflow*

r_{out} = *Rate of material outflow*

T_D = *Average delay time of outflow*

S_D = *Material stock*

The diagram will yield the following first order differential equation:

$$\frac{dS_D}{dt} = r_{in} - \frac{S_D}{T_D} \qquad \textit{Eq. 9}$$

Solving the differential equation will yield,

$$S_D = T_D r_{in} - (T_D r_{in}^o - S_D^o)e^{-t/T_D} \qquad \textit{Eq. 10}$$

Where r_{in}^o and S_D^o are initial values of r_{in} and S_D, respectively, at $t=0^+$ for a given time step interval in the analysis. Examining the above equation will lead one to see that for,

$$r_{out} = \frac{S_D}{T_D}$$

the outflow will be a smoothed and delayed form of the inflow. For a large average time delay, T_D, r_{out} will become less reactive to changes in r_{in}. For a more intuitive understanding, imagine the equilibrium scenario where $r_{out} = r_{in}$ and where $S_D > 0$. If suddenly r_{in} drops to zero, r_{out} would not immediately follow. Depending on the value of T_D, S_D would deplete exponentially based on the exponential decay of r_{out}. This behavior well represents a model of radioactive decay with a half-life of T_D. See **Figure 14** for an illustration of this dynamic.

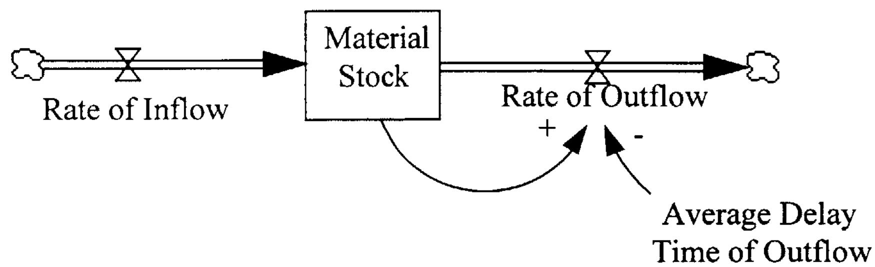

Figure 13. The Stock and Flow Structure of a Material Delay.

It should also be noted that the material delays incorporated in the model are first order delays. The justification is consistent with that of the informational delays described in section 2.4.4.1.

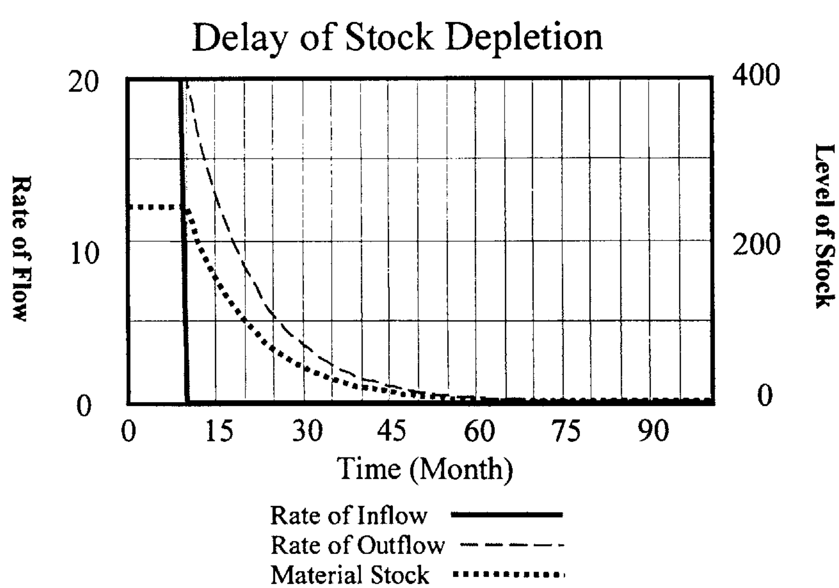

Figure 14. The Time Adjustment Behavior of First Order Material Delay.

2.4.4.3. Application of Material Delays

The application of material delay plays a very important role in the workstations market model. **Figure 15** shows a high level stock and flow diagram depicting the cascaded time delays in an end user decision making process. The ***SOM Volume*** "stocks" are delineated to emphasize the factors that influence the time requirements for the user to move from the ***Natural SOM Volume*** bucket to ***Realized SOM Volume***.

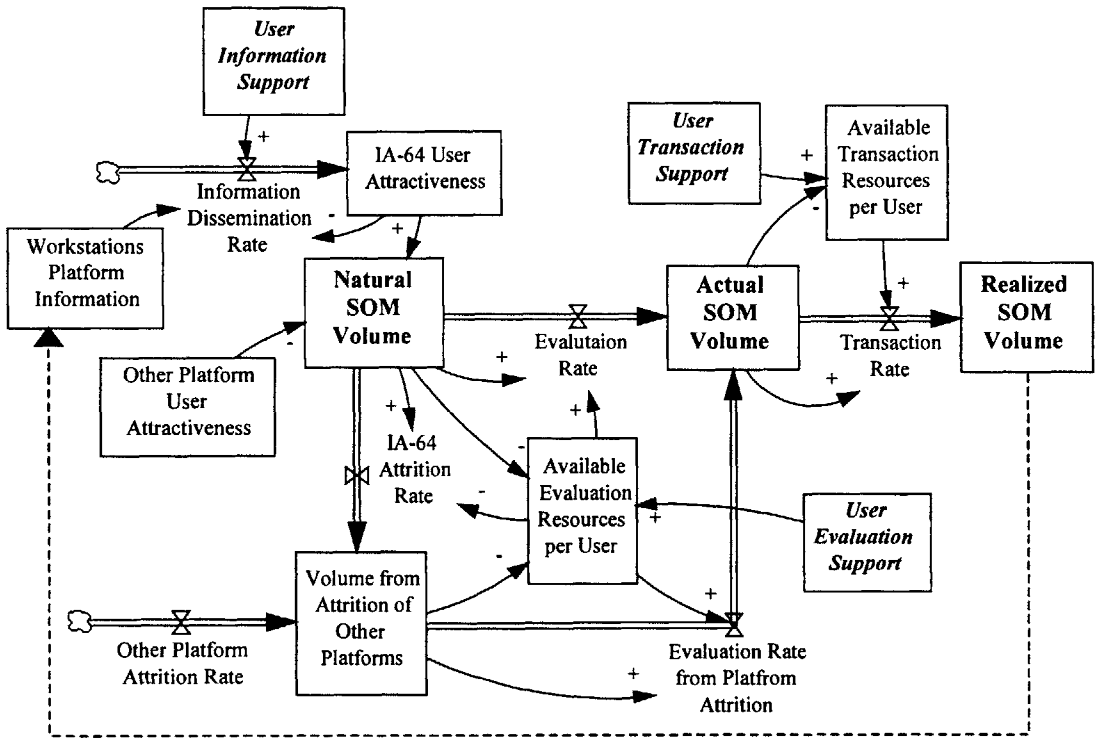

Figure 15. Time Delay Structure of the End User Decision Making Process.

Referring to **Figure 15**, note that the ***Natural SOM Volume*** is derived from the attributes of the workstation platform and is subjected to an informational delay. Once the potential customer receives and establishes the credibility of the information, he or his IT organization will typically conduct evaluation of the platform hardware/software combination and determine the platform fit on a functional and organizational level. The model is designed with the assumption that, ex ante, the ***Natural SOM Volume*** will all translate to ***Actual SOM Volume*** provided that adequate resources (either through marketing or other industry sources) are available during this evaluation phase[15]. If user evaluation support is low, then the available resources for evaluation per user may be inadequate, which in turn, may significantly lengthen the evaluation delay time. In which case, due to platform attrition, the platform's ***Actual SOM Volume*** may be less than its ***Natural SOM Volume***.

The second stage of the material delay mechanism captures the transaction delays inherent in realizing an actual workstation sale. The process of moving from ***Actual SOM Volume*** to ***Realized SOM Volume*** involves significant time delays (relative to the velocity of the industry), especially for large organizations where capital purchase orders may take several months for approval.

