The Dynamics of Innovation and Product Platform Development

-A Case Study in Hybrid Electric Vehicles-

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ABSTRACT

This paper explores the topics of innovation dynamics and investment choices that exist in subsystem design architectures of complex product developments.

A particular theme in the innovation literature is captured and extended. This refers to the process of knowledge development regarding technology intersections within product developments that can sustain product innovation.

This is fulfilled in this research through a composition of analytical tools that are used to match the case study environment. In this regard a unique variety of modeling techniques are sequenced to complement the problems encountered and support the outcome of technical and economic decision criteria. The case study presented here is at the forefront of economic and environmental concern - the evolution of Hybrid ElectricVehicles, HEV, efficiency. This paper outlines an innovative and analytical decision approach that is at the core of HEV evolution.

KEY WORDS

- Complex design paths
- Sustained Innovation
- System Architecture
- System Dynamics
- System Engineering
- Technology Intersections

INTRODUCTION

This article details and advances the topic of complex innovation development at technology intersections within architectural products as they evolve over time.

Technology intersections align with the definition of technology fusion popularized by Fumio Kodama (Kodama, 1995). They are defined as the selection of improvements in technology from several, often disparate sources, that have progressed at different rates to realize a new innovation through their combination at a particular point in time. Architectural products are those that exist as an entity in their own right, such as a computer disk drive, while also playing an essential role as part of a larger system (Tidd; Bessant; and Pavitt, 2001).

A tenet that can lead to sustained innovation is introduced to the topic of technology management. This refers to the recognition of progressive networks that host feedback and feed forward linkages in product sub-systems, and where these revolve between donor and recipient technologies to create new innovations at their intersection. Here a recipient subsystem can be rejuvenated over time from the evolutionary changes in its original donor technology.

Intersections that accelerate the development of donor technologies can also conclude from the entry of new technologies into the mix. Here, limitations in the incumbent technology may be elevated to assimilate faster with the donor technology progression. Moreover, the combination relates a vector that has directional influence as an outcome of the relationship. Vector – a quantity having direction and magnitude, denoted by a line from its original to its final position (*Oxford English Dictionary*). In the case study presented here the vectors relate to three dynamic constraints that bifurcate between two new product innovations. The constraints are – monetary investment and timing, manpower resource availability, and market timing. A systems dynamic model titled, Donor-Recipient, is used to arbitrate between these competing elements to direct the decision making process.

If the technology inputs to the vector can be characterized, and normalized, the outcome could offer potential in the modeling of technology development and future innovations. This follows the earlier belief held by (Rosenberg, 1976) which asserts that there is a characteristic logic in the progress of technological evolution that directs it.

A recent satellite broadcast by the M.I.T. Enterprise Forum discussed the topic of Technology Fusion. The consensus of the forum was that the next wave of innovation has already started - and it's coming from entrepreneurs who recognize opportunity in the fusion of traditional disciplines (M.I.T. Enterprise Forum, 2004). The speaker's related breakthroughs such as adding intelligence to prosthetic limbs to the use of advanced microchips implants used to release drug medication and monitor the effects in a very controlled fashion.

A decade has elapsed since the original concept of technology fusion and the relationship with breakthrough innovations was introduced in Japan. Over this period there has been a pattern of sustained innovation in many technology fusion innovations through the reciprocal nature of evolving developments between the original donor and recipient technologies that inspired the first product innovation. The second generation Hybrid Electric vehicle, Prius II, from Toyota is a clear example here. The first model from Toyota was introduced to the U.S.A. in 1995, but received little attention from other major car manufacturers at that time.

In the intervening period between the two models Toyota built upon the learning from the Prius 1 and created a new and significant product platform design that is today's passenger Hybrid Vehicle standard.

LITERATURE REVIEW

The literature on product platforms has been growing in recent times, (Sanderson and Uzumeri 1999), (Meyer and Tertzakian et al. 1997); (Cusumano and Nobeoka 1998) ;(Muffatto 1999); (Robertson and Ulrich 1998).

A product platform has been defined by, McGrath 1995, as a set of subsystems and interfaces that form a common structure from which a stream of related products can be efficiently developed and produced. Product platforms are therefore deemed to be uniquely designed to serve one group of related products, while product architecture is not necessarily developed with this restriction in mind.

The definition of what constitutes a product platform appears to significantly outpace the understanding of industrial companies approached in many case studies (Vuuren and Halman 2006). According to literature, a platform can be related to product technology, sourcing, manufacturing and supply processes, customers, segmentation, brand positioning, or even people and relationships. Platform management is well understood by automotive companies, however. There are many examples of automobile subsystems that are deployed across a breadth of different vehicles; the FORD™ Lincoln LS brand for example, uses a V8 engine that was designed for the Jaguar™ product line. This elevates product technology and manufacturing economies of scale as the kernel of product platform design in this sector.

In contrast, many practitioners who understand product platform attributes juxtapose product architecture with good design practice. Architectural development in this respect denotes the effective partitioning of a product, attention to the connectivity and physical relationships between sub-system functional elements, and always the need for a fallback design in complex product developments. These facets of architectural design have significant imperatives for product platform development. Partitioning a design has as its objective the dual goals of product performance and economics, while the simplification in interconnection and interfaces relates lower manufacturing cost, higher reliability and reduced space density. A backup design is without question. Many aircraft designs would never have met deadlines if contingency design paths were not invented!

The delineation between the architectural design of sub-systems within a platform product, where the emphasis is based upon product and manufacturing assets, is adopted in this paper.

In the scope of current literature little attention is paid to the dynamics that occur within product architectures as they relate to product platform development and sustainability. Repenning's work (2000:2001), touches on one aspect by discussing the development of consequent product designs using the same development organization. In this respect it touches a part of the model development used in this article where resource constraints are in conflict when faced with the dual task of a new concept design and the continuing development phases of an existing product.

Platform product development is not without risk. Developing the initial platform in most cases requires more investment and development time than a single product. There is also the system partitioning aspect that can lead to the over-design of some subsystems when a company seeks to share subsystems between high and low end products. Here, the profitability of the low end products can be compromised (Krishman and Gupta 2001).

Meyer and Lehnerd (2005), address the risk involved with the balance between commonality and distinctiveness. To elect commonality in deference to uniqueness could definitely have an impact on competitiveness. They also highlight the need to renew and employ continuing innovation in product platform developments for long term success, (Flett 1992) – a topic that is core to the case study detailed in this paper. The introduction of complementary technologies into existing architectural products has the potential to reduce investment risk and increase product development efficiency through the insights and knowledge gained in the repository of existing user feedback. At the, "fuzzy front end", of new product development they permit early experimentation by building upon existing application knowledge (Thomke 2003). Similarly, their adoption rate is enhanced due to the awareness and association between the existing need and the application. Conversely, they permit timely exit, and thus diminished investment, though the ability of early experimentation, which in turn leads to the possibility to test more products derived by this concept.

An image that provides the theme for this paper follows that of the Engineering Systems Division at MIT. In particular this paper aligns with the top right box titled "Systems Theory and the related sub-task subjects, referenced in the ellipses of figure 1.

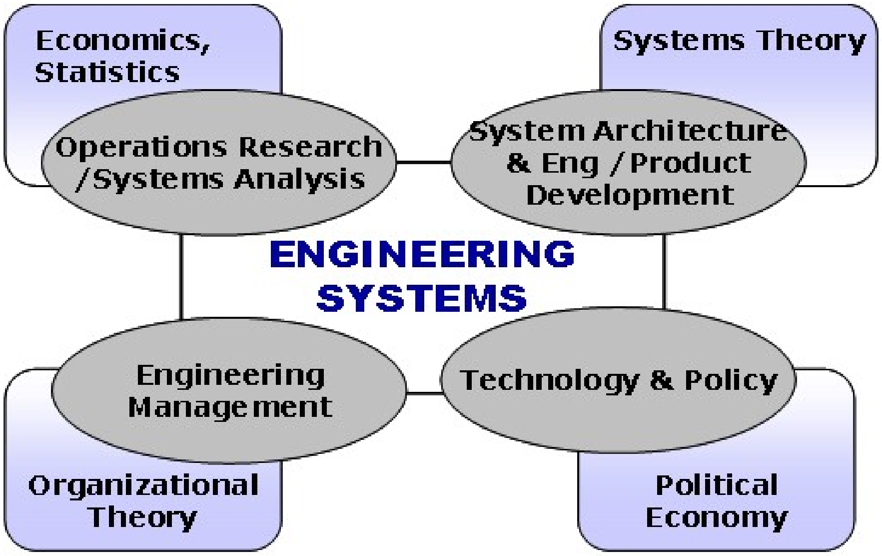


Figure 1. MIT Engineering Systems Division

Discrete quantitative techniques have been employed to support the systems dynamics framework, with a substantial amount of engineering management experience. It is also acknowledged that the determination of engineering systems cannot disregard the influence of the associated topics in figure 1.

