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MANAGING INNOVATION IN THE GAME OF R&D AND ENGINEERING TOOLS PROVIDERS: AN ARCHITECTURAL APPROACH

KARIM HAGGAR
DÉPARTEMENT DE MATHÉMATIQUES ET DE GÉNIE INDUSTRIEL
ÉCOLE POLYTECHNIQUE DE MONTRÉAL

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Ce mémoire intitulé:

MANAGING INNOVATION IN THE GAME OF R&D
AND ENGINEERING TOOLS PROVIDERS:
AN ARCHITECTURAL APPROACH

présenté par : HAGGAR Karim
en vue de l'obtention du diplôme de : Maîtrise ès sciences appliquées
a été dûment accepté par le jury d'examen constitué de :

M. TRÉPANIER Martin, ing., Ph.D., président
M. MILLER Roger, Ph.D., membre et directeur de recherche
M. TRÉPANIER Jean-Yves, Ph.D., membre

I would like to dedicate this thesis to my parents, Colette Frège and Jean-Paul Haggar, who always give me love, energy and inspiration.

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SUMMARY

The management of innovation is an essential capability for firms to develop and constantly improve. Existing models such as the Schumpeterian and Disruptive Innovations models, Porter's Five Forces model, the Co-opetition model and the Dynamic Capabilities models are too narrow for managing innovation in complex games. We have observed a lack of coherence between these models and the apparent logics of innovation in the R&D and Engineering Tools game.

Innovation patterns are heterogeneous and vary from game to game, and differentiation is the basis of the competitive advantage. This is the motto of the Games of Innovation concept and the trigger of this thesis. Furthermore, the thesis is a direct contribution to the concept currently under development at Ecole Polytechnique de Montreal.

The new economy is an economy of information and knowledge that emerged with electronics, computing, IT and software tools. The most powerful aspect of these tools is their use for researching, developing and engineering novel artifacts, molecules or systems. As cognitive amplifiers and means for more collaborative work, these tools are replacing intellectual routine and traditional processes, accelerating development, reducing costs and supporting innovation throughout organizations.

The first goal was to find the dominant innovation patterns and understand how leading providers of R&D and engineering tools created and captured value from an innovation perspective. The second goal was to find a coherent model for explicating the innovation patterns found.

Our hypotheses were the following: (1) firms invest very large portions of their revenues on R&D and innovation activities to integrate leading scientific and

engineering concepts in their tools and build their competitive advantage, (2) firms need to tightly integrate and close their product architectures to solve the complex problem and create value for the customer, and finally (3) firms use the large and complex problem solving projects with their large customers to scale down standard software products for use in large and low-complexity sectors. The scaling-down of innovations is a concept that existing models fail to capture.

The research and exploration of the R&D and Engineering game was done in a systemic and very practical way to avoid theoretical traps. Nevertheless, literature had to be explored and many books and articles on innovation models, management, strategy, software development, and the evolution of cognitive tools were addressed.

Interviews were carried out with chief technology officers, R&D VPs, marketing VPs, knowledge managers, engineering directors and other senior managers at ten of the leading tools providers. These leading tools providers are for instance Dassault Systemes, provider of Product Lifecycle Management solutions, Cadence, provider of Electronic Design Automation solutions and Autodesk, provider of the democratized AutoCAD tool for design and engineering. Other interviews were carried out in China and Taiwan in other sectors but inevitably enriched the study.

Moreover, a survey was conducted using a questionnaire on innovation management developed by the MINE project (Managing Innovation in the New Economy); the sponsor of this study. Fortunately, thirty senior managers in different R&D and Engineering tools companies responded to the survey. Many survey questions were too detailed to capture critical patterns but in general, the survey results strongly contributed to the research.

The problem with multiple-choice surveys is the pre-conception of their outcome. In some interviews, important game-specific concepts appeared that did not figure in any of the over three-hundred survey variables.

With the first interviews, the concept of open and closed architectures popped-up and was introduced in the study, redesigning the theoretical framework as well as our hypotheses.

The synthesis of value creation activities, innovation strategies, value networks and the game's best practices for innovation unfolded into a series of exciting innovation patterns that greatly improved our understanding of innovation.

We have found that large multinationals face important challenges for managing new product development and operations through their complex supplier networks and tools such as Product Lifecycle Management are currently solving this development and coordination problem.

We thought that scientific capabilities were much more important and realized that capabilities for coordinating science and business came first. Players invest in their engineering capabilities to integrate their field's scientific concepts and business dynamics.