From the user decision dynamics depicted in **Figure 15**, it can be recognized that factors influencing the transition from platform attributes to a realized sale may be heavily dependent upon marketing and customer support investments. Therefore, the benefits of capturing these material delays are not just to enhance the accuracy of the model, but to bring about recognition in their potential for leveraging competitive advantage. A quantitative tool, like the workstation market model, will not only aid in the decision of where to invest, but how much to invest. This point will be further illustrated in Chapter 3.

2.5. Model Outputs

To put some flesh on all the modeling concepts discussed in the previous sections, this section will provide an overview of the key workstation model outputs from several time sweeps. It will also detail the assumptions made in the model for better understanding of the analytical premises.

[15] One approach to grasp the intuition of this dynamic is to consider an environment with no time delays in platform evaluations and transactions. In such a market environment, no platform attrition occurs and the end users will base purchasing decisions solely on platform attributes. Therefore, all users in ***Natural SOM Volume*** stock will be realized in ***Actual SOM Volume*** and eventually ***Realized SOM Volume***.

2.5.1. Model Premises

The model is designed based on the following premises:

- A five-year time horizon is the furthest that accurate industry data can be obtained or forecast.
- On average, ISVs conduct their ROI analysis one-year into the future.
- A majority of the end users have no firm platform preferences. They can be swayed if given the right incentives.
- The cause for Merced schedule is an exogenous input (not influenced by any entities modeled).
- All actors in the industry have access to relevant information and will act rationally in their decision making.

All the inputs into the model indicated in **Figure 1** are exogenous drivers. Input parameters such as price or performance are characterized by time varying profiles that were provided by Intel marketing sources. The inputs used in the analysis of this thesis, both constants and time profiles, have been altered and bear no resemblance of the original Intel data.

The market system time sweeps also account for the interactions of five competitive platforms. With the exception of IA-64, all platforms were characterized with equal-valued feature profiles (price, performance, etc…).

2.5.2. Time Sweep Results

The following section shows three most relevant outputs of the analysis. They are SOM in unit volume, present value of cash flows from Intel microprocessors, and platform equity. **Figure 16** is the plot of IA-64 volume SOM that illustrates the impact of launch delay. The interesting feature to note is that, with a delay, the SOM never recover to the baseline scenario. This is characteristic of a reinforcing system.

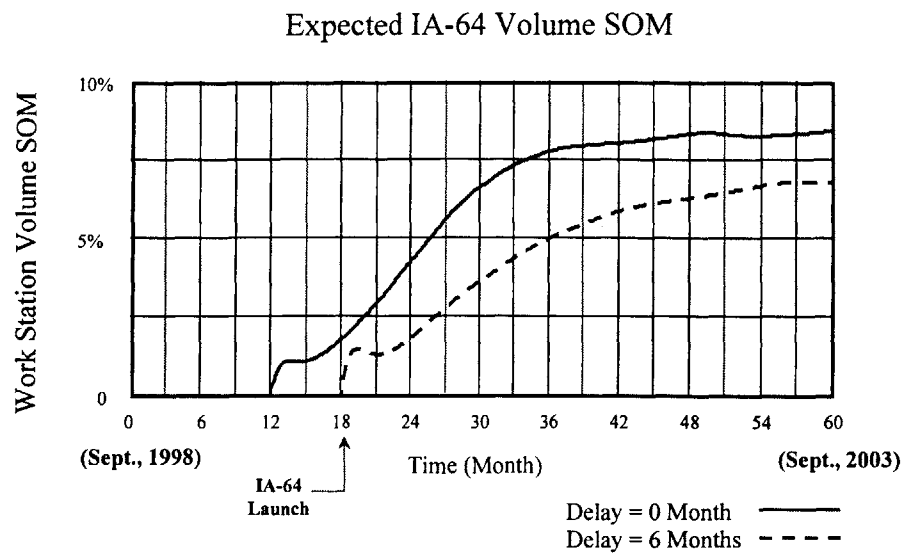

Figure 16. End User Reaction to Launch Delay.

From a financial perspective, the figures in **Table 1** show the schedule slip's impact on cumulative microprocessor cash flows to Intel discounted 5 years into the analysis (please refer to section 5.1 of the Appendix for details relating to present value calculations). The IA-32 results have been included in this analysis because of its interesting interactions with the Merced delay. By examining the ***$ Difference*** row, it is evident that IA-32 benefits from the delay scenario and balances the "lost cash" of IA-64, thus, stabilizing Intel's overall cash position (where there is only a 1.3% impact on PV of positive cash flow).

	IA-64	IA-32	Total
6 Month Launch Delay	$370.2	$3,094	$3,465
No Launch Delay	$523.4	$2,987	$3,510
$ Difference	($ 153.2)	$ 107	($ 45)

Table 1. Cumulative Present Value (Millions) of Microprocessor Cash Flow for 60 Months.

The ISV reaction to Merced delay, shown in **Figure 17**, is very similar to that illustrated in **Figure 15**. Again, because of the market system's reinforcing, feedback nature, the platform equity gap between the delay and baseline scenarios widens as time progresses.

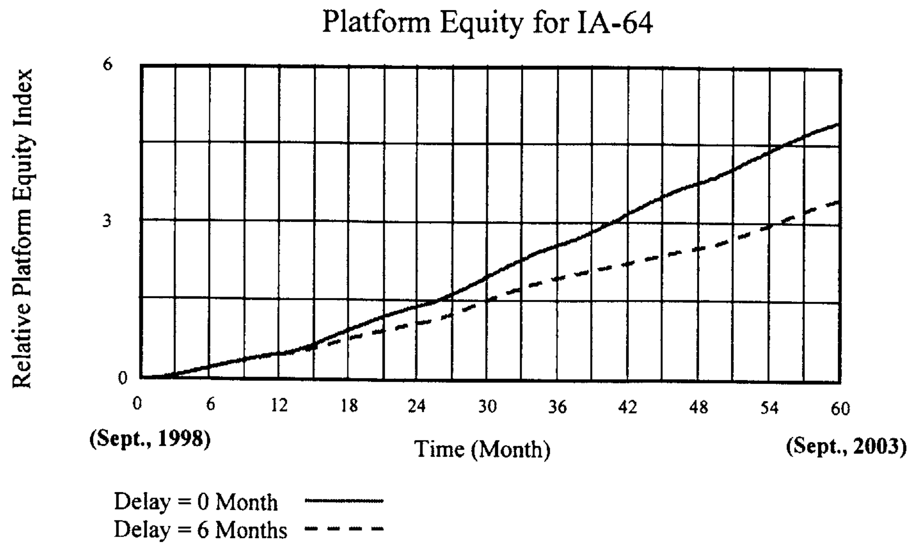

Figure 17. ISV Reaction to Launch Delay.

2.6. *Model Improvement and Validation*

2.6.1. Possible Improvements

At the conclusion of the Intel WPG project, the workstation market model, although comprehensive, still has many areas for improvement. It is the opinion of the author that the general framework of the model, in term of market drivers, feedback relationship, and system delays, provides an adequate basis for analysis. The area where the improvement opportunities lie is in the mathematical relationships of the causal links, especially with the perception functions and platform attribute weighting factors that drive ***PUA*** and ***PIA***.

If more time and resources were available, one could derive more accurate perception functions. This can be accomplished by conducting detailed industry surveys and employing conjoint analysis. Another improvement opportunity one can embark upon is to incorporate the market size as an endogenous factor in the model. This may involve incorporating econometric factors specific to the workstation and high-end computing industry.

2.6.2. Framing the Validation Approach

After the process of building a comprehensive market analysis model, the customers of the tool would naturally wonder about the validity of the outputs, especially if the outputs suggest drastic policy changes and potentially high economic impact. Due diligence dictates that the outputs of a forward-looking model should always be evaluated for their reliability. There are two points to be made with this regard.