While the inclusion of many of these topics is beyond the scope of this paper an open architecture software program centered upon system dynamics, SD, modeling has been developed to enhance wider knowledge in this field. The menu driven program, 'Innovation Development Modules for Action Based Teams©' is a set of interlinked and interactive software modules that increase the speed of and effectiveness of knowledge within the wider area of new product innovation and development.

This CD-ROM is available upon request from the author. A contents list can be viewed in the appendix, 1.

OUTLINE

The outline of the paper is as follows. A combined model approach to the complexity of synthesizing, ranking and choosing between appropriate technologies within sub-systems of an architectural product is introduced. A system dynamic model that arbitrates between the physical engineering principals of two system components follows. To complete the process, the main actor, a system dynamics model titled, 'Donor-Recipient' addresses the complexity of investment timing in complex new product development.

The foundation of this latter model is built upon the dynamics of innovation where a particular donor technology is first introduced into a system product and over time spawns changes in other sub-system elements due to its evolution. In this respect it acknowledges and adapts the product-process life cycle theory of Utterback and Abernathy (Utterback, Abernathy 1975) to reflect a rejuvenation process that can occur in a system based product as the process technology of a donor technology evolves.

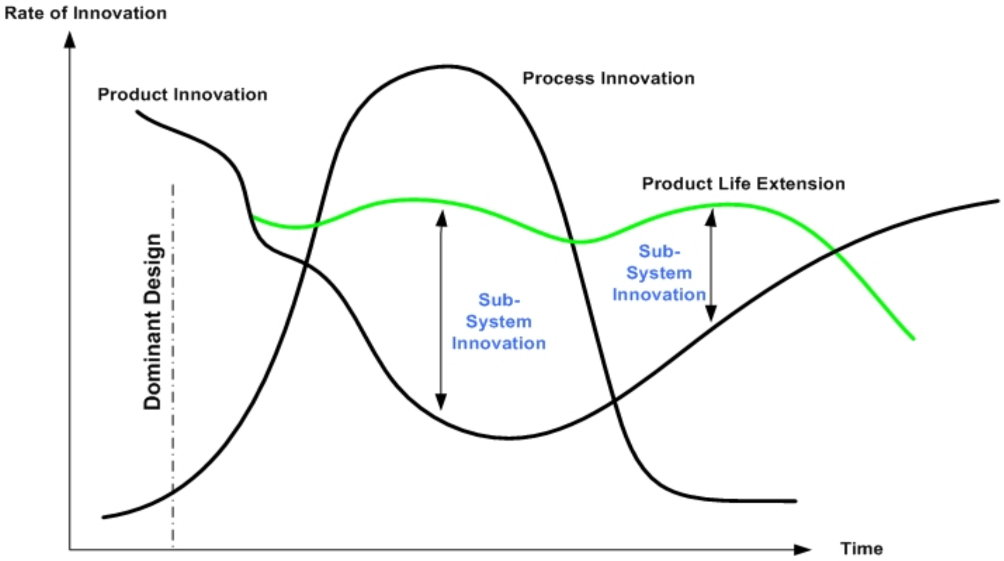


Figure 2. Utterback/Abernathy's model of industrial product and process innovation (Utterback, Abernathy 1975, p.645 modified)

The new feature of significance is the product life extension made possible through the purposeful innovation development of sub-system technologies, where these changes permeate throughout the complete architecture of a product platform. As evidenced in the case study economic and performance related criteria are enhanced as an outcome.

The Donor-Recipient SD model assigned to the discovery process is a hybrid incorporating a Bass diffusion model that arbitrates between the cycles of continuing investment in a product seeded from the original donor technology, titled, first stage recipient, and the creation of new leapfrog product. Considering these investments are not mutually exclusive multiple feed forward and feedback loops exist in the model.

The decision process is augmented by the addition of a Bayesian framework. This takes into consideration prior adoption and diffusion data and combines them with industry forecasts and the results of a DELPHI investigation. The DELPHI technique is used to enhance the market research outcome by augmenting the data with a critique carried out by industry experts.

The case study presented here involves sub-system components of the electric engine - the partner to the gasoline combustion engine in a Hybrid Electric Vehicle.

The first task is directed to recognize the priority attached to highly interdependent design factors. This data is extremely useful for product planning with an emphasis on prototype testing and investment timing. In complex products such as Hybrid Vehicles the attributes of sub-system interaction are extremely complex and include most areas of physics, ranging from variables such as, temperature, pressure, fluid flow rate, electricity, magnetism, for example. The components that control these variables are bound by individual technological limitations and the operating conditions that will assure their long tem reliability.

Further, the approach taken to arbitrate between the variables must also take into account their component interdependence within, and between each sub-system.

RANKING INDIVIDUAL AND MUTUALLY DEPENDENT VARIABLES

This rationalization begins by using Boolean charts for a selected sub-system element where many of the physical relationships mentioned above exist. The rational for using Boolean algebra is supported by its definition. The notional system was developed by George Boole, circa 1850 to permit an algebraic manipulation of logical statements. By definition it is an abstract mathematical system primarily used in computer science that expresses the relationships between concepts, groups, or objects. The Boolean approach directs the analyst to compare all associations, which exist. The purpose of the design methodology differs from an orthodox approach in that it was appointed to determine, first, the individual and combined attributes in one particular technology. Secondly it was designed to detect a connection with both competing and complementary attributes in a companion technology. The outcome of these relationships is the establishment of a path diagram that prioritizes the association of linked attributes in each technology.

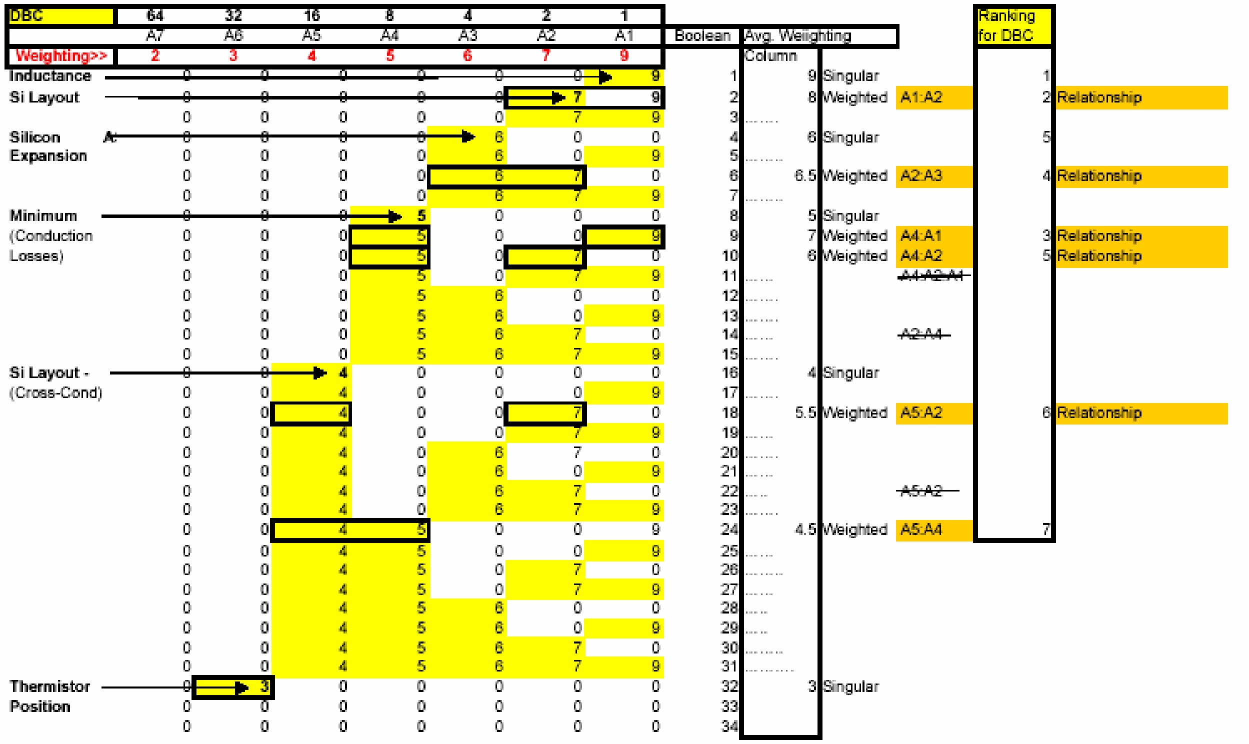
The exploration of the path outcome associates with fitness landscape theory that was developed in the 1930’s (Morel and Ramanujam 1999) and is now a key concept for understanding the structure and interactions in complex adaptive systems. The term fitness is a tautology that declares that if components of a system already exist they must fit by definition. In the technology arena the objective is to ensure that the complementary relationships between product, process and strategic technology management are adapted to compete now and in the future, (McCarthy 2003). This technique is no more than an aid to complex problem solving using a tool that dictates scrutiny, focus and thought. In this vein it relates to the theme of system dynamics simulation, namely, foresight and insight.