The solving of complex problems through corporate and governmental large projects creates new markets and triggers very important technological cycles. Many of the R&D and engineering tools were scaled down from such projects.

The central message of the thesis is the importance of looking at architectures to understand innovation and solve the customer's problem. The finding is the key capability for managing the paradox of architectures. Architectures are always hybrid and the goal is to find the right point on the open-closed slide-rule to solve the customer's problem. Value is created when the chosen point on the slide-rule solves the problem.

Furthermore, software tools should not be taken for granted and the threats behind the adoption of standard tools should be known. The tool is not the rule but a means for automating routine work and coordinating people. As the Dynamic Capabilities model puts it, routine is not a competitive advantage and innovation should not depend on tools.

Finally, an architectural approach for understanding innovation and value creation and capture patterns should be developed and taken seriously. For the time being, entrepreneurs and managers should understand the game, move on with their business plans and capitalize on the million emerging opportunities. The Chinese and construction markets are the first of these major opportunities.

ABSTRACT

Organizations and societies are confronted with emerging complex information and software tools that change processes, competencies and the rules of the game for innovation and competitiveness.

There is no 'One Best Way' for managing innovation and the very specific innovation logics observed in complex systems deserve a deeper understanding and more refined models. Furthermore, the emphasis on concepts such as disruptive innovations and open architectures has proven to be counter-innovative in sectors such as the high-velocity R&D and Engineering tools development game.

External factors, internal capabilities, industry structures, technological change, S-curves and network effects are important levers for understanding innovation and generating competitive business models. However, higher patterns exist in complex systems and underlie not only business value networks but larger socio-technical and cognitive value networks.

Through the MINE project (Managing Innovation in the New Economy), interviews and surveys were carried out with the leading R&D and Engineering tools developers such as Autodesk, Cadence, Agile, Dassault Systemes, PTC, Accelrys and SAP to truly understand value creation and capture through systems architectures.

Value creation patterns and innovation dynamics vary with the degree of expertise of customers and the necessary architectural adjustments for system integration. Innovative software tools are typically created through large cost reduction and coordination projects with large and demanding buyers. However, tools providers capture great value when new scientific and engineering processes are captured,

automated and modularized into standard products for lower performance and large scale applications.

The study addresses practices, dynamics, value creation and capture activities, and economics inside the game of R&D and Engineering Tools Providers with a special focus on systems architectures for value creation. Further interviews with complex tools developers, complex systems architects and large demanding buyers will hopefully lead to the development of an architectural model for understanding innovation, technological change and perhaps evolution.

CONDENSÉ EN FRANÇAIS

INTRODUCTION

La gestion de l'innovation est une approche systémique de management qui permet l'intégration des éléments de l'environnement complexe de l'entreprise pour sa différenciation et la création de son avantage concurrentiel.

La nouvelle économie est une économie d'information, de connaissances et surtout de logiciels qui permettent la coordination et l'automatisation des processus de développement et de engineering de produits. Les logiciels sont aussi des amplificateurs cognitifs qui automatisent les routines intellectuelles et dont l'impact pourrait se comparer à celui des systèmes de symboles et des logarithmes il y a des siècles voir des millénaires.

Dans les années 70, les pressions politiques et militaires aux É.U. causées par plusieurs facteurs comme celui de l'émergence du Japon ont déclanché des projets nationaux comme le projet CALS qui obligeait tous les fabricants militaires d'intégrer rapidement les technologies IT dans leurs systèmes organisationnels et ce surtout pour augmenter la productivité du processus de développement de nouveaux produits.

Les conséquences ont été l'émergence d'un nouveau secteur industriel, celui des développeurs spécialisés d'outils de R-D et engineering. Les logiques d'innovation très particulières de ce secteur qui ne semblent pas se retrouver dans les modèles d'innovation existants ont déclanché la présente étude.

CADRE THÉORIQUE

Le cadre théorique comprend les modèles d'innovation comme les modèles de Schumpeter, Porter, Christensen, celui des Dynamic Capabilities et celui de Co-opetition. Des modèles qui s'appliquent difficilement aux systèmes complexes comme ceux des outils informatiques étudiés.

D'autres concepts comme celui des innovations ouvertes et fermées de Chesbrough, celui de l'économie de l'intégration des systèmes de Dosi, des concepts de développement de logiciels comme le Open Source et bien sûr le concept des Joutes d'Innovation du programme MINE ont fortement contribué à cette étude.