First, no forecasting tool can be verified in an ex ante fashion. In other words, aside from experience and intuition, the accuracy of the workstation market model can never be fully assessed in a deterministic manner. One may attempt to conduct a regression exercise by applying the model to similar historical scenarios such as the transition between 16-bit to 32-bit technologies. But it must be noted that several caveats persist with such a validation approach. One, such exercise must assume strong congruence in market conditions between the forecast and historical scenarios. In most cases of high velocity and high growth industries, this assumption is very difficult to justify. A careful observation of the personal computing industry in the last 15-20 years will reveal that no two technological transitions behaved identically. It would be very difficult to even identify congruency in basic market characteristics such as target segment, price/performance ratio, factors driven by complementary products, let alone all market conditions. Therefore, the inconsistencies in the experimental environments may result in an inconclusive hypothesis testing effort.

Another caveat to realize is that crunching the model against historical data only serves to validate the model calibration for that market scenario. It may not offer any significant insights that can be readily applied to current market conditions. In other words, every phase of the market development in an industry requires a unique calibration set that reflects the distinct behaviors of end-users and value chain entities. The true art of leveraging the model for forecast and strategic analysis is to derive calibrations that offer sufficient linearity over the time horizon of interest, provided that adequate congruency can be maintained with market conditions.

The second point, in conjunction with the first, speaks to the manner in which one maximizes the accuracy of the model outputs. In the course of validating a predictive model, it may be deemed appropriate to develop a conjecture that assumes the validity of the output[16] . But the model would be subjected to continuous scrutiny for unaccounted causal relationships and logical inconsistencies. The predisposition on the hypothesis of a valid output provides an important foundation for the model's refinement and interpretive processes. It steers the model users away from the temptation to question the validity of the outputs, which in principle, cannot be answered in an *a priori* manner, nor can it be accurately tested. The highly dynamic market system does not offer a basis for controlled experimentation, an environment where one can repeatedly test and verify various hypotheses.

By adopting a "continuous model improvement" approach, the model users assume a more pragmatic basis for critical analysis of the model's robustness. It stretches the analytical discipline of the model stakeholders to explore all relevant factors that will minimize the model's probability in introducing a *predictive error*[17]. The degree of model accuracy and complexity achieved should be consistent with the model user's needs and expectations. Ideally, this iterative process will maximize the probability that the model results correlate with future reality.

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[16] This notion is consistent with the general application of predictive tools. Take, for example, the exercise of planning production capacity. In the course of determining specific resources and materials needed to fulfill expected demand, the planners, by their allocations, implicitly assume total accuracy of volume forecast.
[17] The idea behind *predictive errors* is, given that there will be a future data set which may be tested against the hypothesis generated by a forecasting model today, minimizing the predictive error is analogous to believing ***model hypothesis = future data*** until flaws in the model are identified. Upon which, ***model hypothesis = future data*** again when the flaws are mitigated.

3. Strategic Analysis

This section will examine in detail the mechanisms of applying the market dynamics model in the analysis of various strategic options. The options that are considered are broken into two groups, operational strategy and marketing strategy. The discussions for each strategic option will consist of an evaluation of its plausibility given the model limitations, a benefit analysis, and an assessment of its practicality in implementation. Note that the results of the following analysis are derived from contrived data and do not, in any form, resemble the actual Intel analysis.

3.1. Early Time to market

3.1.1. Strategy

This operational strategy involves an aggressive product roll out that puts the technology road map back on the original schedule. A note on terminology clarification: the term "original schedule" referenced in the context of this section signifies the product launch schedule without the six-month delay. **Figure 18** is the technology rollout profile for the IA-64 systems with and without a six-month schedule slip. Given that a launch delay is inevitable, the management decides to squeeze the engineers to perform a miracle. As illustrated in **Figure 19**, the proposed performance profile not only recovers to the original schedule six months after Merced launch, but it actually begins to exceed the original road map six months after initial rollout. The plausibility of such a feat is questionable, but even it were possible, this analysis manifests a rather stunning outcome.

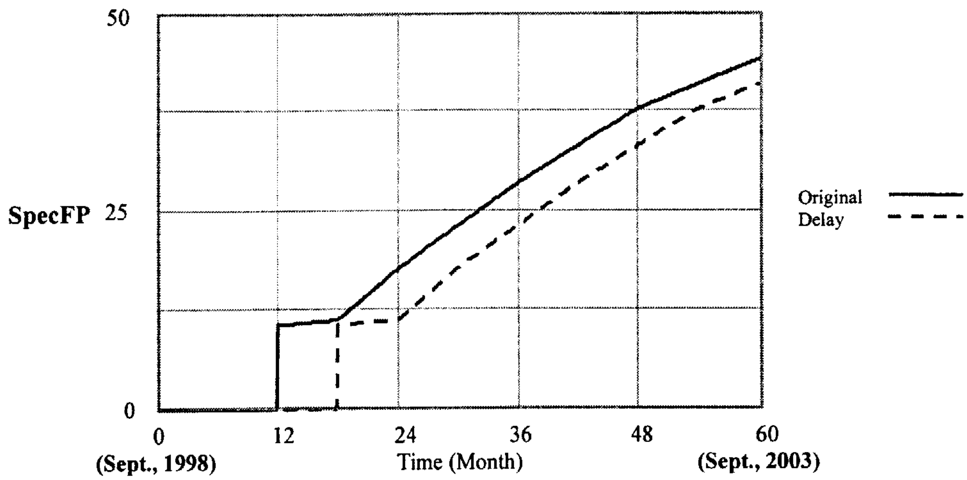

Figure 18. IA-64 Performance Profile as Consequence of Delay.

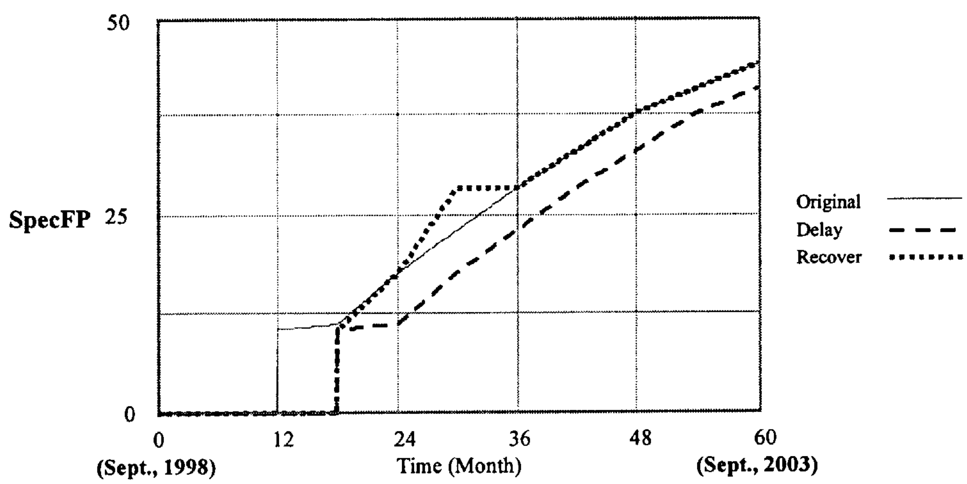

Figure 19. IA-64 Performance Profile with TTM Recovery Strategy.

3.1.2. Results & Key Learning

The output of this strategy analysis compared to the original and delay baselines can be seen in **Figure 20**. With the effort to get the product roadmap back on schedule, the strategy makes a remarkable comeback. But interestingly, the market penetration flattens out at about 7.5%. The trend seems to indicate that the early time to market effort will not bring the desired recovery.