Product development efficiency gains are numerous. In the first instance the number of alternative solutions elected for testing is reduced due to the scrutiny inherent in the scheme. Additionally the selected variables are prioritized and non-critical variables eliminated. Thus, focus can be directed to the specific engineering modeling tasks thereby lowering complexity and increasing the fidelity of the results. Table 1 identifies two distinct components, titled, DBC-Substrate and Fluid Channels respectively. The technical names are unimportant to the methodology. The variables associated with each technology are listed in the left hand column of each table. These variables were assigned either a single weighting, or an averaged weighting if it was considered that a high interdependence exists between variables. The individual score, recognizing the importance of both the singular and weighted outcomes, is listed in each table under the column titled, Avg. weighting. Finally the variables, either singular or combined, are ranked in the column titled, Ranking. As can be seen from the tables there were a number of interdependent variables found in each technology.

The dependency between the two component technologies, DBC-Substrate and Fluid Channels, prioritizes the fact that they be considered as one design entity. Clear and concise design direction is critical here as the development engineering manpower resources are specific to each technology. To aid the process of recognizing the sequence of essential design tasks and crossover between each component technology the ranking scheme was transferred into a Boolean path diagram. In this example it became clear that the interdependent variables in each component technology identified a common and prioritized design goal that should be assigned to both, namely conductive efficiency. In the case of the DBC-Substrate technology the goal was to reduce inductance, a leakage variable that causes unwanted losses, and lowers conductive efficiency. For the Fluid Channel technology the design goal focused on achieving the pressure drop specification while fulfilling the goals of maximizing conductive efficiency. Pressure drop is related to the effective flow rate of cooling which in turn acts to remove heat from the DBC-Substrate technology. The success of this simple exercise has some subtle attributes that relate to the effectiveness of design teams. By distilling the complexity of technology relationships within, and between, the individual technologies each team was able to focus on specific and prioritized design topics that would achieve the mutual goal. This, in turn, streamlined the development process by removing the confusion in the different development teams.

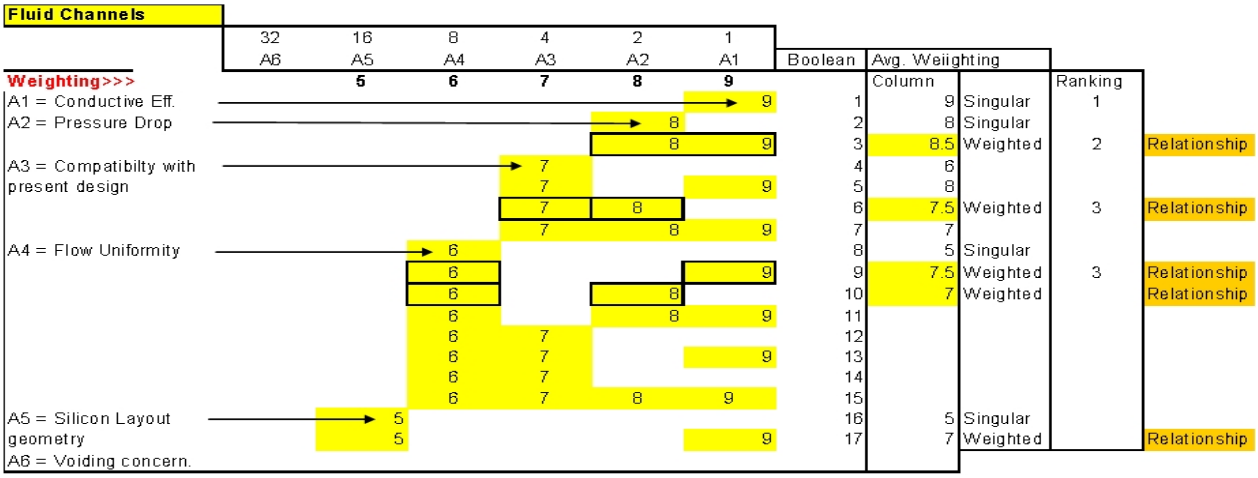
Table 1.