HYPOTHÈSES

Les hypothèses de l'étude se résument comme ceci :

- Pour créer de la valeur et pour résoudre le problème complexe du client, des architectures fermées et intégrées sont nécessaires.
- Pour créer leur avantage concurrentiel et pour intégrer des concepts scientifiques clés, les entreprises de la joute investissent de grandes sommes en R-D et en innovation.
- La résolution de problèmes complexes grâce à des investissements importants est une opportunité pour les développeurs d'outils RDE de créer des modules plus simplifiés vendus à grande échelle.

MÉTHODOLOGIE

Une approche systémique et pratique a été choisie pour la réalisation de l'étude. 10 entretiens avec des leaders de la joute ont été réalisés entre Montréal et la Silicon Valley et 30 réponses au sondage du projet MINE comptant plus de 300 variables ont été obtenues et analysées. Les dirigeants qui nous ont rencontré et qui ont répondu au questionnaire sont des CTO, des VP R-D, des VP Marketing, des directeurs d'ingénierie, etc.

SURVOL DE LA JOUTE

Les entreprises étudiées son des leaders technologiques et dépensent en moyenne 25% de leurs revenus en R-D. Les outils RDE sont souvent issus de grands projets d'intégrations de systèmes pour l'amélioration du développement de produits des grands joueurs industriels. Le logiciel CATIA par exemple, qui se retrouve aujourd'hui au sein des universités et des PME manufacturières a été originalement conçu pour la conception, la simulation et le développement plus rapide d'avions militaires plus performant chez Dassault Aviation en France.

Les outils RDE, les entreprises qui les développent et les réseaux de valeurs qui les gouvernent sont présentés.

Les outils de R-D et Engineering

Les outils RDE sont surtout des outils cognitifs et de travail collaboratif mais aussi des versions plus avancées de nos alphabets, logarithmes et calculatrices de poche. Les principes qui se retrouvent à l'intérieur de ces outils ont été découverts dans l'environnement physique comme par exemple le principe de gravité de Newton.

Ces outils permettent de faire des conceptions, simulations et de gérer et communiquer des données relatives au développement de produits et ce grâce à l'accumulation de programmes, logarithmes, théories et données scientifiques, ainsi que l'automatisation de processus d'affaires, de développement et d'Engineering. Les outils RDE sont par exemple des outils CAD, CAM, CAE, PDM, PLM et des outils de simulations et design de molécules.

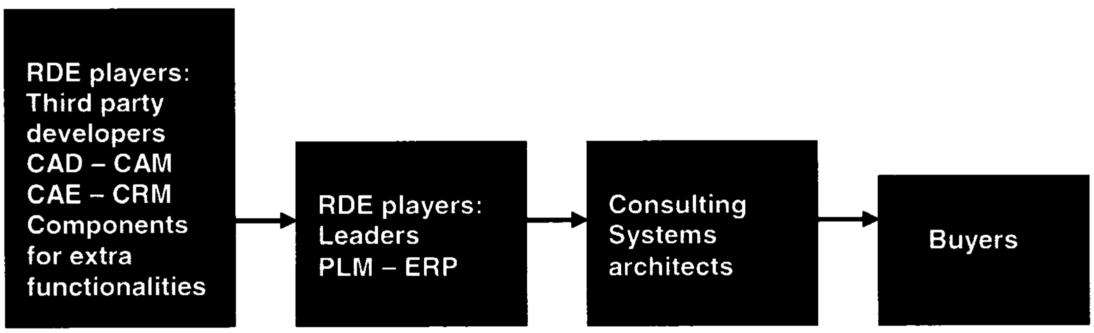
Les outils PLM sont les outils archétypes de la joute et ceux-ci regroupent des composantes CAD, CAM, PDM et même ERP sur une même plateforme qui permet de coordonner les processus scientifiques, les processus d'Engineering et les processus d'affaires de l'entreprise.