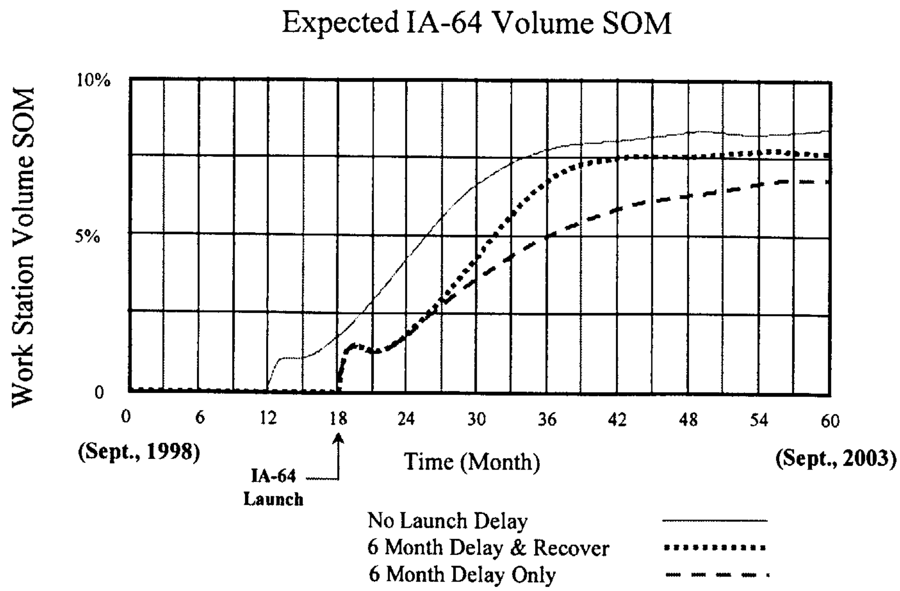

Figure 20. Volume SOM for Early Time to Market.

There are several key learning that pertain to the feedback dynamics of the market system. First, because of the reinforcing nature of the market described in section 2.3.1.3, the system behaves similarly to compound interest. The volume SOM is like principal. The greater the principal invested, the more interest (platform equity) is earned, which then will drive a greater level of principal. The important point to note is that the earlier the principal is invested, the greater the realized return. Similarly, any delay in the Merced rollout will deny the platform the opportunity to earn initial platform equity. The real cost of this delay will come at the unrealized long term IA-64 volume SOM because IA-64 could not generate any market adoption, and hence platform equity, for 6 months. This dynamic is the key reason for the failure of this strategy to realize a market share recovery, even with a "better than before" rollout plan from month 24 to 36.

The second point, which is a more generalized notion of the previous discussion, pertains to the idea of optimal market entry. In a market system that is heavily influenced by the down-stream value chain, first or early to market may not yield the greatest ROI. For Intel, it must fully understand the state of the market environment from three dimensions: the end user, the value chain entities, and the competitor. By fully comprehending the industry's readiness for the new technology through extensive market research, Intel can then target on an optimal market entry point. Given that Intel is the last major semiconductor player to get into the 64-bit game in addition to strong competitor platform equity, it is the author's opinion that the Pentium maker has missed that window of opportunity.

From a cost benefit perspective, this strategy of product roadmap recovery will come at an enormous operational cost (if it can be achieved). It is strikingly obvious that a more viable strategy with greater yields should be sought.

3.2. Product Repositioning

3.2.1. Strategy

This operational/marketing hybrid strategy takes on a more pragmatic approach. It will initially reposition the products in terms of price and performance to target a different market segment. The analysis assumes that the delay is the result of IA-64 designers' inability to meet initial performance requirements. The strategy will dictate a "no delay" launch schedule with a scaled back version of the microprocessor for the first 2 years. To maintain value consistency with a lower platform performance, marketing will initiate a campaign for a lower product price point. The price will make its way back up in year 3 into the analysis. **Figure 21** illustrate this strategy with an "original" and "revised" perspective.

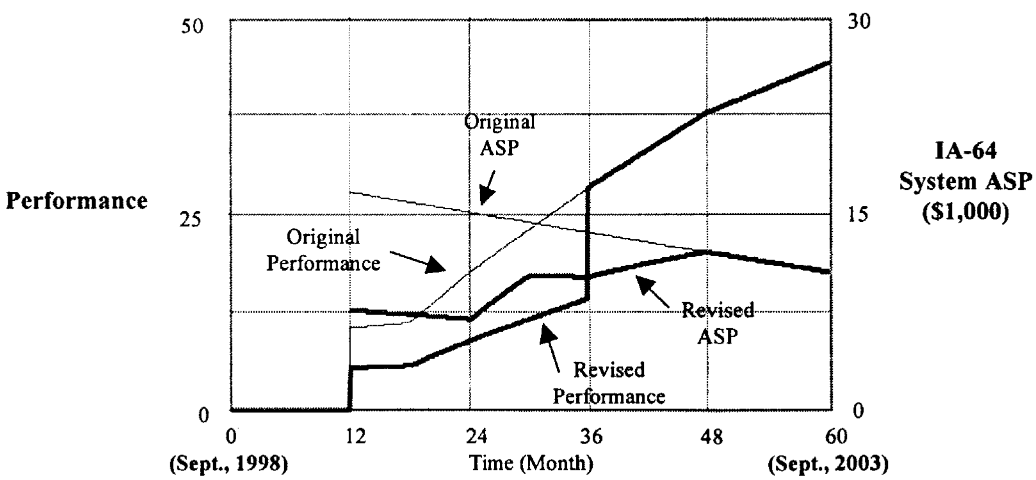

Figure 21. Performance and Price Profiles for Product Repositioning.

3.2.2. Results & Key Learning

Plot of the volume SOM in **Figure 22** shows a market penetration that closely correlates with the original schedule. One exception is the period between months 39 to 54. The higher volume is due to a period of lower than originally planned prices (resulting in higher performance/price ratio). The similarity to the baseline also comes about because the analysis assumes the existence of a significant customer segment that favors lower performing, lower priced workstations. This result supports the importance of early (or on time) market entry, in which one can realize the market's long range reinforcing effects.

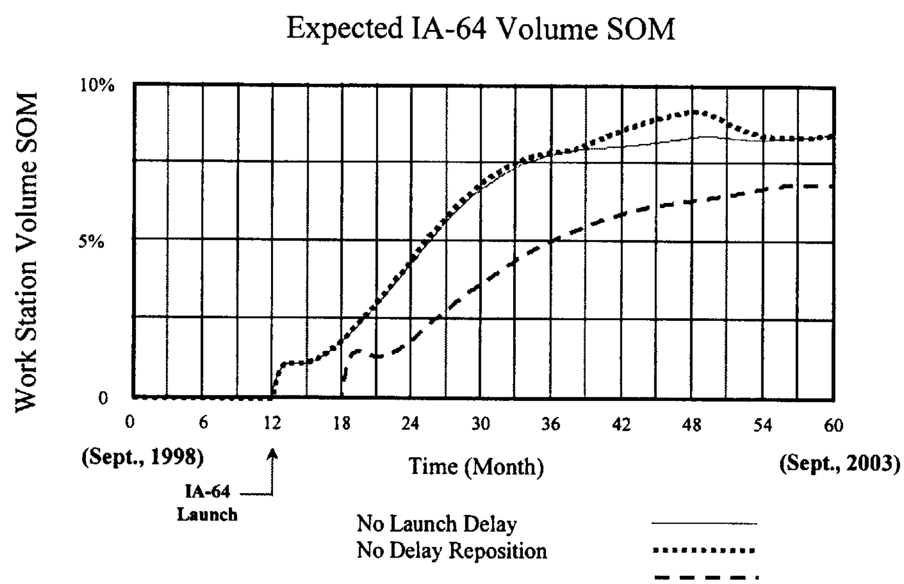

Figure 22. Volume SOM for Product Repositioning.

The interesting downside to this strategy is shown **Table 2**, the discounted positive cash flow of the product positioning adjustments. The computations indicate that this strategy of driving up IA-64's volumes will actually cannibalize the IA-32 platform, compared with the six-month delay scenario. And because IA-64's volumes were gained at significantly lower margin, the strategy will result in a lower overall investment value for Intel. But due to the higher volumes generated for IA-64, its gain in platform equity shown in **Figure 23**, indicates that this may be a compelling strategy for supporting IA-64's market position in the long term. The impact of this decision will cross boundaries of profit centers, which would make for a very interesting organizational challenge.