DBC-SUBSTRATE

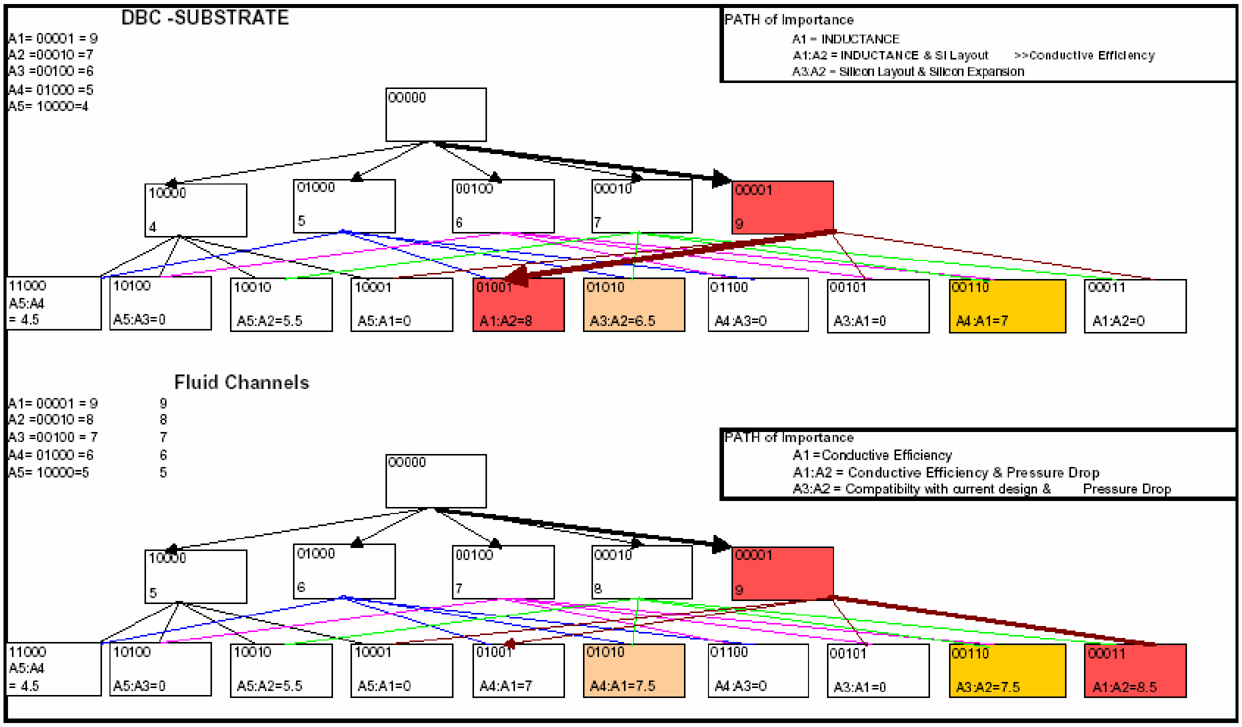


DBC	64	32	16	8	4	2	1					Ranking for DBC	
	A7	A6	A5	A4	A3	A2	A1	Boolean	Avg. Weighting Column				
Weighting>>	2	3	4	5	6	7	9						
Inductance	0	0	0	0	0	0	9	1	9	Singular		1	
Si Layout	0	0	0	0	0	7	9	2	8	Weighted	A1:A2	2	Relationship
	0	0	0	0	0	7	9	3	....				
Silicon Expansion	0	0	0	0	6	0	0	4	6	Singular		5	
	0	0	0	0	6	0	9	5	....				
	0	0	0	0	6	7	0	6	6.5	Weighted	A2:A3	4	Relationship
	0	0	0	0	6	7	9	7	....				
Minimum (Conduction Losses)	0	0	0	5	0	0	0	8	5	Singular			
	0	0	0	5	0	0	9	9	7	Weighted	A4:A1	3	Relationship
	0	0	0	5	0	7	0	10	6	Weighted	A4:A2	5	Relationship
	0	0	0	5	0	7	9	11	......		~~A4:A2:A1~~		
	0	0	0	5	6	0	0	12	....				
	0	0	0	5	6	0	9	13	....				
	0	0	0	5	6	7	0	14	......		~~A2:A4~~		
	0	0	0	5	6	7	9	15	......				
Si Layout - (Cross-Cond)	0	0	4	0	0	0	0	16	4	Singular			
	0	0	4	0	0	0	9	17	....				
	0	0	4	0	0	7	0	18	5.5	Weighted	A5:A2	6	Relationship
	0	0	4	0	0	7	9	19	......				
	0	0	4	0	6	7	0	20	....				
	0	0	4	0	6	0	9	21	......				
	0	0	4	0	6	7	0	22	.....		~~A5:A2~~		
	0	0	4	0	6	7	9	23	......				
	0	0	4	5	0	0	9	24	4.5	Weighted	A5:A4	7	
	0	0	4	5	0	0	9	25	......				
	0	0	4	5	0	7	0	26	....				
	0	0	4	5	0	7	9	27	......				
	0	0	4	5	6	0	0	28	.....				
	0	0	4	5	6	0	9	29	.....				
	0	0	4	5	6	7	0	30	....				
	0	0	4	5	6	7	9	31	....				
Thermistor Position	0	3	0	0	0	0	0	32	3	Singular			
	0	0	0	0	0	0	0	33					
	0	0	0	0	0	0	0	34					

FLUID CHANNELS



Fluid Channels	32	16	8	4	2	1					
	A6	A5	A4	A3	A2	A1	Boolean	Avg. Weiighting Column		Ranking	
Weighting>>>		5	6	7	8	9					
A1 = Conductive Eff.						9	1	9	Singular	1	
A2 = Pressure Drop					8		2	8	Singular		
					8	9	3	8.5	Weighted	2	Relationship
A3 = Compatibilty with present design				7			4	6			
				7		9	5	8			
				7	8		6	7.5	Weighted	3	Relationship
				7	8	9	7	7			
A4 = Flow Uniformity			6				8	5	Singular		
			6			9	9	7.5	Weighted	3	Relationship
			6		8		10	7	Weighted		Relationship
			6		8	9	11				
			6	7			12				
			6	7		9	13				
			6	7			14				
			6	7	8	9	15				
A5 = Silicon Layout geometry		5					16	5	Singular		
		5				9	17	7	Weighted		Relationship
A6 = Voiding concern.											



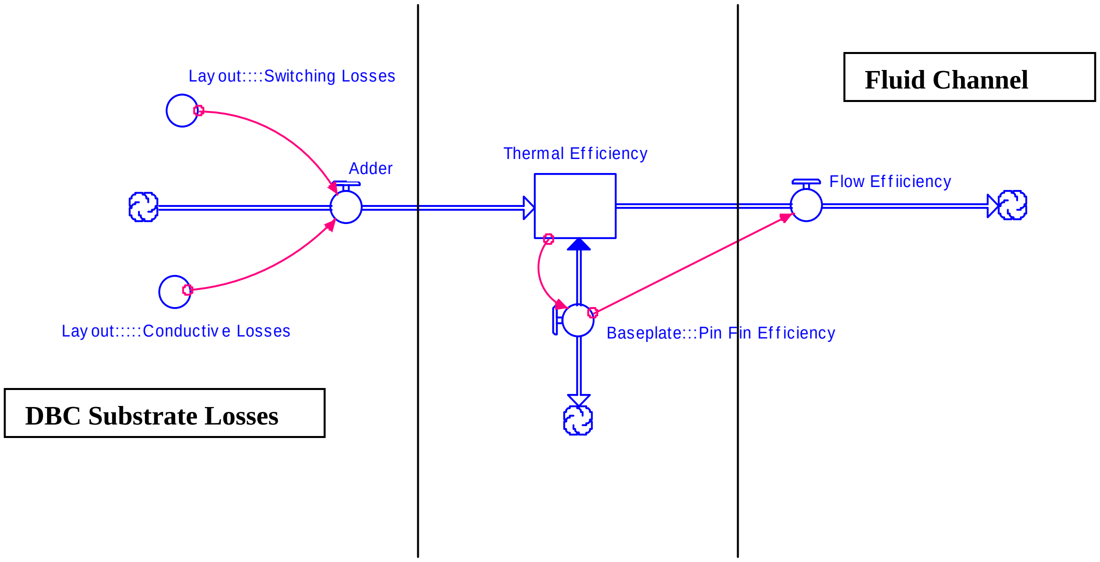
The scheme above provided the necessary guidance to each design group. A statement that was vindicated through the emergence of two linked designs, consisting of a paired substrate and fluid channel component technology set, in two weeks. These selections were then modeled using engineering simulations tools and compared against an existing baseline solution from a previous design.

The effectiveness of each solution benchmarked the twinned ratings necessary for the ultimate selection, namely peak thermal conductive efficiency and also the time taken to reach this efficiency plateau.

An analogy can be drawn between conductive efficiency and a commonplace activity that many have experienced; the dentists drill. As dentistry technology developed the heat losses generated, due to abrasion between the drill bit and the enamel of the tooth, increased due to the faster rotational speed of the drill bit. These losses could both damage the tooth and the drill bit. To abate these losses the rotating drill bit is now accompanied by pressurized water spray to reduce the heat generated in the contact between drill bit and tooth.

A system model that follows this description is identified in Figure 3. The heat losses described above can be linked to the input flows in the diagram, namely conductive and switching losses. The drill bit can be likened to the flow titled, Baseplate:::Pin Fin efficiency, placed directly under the stock titled, Thermal Efficiency. And the output flow, Flow Efficiency, is analogous to the pressurized water spray in the example above.

The major difference between the example and the case study cited here is the amount of heat generated and the potential for damage.



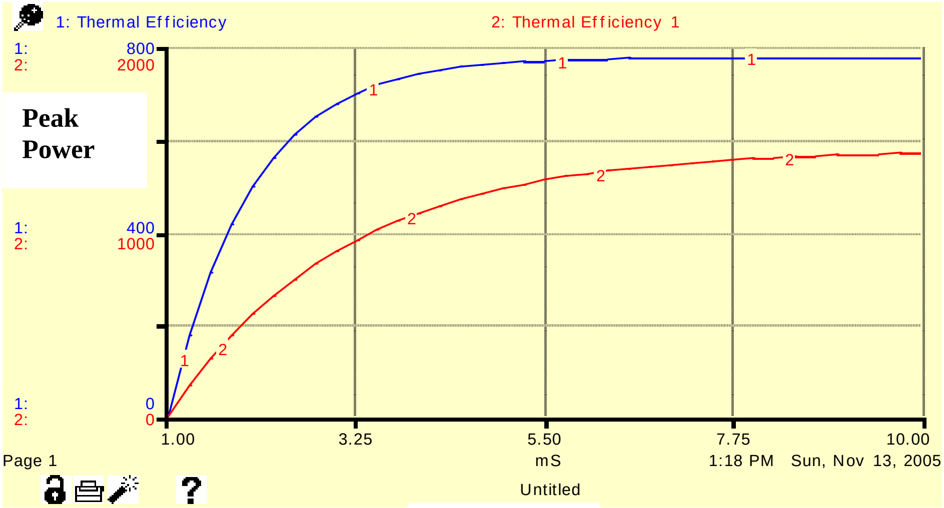


Figure 3.

The rationale behind using a systems dynamic model for this particular topic is explained by the graph detail. As previously discussed the criteria for component selection is the magnitude of heat rejected in the shortest time. The magnitude of heat is identified on the Y-axis, in watts, and the time, in milliseconds, on the X-axis. The lower curve in the diagram wins because it evacuates more heat faster. This translates into higher reliability and lower power losses respectively.

The conclusion to this design exercise established a new sub-system innovation that was essential to the project. It is considered remote that this technology fusion solution would have been found in a timely manner without the methodology adopted here.

THE DONOR-RECIPIENT SD MODEL

In the process of any new technology adoption it is necessary to examine criteria that offer the opportunity to mitigate risk. Failure to take these into account could manifest in delays to a vehicle platform launch, where the costs are quite substantial compared to the components. A discovery was made in the ongoing procurement process of a critical components selected in the previous Boolean analysis. Here, it was found that the supplier of one of our selected component technologies was about to make an imminent decision between continuing investment in the existing donor technology, or a diversification to a new leapfrog component. Our design, the first stage recipient product, was highly dependent upon the continuing funding in the donor technology. Due to the criticality it was agreed that we would assist the supplier in the decision process by jointly building a system dynamic model that arbitrates between the continuing investment necessary to fund the existing donor technology and that required to fund the new leapfrog product. Continuing to fund the donor technology would extend our critical component, the first stage recipient, while a divestment of funds would highlight obsolescence- a situation that would force an exit strategy from our planned innovation.

In an attempt to mediate this situation an exercise that supports the original tenet, where it was proffered that sustained innovation can be concluded from the linkages at intersections within sub-systems of architectural products, was undertaken.

In this endeavor it was decided that the desired outcome was a funding balance between the two component technologies, which would maximize sales over a thirty-six month period.

This was to be figured from a total investment of $10m, over the same period, ending with a positive cash balance.

As previously mentioned the Donor-Recipient SD model involves a compound model where the pivot of this investment relies heavily on the input from a BASS diffusion model. The output of the BASS diffusion model, Adopters, is used as a SD stock input to the investment decision model, figure 4.

The BASS diffusion technique is extremely useful for looking at diffusion patterns and is often used to predict future adoptions of a product. There are two main characters in the development of the diffusion characteristics. One is the “P” factor that reflects people’s intrinsic tendency to adopt the product. This is represented by the slider prefixed by “P” in the model, Appx.2. The other is the “Q” factor, containing three sliders, that captures the tendency to buy through word-of-mouth. These sliders are prefixed by “Q” in the model, Appx.2. These two players provide us with information that relates the speed of diffusion. In this model the total number of susceptible adopters can also be scaled by a slider titled “M”.

The BASS output will be seen to have a high dependency in the investment model with regard to delays in the diffusion related to the first recipient product of the donor technology.

A respectable treatment that relates the full merit of the BASS diffusion model and subsequent variations that have been published is beyond the scope of this paper. This is in part fulfilled in the references cited at the end of this paper (Bass 1969), (Bass 1999), (Mahajan and Muller 1990).

Product Platform Development & Sustainability

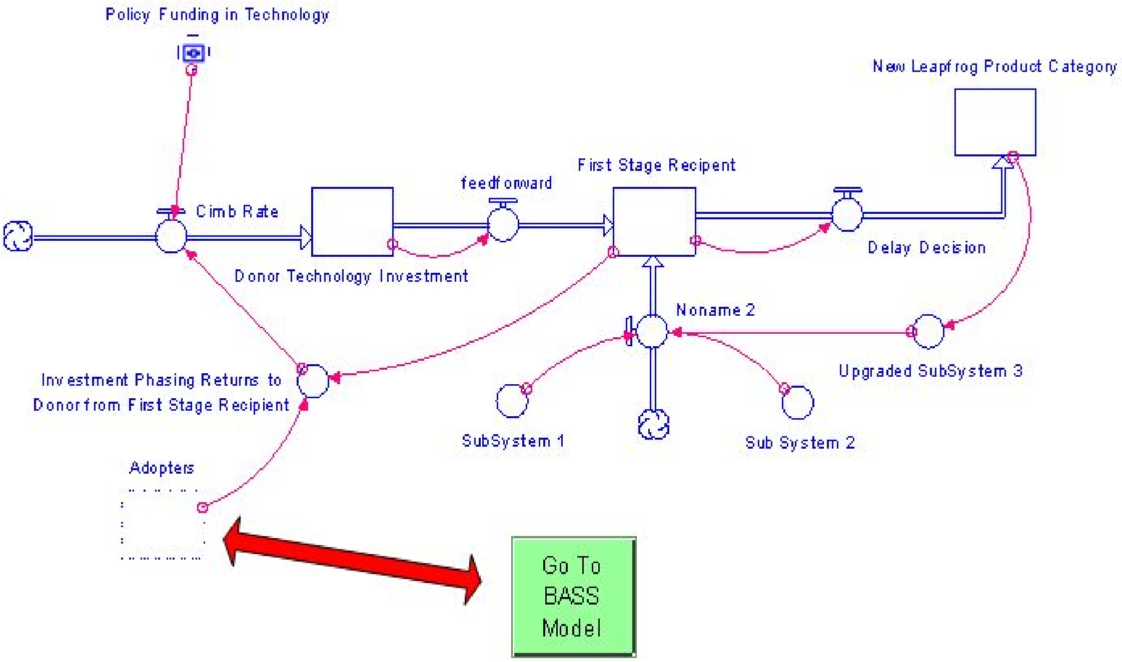


Figure 4.

The SD stocks in figure 4 depict the Donor Technology Investment, DTI, the First Stage Recipient, FSR and the New Leapfrog Product Category, NLP, from left to right in the diagram. Primary input to the DTI originates from the stocks representing the, Adopters SD stock, the FSR, and from the slider titled Policy Funding in Technology. The FSR donates a continuing investment value of 5% to the DTI as a beneficiary from product growth in the simulation. The Adopter stock contributes 1.5% of investment returned from the procession of increased purchases. A slider titled, Policy Funding in Technology, provides a dual function.

(a) In the simulation it is used to maximize the utility of the investment for both the FSR and NLP products.

(b) It is used to identify the percentage amount that is required from other contributory areas in the model to "null" the $10M investment between both products.

In this respect the slider acts as a tuning mechanism for the model whereby a specific percentage figure of adjustment to reach the full $10M value is linked to each of the quadrants, A through F, identified in Table 2. It is redundant to the model after it fulfils this function.

The feed forward ratio from the DTI stock to the FSR is 50% of the DTI accumulation.

As previous, a feed forward loop that moves 15% of the accumulated FSR stock to the converter titled 'Delay Decision' is made. These twin routes of investment are combined with a six-month initial delay of investment in the NLP product and a further six months of delay in diffusing the funds. This is a natural consequence considering the start-up time for the new development. The final feedback loop is made from the NLP to the FSR. This signifies that the investment in the

NLP will enhance sub-systems of the FSR and provide an extension to the initial anticipated product life cycle. An amount of 10%, after a delay of 12 months, has been factored here. Subsystem 1 and 2 are normalized flows into the FSR and are not planned to take advantage of the NLP innovation at this point in time.