	IA-64	IA-32	Total
No Launch Delay	*$523.4*	*$2,987*	*$3,510*
IA-64 Repositioned Strategy	$393.5	$3,006	$3,400
6 Month Launch Delay	$370.2	$3,094	$3,465
Improvement Over 6 Month Delay	$ 23.3	($ 88)	($ 65)

Table 2. Cumulative Present Value (Millions) of Microprocessor Cash Flow for 60 Months with Product Repositioning Strategy.

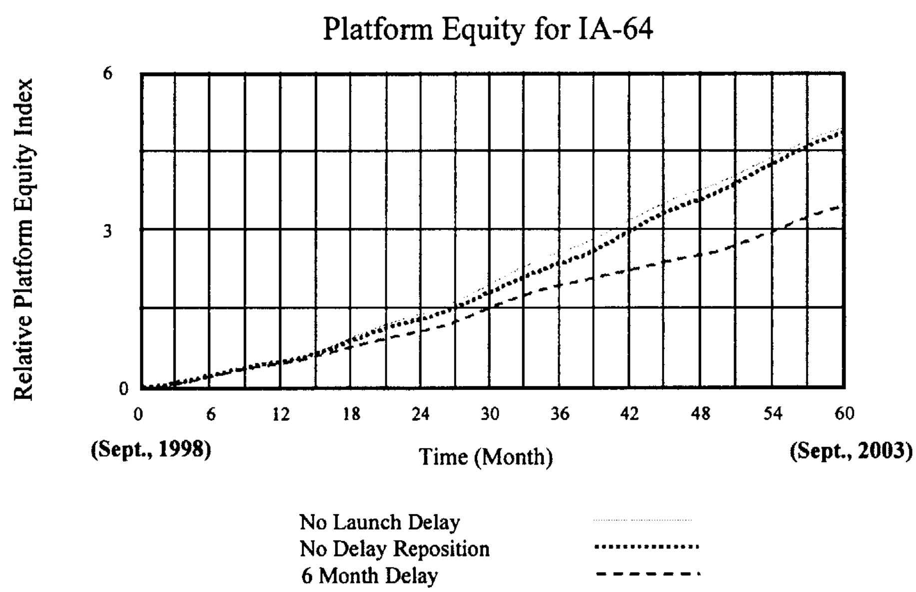

Figure 23. Platform Equity for Product Repositioning.

Others issues that may arise from this strategic approach relate to branding and ability to elicit support from down stream OEMs. From a branding point of view, one may be concerned with the long-term market impact of "dumbing" down the CPU. And with the OEMs, who is to say that they will buy into the program by slashing their prices 50%? These difficulties, coupled with the unfavorable value proposition, render this strategy non-beneficial from an overall Intel point of view.

3.3. Pricing & Marketing Investment

3.3.1. Strategy

This strategic option takes on a predominately marketing approach for market share recovery. The levers for this strategy do not impinge on the current product rollout schedule, thus, the entire strategic effort can be sponsored by a marketing organization. The key factors considered are the pricing and its combined effect with time lags adjustments in the end user decision making process (**Figure 15**). The case of adjusting just the price alone will first be present. Then, the effects of time lag adjustment will be incorporated to induce further SOM enhancements.

The proposed pricing profile for a market recovery is shown on **Figure 24**. It shows a steady increase in system level price cut (average selling price of all products) from 0% to 20% of planned price. The resultant SOM, shown on **Figure 25,** is very encouraging in that market recovery is achieved at month 54. But as expected, **Table 3** shows the cost on ROI for such a strategy. This cost comes about because IA-64 generates less revenue while IA-32 loses volume (to IA-64).

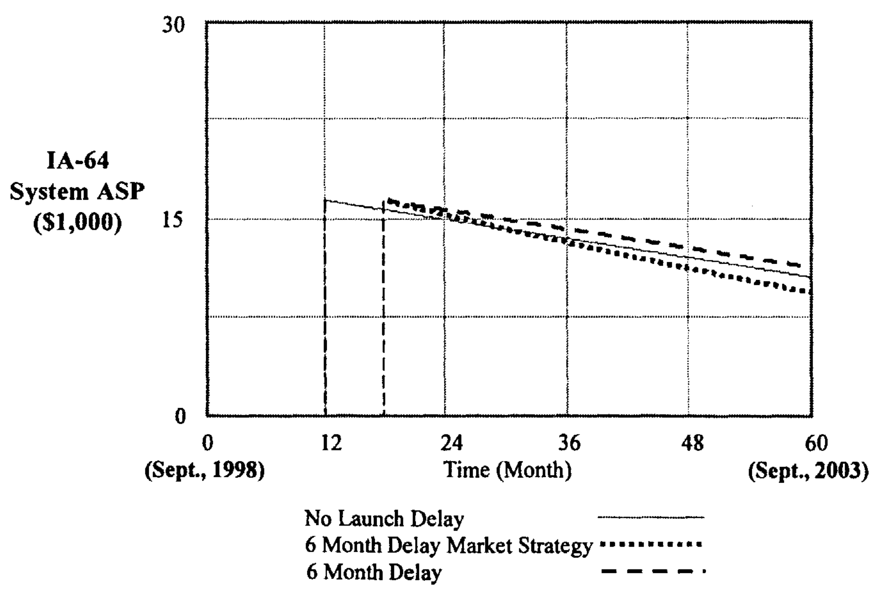

Figure 24. Proposed Strategic Pricing Profile.

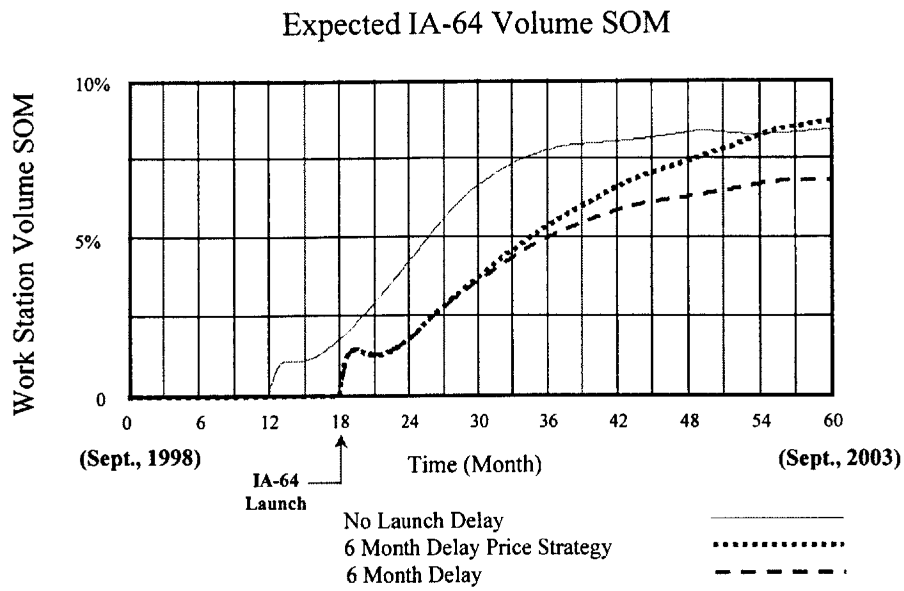

Figure 25. Volume SOM with Only Pricing Strategy.

	IA-64	IA-32	Total
No Launch Delay	*$523.4*	*$2,987*	*$3,510*
IA-64 Pricing Only Strategy	$360.4	$3,080	$3,440
6 Month Launch Delay	$370.2	$3,094	$3,465
Improvement Over 6 Month Delay	($ 9.8)	($ 14)	($ 25)

Table 3. Cumulative Present Value(Millions) of Microprocessor Cash Flow for 60 Months with Pricing Only Strategy.

The investment proposition shown above can be improved by compounding the pricing strategy with the effects of shortening time delays in the end user purchasing process. The strategy proposed is to increase the user support for both the evaluation and transaction processes. The analysis done had reduced the time lag for these processes by 20%, with the assumption that no competitor has also taken on such an initiative.