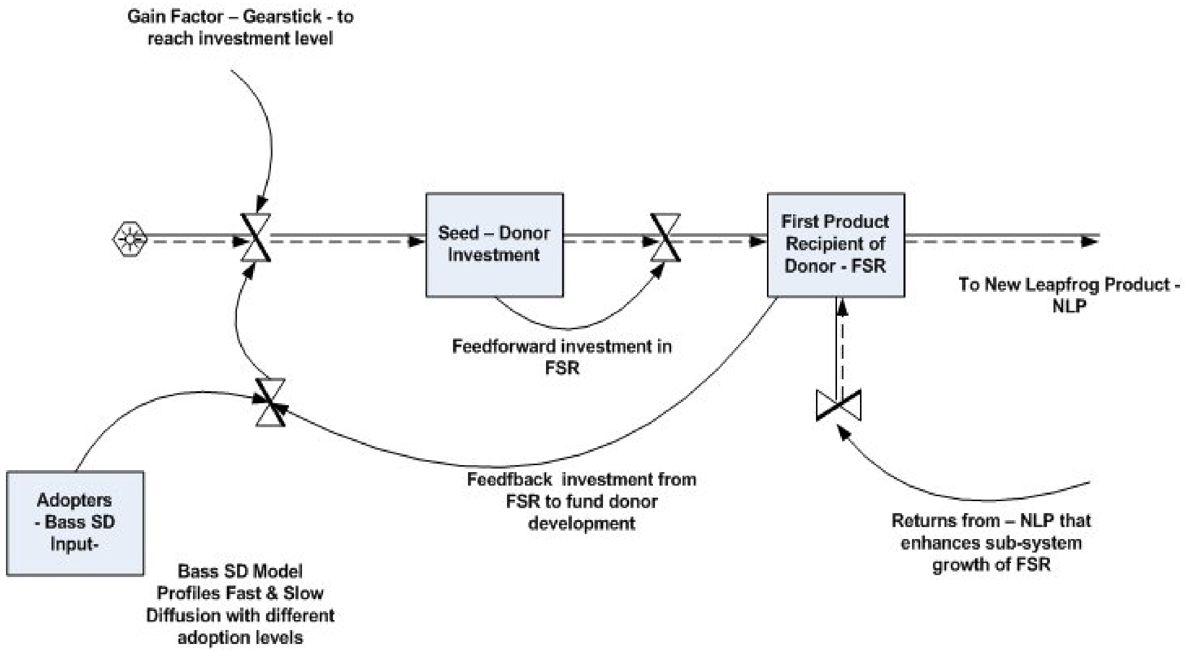
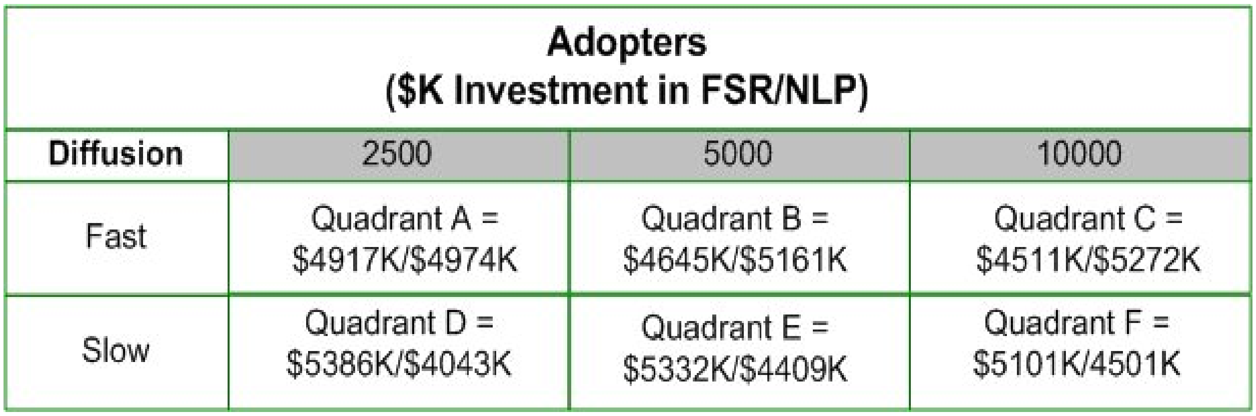


Figure 5.

The prime sensitivities in the model relate to the front-end constituents of feedback from the FSR, and feed forward to the Donor identified in figure 5 above as they interact with the Bass diffusion model. The dependent variables are captured below,

(a) The adoption level and the rate of diffusion.
(b) The percentage of donor investment provided by Adopters
(c) The initial funding in the FSR and Donor.
(d) The percentage of FSR feedback accumulation that is added to the Adopter contribution.

The table below attempts to assert how the influence of the BASS diffusion model plays a major role in the decision process.

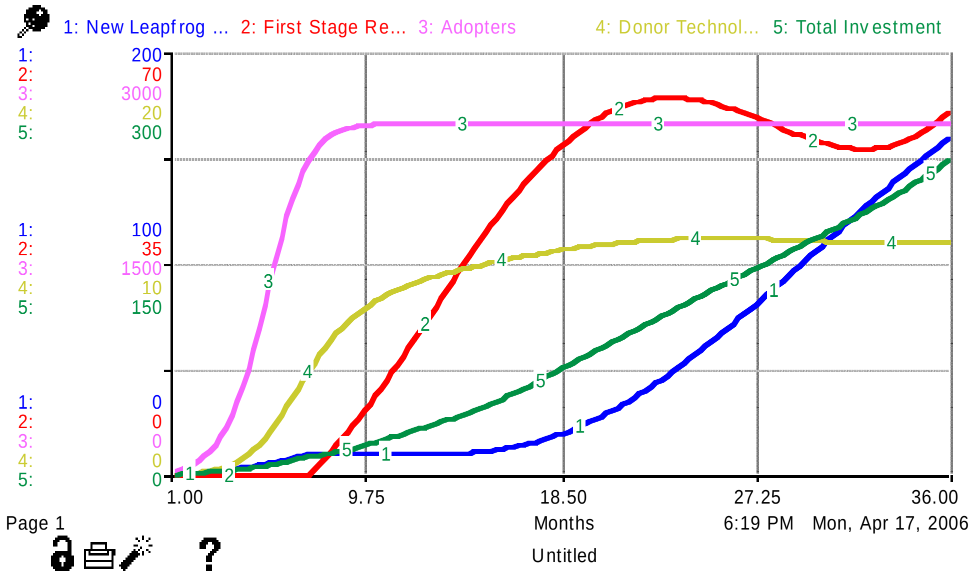


Adopters ($K Investment in FSR/NLP)			
Diffusion	2500	5000	10000
Fast	Quadrant A = $4917K/$4974K	Quadrant B = $4645K/$5161K	Quadrant C = $4511K/$5272K
Slow	Quadrant D = $5386K/$4043K	Quadrant E = $5332K/$4409K	Quadrant F = $5101K/4501K

Table 2.

The number of adopters in each quadrant represents, 2,500, 5000 and, 10,000 additional buyers. Each of these values was contrasted against a fast and slow diffusion of adoption where a slow diffusion in this exercise was judged as 18 months to peak sales while a fast rate of diffusion was attributed a 9 month period. The simulation results shown in each quadrant are those that meet the criteria of balancing the investment between the two products, FSR and NLP respectively, while matching the available investment and ending cash balance.

Two simulation runs that exemplified contrasts in investment were selected for more critique and analysis, figure 6. The graphs represent the simulation outcomes of quadrant ‘A’ and quadrant ‘E’ respectively.



- Quadrant A, representing an investment split of $4917K in the FSR, and a $4974k contribution in the NLP product over 36 months.

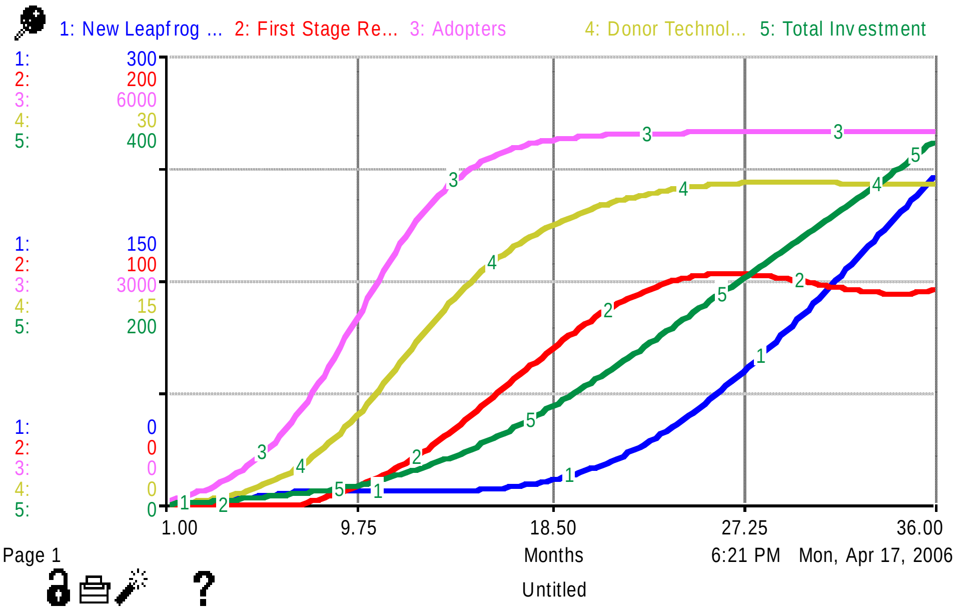


Figure 6.

- Quadrant E, representing an investment split of $5332K in the FSR, and a $4409K contribution in the NLP product over 36 months.

As can be seen from the diagrams the lower graph displays a slower diffusion and a delayed investment in the FSR, although the peak is higher due to the higher adoption rate. The monetary difference between investment totals in Quadrant A and E were deemed insignificant compared to the importance of the investment time profiles over the 36-month period. This is an important finding that could have been obscured if only the investment totals are considered,
In this respect the slower diffusion and higher peak of adopters in Quadrant E is desired due to the non-availability of additional critical manpower resource that could actually be deployed earlier on the FSR project to take advantage of the investment accrual rate.

The slider titled, Policy Funding in Technology, shown in figure 4 is used to identify the additional percentage of investment required in the simulation runs that relate to quadrants, A through F, in table 2. In this respect it calculates the shortfall that must be made up by the other dependent variables which interact with the BASS diffusion outcomes to achieve a total investment of $10M in the FSR and NLP products.
Two major factors were previously cited as dependent variables that could make up the shortfall in achieving the investment total. One of these, the level of initial funding, was chosen for further scrutiny. Two levels of policy funding were selected, 10% and 25% and the different levels of funding required in the Donor and FSR product. Here it was found that a figure of $100K as an initial funding in both would reach the $10M investment figure with the policy funding set at 10%. As a funding level of 25% was regarded as the upper ceiling of policy funding this alternative was deemed a satisfactory solution.
The other opportunity selections that could increase investment, namely the increase in investment level from Adopters, or a permutation that included an increase in contribution from the feedback from the FSR product to the Donor were deemed too aggressive for inclusion.

Marketing data that was used to perform the SD simulation to this point, while based upon authentic data from the supplier, was judged insufficient to accept the investment outcomes. It was therefore decided to carry out a separate marketing research program to assess, (a) the practicality of the market responding to the profile identified in Quadrant E, and (b) the marketing mix tools available to the supplier that could be used to manufacture a corresponding sales profile.

As this played a critical part in the decision process it was decided to adopt a Bayesian decision process related to the analysis of prior marketing data and new research. In due course this was augmented through data collected from expert focus groups.

Perhaps the simplest explanation of the Bayes rule was penned by the Economist magazine in the September 30th issue of 2000. *"The essence of the Bayesian approach is to provide a mathematical rule explaining how you should change your existing beliefs in the light of new evidence. In other words, it allows scientists to combine new data with their existing knowledge or expertise. The canonical example is to imagine that a precocious newborn observes his first sunset, and wonders whether the sun will rise again, or not. He assigns equal prior probabilities to both possible outcomes, and represents this by placing one white and one black marble into a bag. The following day, when the sun rises, the child places another white marble in the bag. The probability that a marble plucked randomly from the bag will be white (i.e., the child's degree of belief in future sunrises) has thus gone from one half to two-thirds. After sunrise the next day, the child adds another white marble, and the probability (and thus the degree of belief) goes from two-thirds to three-quarters. And so on. Gradually the initial belief that the sun is just as likely as not to rise each morning is modified to become a near-certainty that the sun will always rise."*

This discussion provides an ideal platform to discuss the Bayes development carried out for this project. The construct shown below is derived from a Bayesian program titled Netica™ a program supplied by Norsys Software Corp.

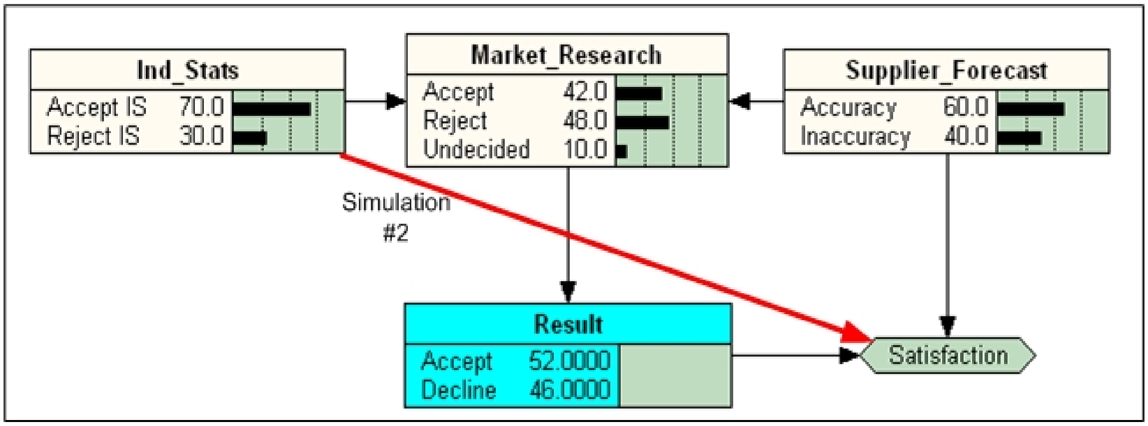


Figure 7.

The essence of this model is to enhance the decision process through the availability of increased information. The diagram has two nodes, representing prior forecast data - the supplier forecast, Supplier_Forecast, and Industry Statistics, Ind_Stats. These are called nature nodes where estimates of "chance" or, probability, are applied. The figures inset in the bar charts of these nodes relate heuristic data of perceived accuracy attributed to these forecasts. The center node, Market_Research is new information that has recently become available. This node applies probability weightings to the combined industry statistics and the supplier forecast. The outcome is linked to the ‘Result’ decision node. The results seen in the ‘Result’ decision node are calculated results from the simulation that combine the Market Research and the levels of satisfaction in the utility node titled, ‘Satisfaction’. The links to the utility node capture the rationale that there is a hierarchy of satisfaction where, initially, the supplier is biased towards his own data and would accept a level of 60, accept, to 50 reject, in favor of an acceptance and the accuracy of the supplier forecast. As seen from the data in the ‘Results’ decision node this level was not met. To prevent a skew in the decision process it was decided to add a link between the industry statistics and the satisfaction utility node. This was carried out for several reasons. The first was to involve a wider audience of industry experts in the judgment process. Secondly it was considered that this would balance the third party market research data in later sensitivity runs of the Bayesian model. The outcome was not predictable. In this simulation run the ‘Satisfaction’ utility was appointed a value of 70, signifying acceptance of the combined input from the industry statistics and supplier forecast and a rejection value of 65. This was a narrow separation, but enough to meet the acceptance criteria of 60 previously asserted for acceptance. A further trial was made to assign a value of 100%, in succession, to each of the, accept, reject, or undecided variables in the Market Research node. The variability in the acceptance criteria related to the ‘Result’ node still remained above the acceptance level. It was therefore decided to accept the data provided by the supplier forecast and industry statistics. After review of both data sets it was found that the combined diffusion resembled the sales profile found in Quadrant E, Figure 6, in all but one respect. This referred to a lower value of peak sales sustainability, equal to 2 months in the data versus 5 months referenced in the Quadrant E graph. At this juncture it was decided that marketing initiatives to correct this deviation were plausible and that the adjustment could be made with a pricing scheme that would retain the average profitability used in the model. The project was declared complete at this stage and the decision was made to apply the investment to the FSR and NLP product as detailed in Quadrant E of table 2.

CONCLUSIONS

The successful outcome of this complex product development was, of necessity, matched by the analytical tools applied to extract the insights. In this regard complementary simulation models were applied to balance discrete and continuous time-based related sequences found in most decision based problems. The SD Donor-Recipient model did provide significant insight into the relationships that exist when new sub-system innovations include predecessors in the assessment. It is asserted that this recursive behavior enhances the success of new innovations.

It is suggested that the application of acknowledged modeling techniques embedded within new SD simulation models enhance the rigor of analysis and of SD in general. A trend that is likely to continue in tandem with the theme pronounced in this paper - that the intersections of knowledge will spawn compound simulation techniques where their fusion provides greater insights.