3.3.2. Results & Key Learning

The outputs of this strategy contain several observations worthy of mention. First, the initial bump in **Figure 26** at launch reflects the higher initial ***Actual SOM Volume*** (due to lower evaluation time lag) working in conjunction with the faster transaction process. This dynamic will fill the ***Realized SOM Volume*** stock very quickly at first and then dip down as ***Actual SOM Volume*** get depleted[18]. The system then resumes its increasing SOM trend as the benefits of the lower price drives higher platform attractiveness.

Second, notice that the market penetration benefits of this strategy tapers to the "pricing only" strategy at around month 42. This is an artifact of the contrived input data and model calibration employed in order to protect Intel proprietary information. In actuality, one would expect the high initial market proliferation to have a significant long-range effect on SOM, primarily due to the reinforcing forces of platform equity.

Table 4 shows the ROI results from the strategy, assuming the cost of the marketing investment is small compared to the operating cost. Again, IA-32 cash stream suffers as a result of IA-64's improved market position. But the numerical results in this case, indicate that Intel may drive its microprocessor investment value towards the baseline ROI with relatively inexpensive and feasible marketing initiative.

[18] Remember from section 2.4.4.2 where it showed that the rate at which ***Realized SOM Volume*** is fill is dependent on the level of ***Actual SOM Volume*** stock.

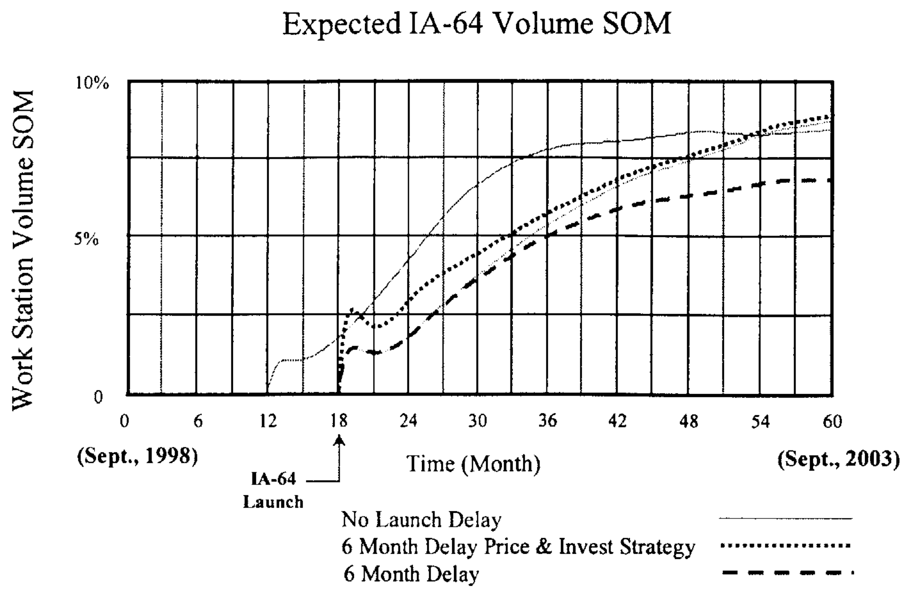

Figure 26. Volume SOM of Investment and Pricing Strategy.

	IA-64	IA-32	Total
No Launch Delay	*$523.4*	*$2,987*	*$3,510*
IA-64 Pricing & Investment Strategy	398.1	$3,072	$3,470
6 Month Launch Delay	370.2	$3,094	$3,465
Improvement Over 6 Month Delay	$ 27.9	($ 22)	$ 5

Table 4. Cumulative Present Value(Millions) of Microprocessor Cash Flow for 60 Months with Pricing & Channel Investment Strategy.

From a manufacturing perspective, **Figure 27** may serve as a useful output in determining the ROI based on economy of scale (EOS). If say, the manufacturing process operates at optimal scale at 200,000 units/year, and one is able to derive the dollar benefit as a function of time saved in reaching that volume rate, then the savings can be incorporated into the cost benefit analysis of a strategy. This type of volume analysis is particularly pertinent to Intel because of the high impact of EOS on semiconductor processes. The strategy proposes an improvement of over three operating quarters in reaching its optimal EOS due to the increase market demand.

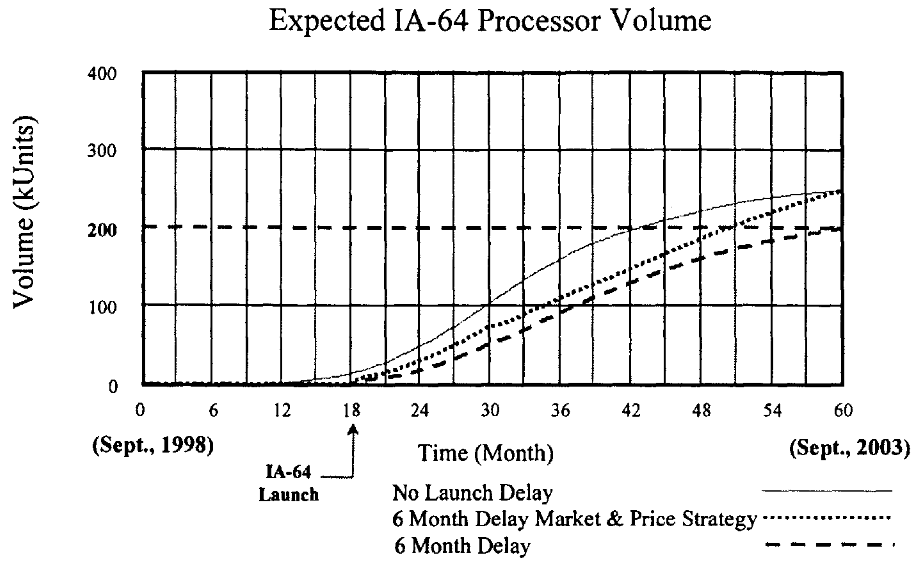

Figure 27. Expected Volume Over 1 Year Time Horizon for Investment/Price Strategy.

4. Recommendations

4.1. Summary of the Key Learning,

4.1.1. Market System Behavior

Applying the modeling techniques of system dynamics to analyze the behavior of the workstation market has yielded several key insights. First, the reinforcing feedback nature of the market, in a competitive environment, dictates optimal market entry. This does not necessarily mean a first to market strategy. If the industry, from both value chain and end user perspectives, is not ready for rapid technology adoption, an early market entry can be counter-beneficial. A salient example is the Alpha chip. Digital was by far the first to market on 64-bit technology, but could not generate any market support because the industry lacked the infrastructure and demand to propagate the platform equity feedback loop.

A proposed approach to identify the optimal market entry point may be formulated with the market dynamics model. From an engineering angle, one can interpret the "readiness" of the industry for a new technology by the relative gain of the feedback loop. With higher feedback gain (or loop gain), the feedback loop will generated greater platform equity. Which, in turn, will ultimately generate greater volume (or user adoption). Illustrated in **Figure 28** is the proposed loop gain profile of a workstation platform technology[19]. Note that because of the loop gain's time varying nature (the level of industry readiness), optimal market entry is not first to market. Instead, the best entry point is on the rapidly rising edge of the gain profile.

From a practical point of view, one can begin this analysis by identifying the drivers of the loop gain. For the workstation market, these drivers can take on the form of investment to application developers, interest of the user population and ISVs in adopting new applications, and level of user sophistication in promoting the technology by word of mouth. Once these

[19] This profile is shown only for the purpose of illustrating the dynamics behind market entry strategies. It is approximated based on empirical observation of the industry history and no claim is made as to its accuracy in either relative magnitude or time horizon.

drivers are identified and evaluated, one can attempt to pinpoint the position of market on the loop gain profile. When this point is determined, one may pursue either one of two paths. First, provided that the industry has not progressed to the optimal entry point, one can wait. Or alternatively, he can try to influence the drivers of the loop gain. Example, one can raise the level of user sophistication and awareness by providing free training and long-term demo units to potential customers.

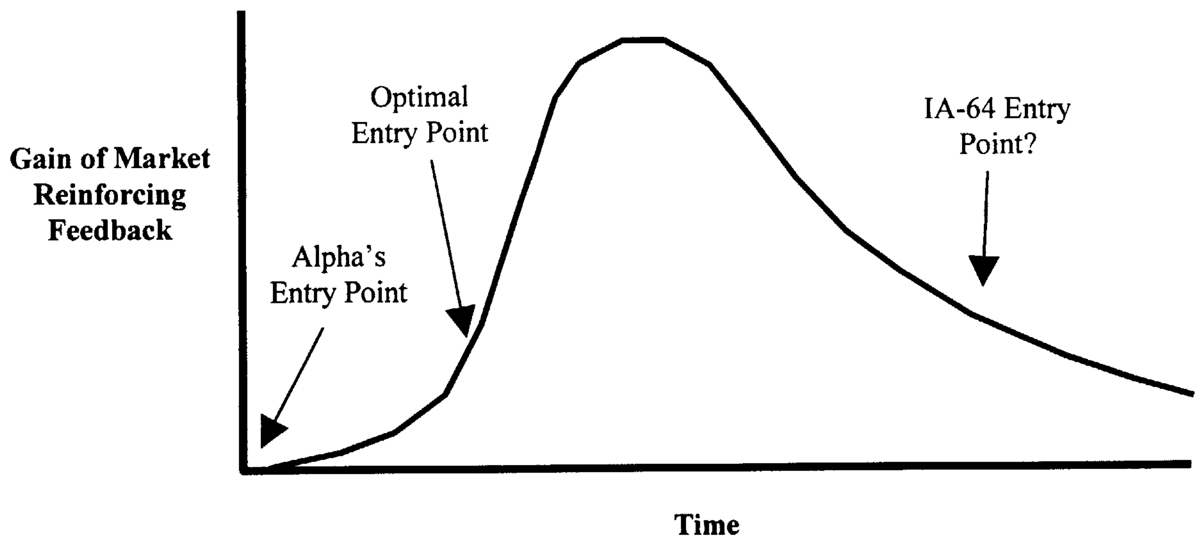

Figure 28. Gain Profile of Reinforcing Feedback Nature of Workstation Market

Another point to note with regards to the system reinforcing nature is that the actions taken today has long term consequences. And the significance of these consequences grows as time progresses. This behavior resembles the nature of compound interest.

The second insight gained from the modeling process is that a platform's natural volume may not always be fully realized (refer to **Figure 29,** which is a replication of **Figure 15**). Depending on the level of marketing investment made to support the end users' evaluation and transaction processes, a platform can realize more or less than its "fair share" of market. By understanding the impact that marketing can have on the mechanisms of information and material delays, one can assess the return on marketing investments at a more specific quantitative level. From the example of IA-64 analysis, the model has shown that a relatively small reduction in material delay can generate noticeable increases in SOM and cash flow.

From a broader market perspective, one may even apply the structure in **Figure 29** for justifying a greater than "fair share" of the market. Such analysis may be of great interest to companies like Intel, who are constantly under the scrutiny of the Justice Department.

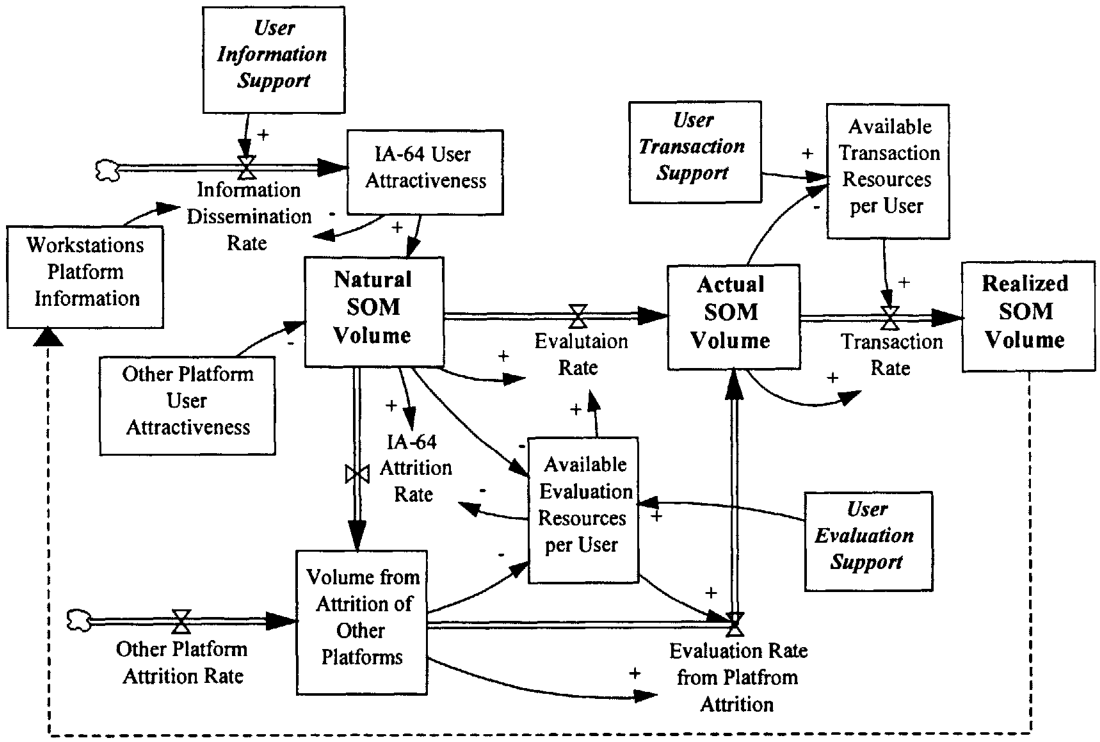

Figure 29. Time Delay Structure of the End User Decision-Making Process.

The third insight gained from the model is derived from the second insight. It is the realization that shortening the process delays in the end users' progression from ***Natural SOM Volume*** to ***Realized SOM Volume*** material stocks, with respect to the rest of the market, can generate a competitive advantage. By increasing the platform volume relative to competing workstations, one can become a more attractive value proposition to the ISVs. This dynamic, in effect, increases the loop gain of the reinforcing feedback loop as illustrated by the dash line in **Figure 29**. The principle of reducing time delays can also be similarly applied to ISVs' decision-making processes. The end result, as mentioned above, is greater platform equity.

4.1.2. Process Benefits of System Dynamics

In undertaking this market study, the process management of the model development has yielded three key learning. First, the system dynamics approach afforded an efficient medium for communicating and understanding the complexity of the market system. One would be hard pressed otherwise to try to explain the non-linear behaviors of the feedback and delay mechanisms, much less to develop any strategic cases.

Second, because of the market intuition offered by the modeling technique, the participants were able to contribute to the model development process with a greater level of coherence. All too often, the group efforts to understand the dynamics of a complex system, such as the workstation market, end up in a confused hodge-podge of scattered ideas. These outcomes are, in part, due to the intrinsic nature of limited expressions and narrow perceptions of individuals collaborating within a group. The system dynamics causal diagrams, in turn, allows for a high level common understanding of the market system. By simultaneously presenting and recreating the causal framework during group discussions, one would be able to develop a system model that captures the interactive insights of every individual contributor. Moreover, everyone involved in the process will come away with a more holistic view of how his microscopic understanding superimposes on the system level behavior of the market. The benefits of this analytical process will not only be realized in the dimensions of time and quality, but also the dimension of mutual learning.

The third key learning of process management pertains to resource focus. A question that is commonly posed in a budget constrained marketing organization is, "how do I focus my resources to obtain the most relevant information?" This question can be easily answered through the process of model refinement. In the course of enhancing the accuracy of the model outputs, one would inevitably identify specific areas of ambiguity or inconsistency with respect to real world expectations. Having an understanding of the impact of these areas to the overall system, the modeler can then determine the worthiness of expending resources to eliminate the ambiguity.