Limitations in the treatment of the topic reviewed here relate, in part, to the closed form of SD simulation models presented in this paper.

Many forms of feedback and feed forward structures were tested and many became too complex to comprehend. This forced a solution where simplicity was axiomatic in the selection.

It is acknowledged that other methods may be chosen for the analysis undertaken here. A second, and perhaps more pronounced limitation, was the lack of awareness regarding the breadth of techniques that can assist decision making in peer management groups. In concert, confusion was evident due to the fractured and overlapping definitions of architectural, platform, and product family innovation in current academic literature.

The selection of analytical techniques chosen to address technological and socio-economic new product innovation decisions, and perhaps more importantly when, and in which order to apply them, is considered a fertile area of future research.

The analytical toolset applied in this paper is intended to stimulate enquiry and investigation in the area of complex innovation design. A full description of the models in this paper is available upon request from the author.

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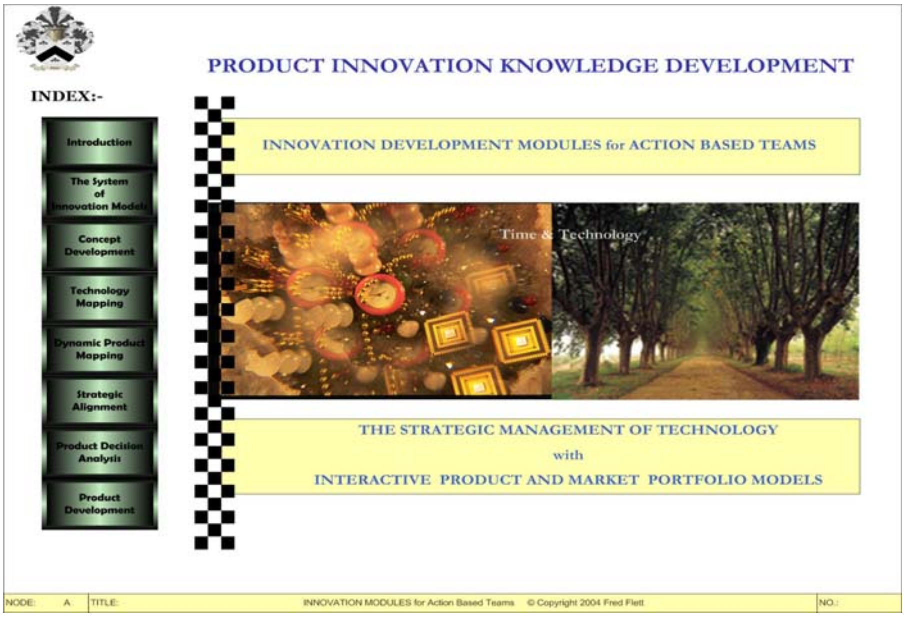
APPENDIX 1.



PRODUCT INNOVATION KNOWLEDGE DEVELOPMENT

INNOVATION DEVELOPMENT MODULES for ACTION BASED TEAMS

THE STRATEGIC MANAGEMENT OF TECHNOLOGY
with
INTERACTIVE PRODUCT AND MARKET PORTFOLIO MODELS

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Product Decisions

PRODUCT DEVELOPMENT MODULE

System Architecture Determination
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Equivalency, Economics and Environmental Specification
Management Science for Product Developers
Product Portfolio Metrics
Project and Product Control Triangles
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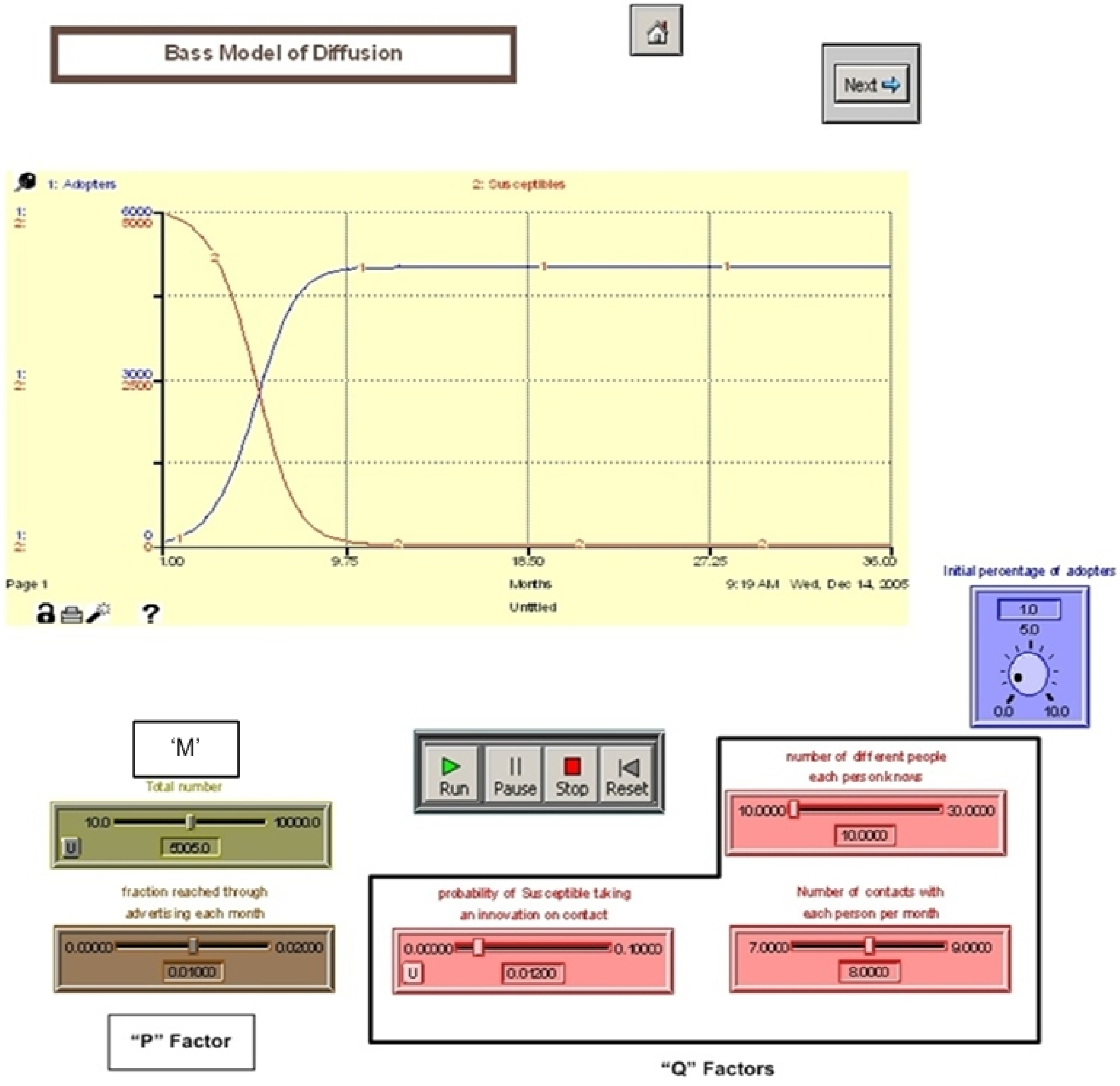
An R&D Knowledge Management Paradigm

SYSTEM DYNAMIC MODELS
S-Curve Theory – Bass, Fisher-Pry, Triple Product Growth, Logistics Models – (5 Models).
Product and Process Development
Scales of New Product Innovation
New Product Investment Criteria
Arc Elasticity of Demand
Product Development Issue Reduction Metrics
Accelerating the Time to Market
Reducing Uncertainty in Marketing Information – (Bayes Calculator)
Innovation Filter Program

POWERPOINT PRESENTATIONS
Step, Stretch and Span Product Platform
8-step diagram of Technology Mapping
Dynamic Interactive Models

APPENDIX 2.



Initial percentage of adopters: 1.0 (0.0 – 5.0 – 10.0)

‘M’ Total number: 5005.0 (10.0 – 10000.0)

fraction reached through advertising each month: 0.01000 (0.00000 – 0.02000)

number of different people each person knows: 10.0000 (10.0000 – 30.0000)

probability of Susceptible taking an innovation on contact: 0.01200 (0.00000 – 0.10000)

Number of contacts with each person per month: 8.0000 (7.0000 – 9.0000)