4.2. Strategic Recommendations

In opting for the most pragmatic approach to mitigate the effects of IA-64 slip, it seems that the incorporation of marketing options (price and time lags), in conjunction with reduced capability, will provide the greatest leverage. This may be seen from both the feasibility and effectiveness standpoint.

From the pricing standpoint, Intel can capitalize on its cost efficiencies with a lower price point. Given the generous return on assets of IA-32 products, this is both a feasible and necessary strategy for Intel. At this point of entry into the 64-bit market, Intel should see the initiative as an investment opportunity. A lower price point is the only way to invest to realize a large return on platform equity.

Dealing with the time lags in the end user decision making process involves knowledge of end user needs. Currently, most of WPG's marketing resource is focused on enabling the value chain, such as OEMs and ISVs. Shortening the user evaluation time may involve providing demo units or technical support. It may even be accomplished by investing in credible benchmarking efforts that may eliminate the hardware/software testing cycle. Ultimately, the platform may gain such credibility through these market investments that brand equity will exhibit a dominant influence on user decision.

To compress the transaction time delay, Intel may be able to work with account teams to reduce the process complexity of order entry and approval. The company can also create financing terms that cut the red tape for capital acquisitions. Over all, these are highly actionable proposals with budgetary requirements that are negligible compared to overall operating expense.

The analysis in section 3.3 has shown, that, enacting just the marketing strategy alone would bring substantial recovery to the market position in terms of volume and platform equity. The overall recovery strategy, though, may result in even greater benefit to Intel if it also adopted the operational option of an earlier launch date by reducing processor performance.

Such actions will not only maximize the long-term accumulation of platform equity, but it may prove to be a viable strategy for realizing a strong market presence in the 64-bit domain.

The merits of an "early launch, reduced performance" strategy is exemplified in the Christensen effect. The phenomenon, coined by Clay Christensen of Harvard, suggests that seemingly invincible incumbents of an industry, who focus primarily on the high-end segments, are vulnerable to encroachment of the low end players as they introduce disruptive technologies[20]. Disruptive technologies represent products that provide the optimal cost/performance for capturing the largest segments of the market. Disruptive technologies can potentially displace the high-end industry incumbents if the benefits of the lower tier products become greater than the switching to the high-end customers.

Intel almost became a victim of the Christensen effect when the sub $1,000 PC players significantly eroded its market share. But now is the opportunity for Intel to turn the tables and pursue the high-end computing market from bottom up. In adopting Geoff Moore's "bowling alley" notion of segmentation focus, the scaled back Merced can, first, establish a market presence with the higher volume, lower end market space. Then, the chipmaker can steadily scale up the IA-64 performance until its value proposition is greater than the switching cost of the high-end Unix customers. The consequences of the disruptive technology phenomenon have already been observed in the rapid growth of the personal workstation market (lower tier IA/NT). The responses from the industry incumbents have been quite dramatic. This is evident through the adoption of IA by HP and SGI. From the Unix end, Sun has also been actively promoting a line of mid tier workstations.

4.3. Final Comments on the Merits of the Market Model

The true test of any forecasting method is its correlation with actual data over time. But in most cases, the analytical value of the forecasts is best served at a time horizon well in advance of any data's availability. So in the absence of real world data, the model can only provide the intuitive disciplines of a well-informed guess. This thesis proposes a method to

[20] Toni Mack and Mary Summers, "Danger: Stealth Attack," *Forbes*, January 25th, 1999, p. 88-93.

methodically maximize the accuracy of that guess through the modeling methods of system dynamics. This modeling approach and its associated tools can attain greater precision in simulating real world dynamics by providing a comprehensive structure to frame, analyze, and manage complex systems. Such application of system dynamics in a marketing context has also exhibited exceptional analytical value. The modeling exercise has effectively transformed the art of market forecasting into a more scientific process based on rational integration of market information. Moreover, the comprehensive and systematic nature of system dynamic models allow for more explicit understanding of the mechanisms and assumptions behind the derivations of "soft" marketing parameters, such as user attractiveness to a workstation platform.

It may be a bold assertion to claim the axiomatic benefits of system dynamics approach without presenting a formal basis for validation. But as discussed in section 2.6.2, within a constantly changing experimental environment such as a market system, the appropriate predisposition of formulating predictive models should be in the spirit of identifying and minimizing causes of predictive errors[21]. In other words, a model's best form of validation is the process of its continuous improvement.

The system dynamics model developed to project the market consequences of the Merced slip was designed to capture the characteristics of systemic feedback and delays inherent to the workstation industry. The level of causal granularity imposed on the model was dictated by the drive to achieve adequate precision in comprehending the value chain's behavior (including end users). The result is an analytical tool for Intel that can rationally formulate the SOM and financial impact in quantitative terms. In addition, it allowed for scenario analysis by the adjustments of relevant and tangible market drivers. The outputs of the analysis provided for Intel a quantifiable basis to place either greater or less confidence in the currently recognized options. In terms of new learning, the modeling process forced several key insights to the surface. Most notably, the scarcity of resources allocated to support the end user purchasing processes. Without the workstation market model, it may turn out to be

[21] See footnote 17 in Section 2.6.2 for a description of *predictive errors*.

very difficult to assess or even realize the significance of end user support in the reinforcing loop gain. Such revelation of high leverage insights is a distinctive strength of system dynamic's holistic approach to market analysis.

5. Appendix

5.1. Discounted Cash Flow Formulation and Assumptions

The purpose of this appendix section is to provide the details of the discounted cash flow (DCF) calculations used in the financial analysis. The motivation of incorporating DCF into the economic analysis is to capture the time value nature of money. This is deemed important because it is consistent with valuation methodologies utilized by firms such as Intel in evaluating ROI over an extended time span. Several key characteristics of the cash flow outputs from the workstations market dynamics model are:

- The cash flows are derived only from the operations of IA-32 and IA-64 microprocessors (for Intel).
- The dollar values in **Tables 1-4** represent the cumulative present value (PV) of all cash flows in the time horizon of the analysis.
- The PV values assumes that the launch delay and all the strategic scenarios imposes no significant difference in initial capital expenditure (capx) and future changes in working capital or capx. In fact, any expenditure for the development of the microprocessor projects should be considered sunk cost. This assumption allows a consistent comparison of cumulative PV's for various scenarios.

The calculation of the cumulative PV is as follows:

PV_C = *Cumulative PV*

$R(t)$ = *Revenue from processor sales at time t*

$C(t)$ = *Operational cost of processor production at time t*

$EBIT(t) = R(t) - C(t)$ = *Earning before interest and taxes at time t*

$D(t)$ = *Capital depreciation for processor production at time t*

T = *Corporate income tax*

r = *Weighted cost of capital for Intel (WACC)*

Then the cumulative present value of cash from processor operations for the 5-year analysis is,

$$PV_c = \sum_{t=1}^{5}\left[\frac{EBIT(t)\bullet(1-T)+D(t)}{(1+r)^t}\right]$$

The time varying profiles of *R(t), C(t)*, and *D(t)* were approximated from Intel projections of cost and average selling price. Where,

$$R(t) = Volume(t)\bullet P(t)$$

And *P(t)* is the microprocessor pricing profile over time. *D(t)* is calculated based on a percentage of *C(t)*. All the numbers for the calculations of the actual analysis done at Intel were obtained from the company's cost accounting organization.

It must be noted that the figures shown in **Tables 1-4** do **not** represent any particular processor's net present value (NPV) with perpetuity assumptions. The purpose of the PV_C calculation is to provide a means to evaluate the relative economic benefits of various strategic options. The PV_C numbers are not to be interpreted as indicators of absolute attractiveness of any investment opportunity.

5.2. *Quantitative Model Source Code*

Due to the vast size of the Vensim source code, the author thought that it would be impractical to include the listing in this document. One may obtain a soft copy of the Vensim source code by directly contacting the author. Contact information of the author may be available through the MIT Sloan alumni database or through the Leaders for Manufacturing program office (http://web.mit.edu/lfm/www).

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