Ce tableau illustre les fonctionnalités des différentes composantes de l'offre PLM de Dassault Systèmes :

Dassault Systèmes	
DELMIA	Manufacturing process simulation. This module enables the visualization and testing of the entire production process using virtual prototypes of the product.
ENOVIA	Collaborative design and 3D data management. The platform enables virtual product modeling and the management of product lifecycle data. Also considered as a knowledge management and PDM (Product Data Management) system.
CATIA	Modeling and products design. This is the leading CAD software worldwide and the core element of Dassault Systemes' PLM solution. The company argues that the CATIA or PLM V5 architecture is open and flexible and enables integration of revolutionary design and development concepts such as the Functional Modeling concept, developed by ImpactXoft (interviewed and surveyed), and totally integrated in CATIA only one year following Dassault's partnership agreement with ImpactXoft.
SMARTEAM (becomes a PLM solution when integrated with CATIA, ENOVIA and DELMIA)	SMARTEAM solutions manage the enterprise product data and other intellectual capital in a highly collaborative Web environment. The system is adapted to all industries and all organizations. SMARTEAM is mainly used by SMEs.
SolidWorks	SolidWorks is a consumer products design software taught in more than 4500 academic institutions worldwide.
SPATIAL / CAA (Component App. Architecture)	This is Dassault's platform and trademark for enabling partners and customers to develop complementary applications to Dassault's PLM portfolio. All Dassault's products and modules are based on the CAA platform.

Les réseaux de valeurs

Les réseaux de valeurs sont constitués des compétiteurs et leaders de la joute (Dassault, Agile, Cadence, PTC etc.), leurs partenaires conseillers et architectes de systèmes (IBM, Accenture, BearingPoint, etc.), des clients (Boeing, Toyota, Sony, etc.) et des développeurs de tiers parties et les plus petits joueurs (ESI, ImpactXoft, Engenuity, etc.). La figure ci-dessous illustre les réseaux :



Routines et processus automatisés

Les logiciels sont des programmes, des codes et surtout des moyens d'automatiser nos routines de travail. Le output d'un logiciel se limite aux compétences de celui qui la conçu et qui a imaginé son application. D'après Drucker, le dénominateur commun à la révolution informatique présente et la révolution industrielle du 18^{ième} siècle est l'automatisation des processus de travail. Les logiciels et les technologies IT d'aujourd'hui font ce que le moteur à vapeur a fait il y a 250 ans. Il est donc impératif de bien comprendre les liens qui existent entre les systèmes informatiques et leurs répercutions sur l'innovation de l'entreprise. Les logiciels ne peuvent pas remplacer l'intuition humaine et ne peuvent pas intégrer plusieurs des processus informels qui créent souvent l'avantage concurrentiel de l'entreprise.

LA GESTION DE L'INNOVATION AU SEIN DE LA JOUTE

Cette section est une synthèse des résultats des entretiens ainsi que des sondages réalisés.

Le contexte d'innovation

Le contexte se résume avec ceci :

- Des besoins complexes et une performance plus élevée – Les clients sont typiquement des grandes organisations avec des besoins d'intégration de systèmes complexes.
- Du ERP au PLM – La mode des systèmes ERP a augmenté la rigidité des organisations et la réaction de Wall Street à déclanché le besoin de systèmes PLM plus flexibles.
- Les standards ouverts et le OSS – Les développeurs suivent IBM qui mène la course dans l'architecture des systèmes et qui pousse les standards ouverts; les entreprises sont passées de UNIX à Microsoft à Linux.
- Une bataille d'architecture et une consolidation – Accelrys par exemple est le résultat de 10 fusions et possède aujourd'hui la plateforme standard de facto pour les applications scientifiques.
- De grands projets et l'intimité avec les clients – La résolution de problème complexe exige une intimité entre le développeur, l'entreprise de conseil et le client.
- L'oligopole PLM – Les résultats du sondage montrent une séparation très claire entre les petits joueurs et les grands joueurs. Le plus petit des grands joueurs (Moldflow) compte 300 employés et le plus grand des petits joueurs (Imagine) compte 82 employés.
- Des interconnections pour résoudre les besoins complexes – La variable contextuelle qui prend la première place au niveau du sondage.

- Le besoin de logiciels de coordination – La coordination des applications scientifiques, de engineering et d'affaires est un besoin critique qui a créé des entreprises PLM en pleine expansion comme Agile et MatrixOne.

Les activités de création de valeur

Voici ce qui est ressorti :

- Diminuer les coûts du client en automatisant ses processus de développement et de communication
- La pensée systémique – Pour Cadence par exemple, le client est l'écosystème de design de systèmes électroniques.
- L'élargissement de l'offre sur une seule plateforme intégrée – Cadence par exemple offre 300 différents modules EDA sur sa plateforme.
- La balance – Balancer les changements de la plateforme et ceux du client.
- Aligner les processus scientifiques, de engineering et d'affaires du client – Accelrys par exemple vise à combattre la fragmentation actuelle qui a lieu au niveau des applications scientifiques et des applications d'affaires des entreprises pharmaceutiques et chimiques.
- Une bonne réputation et des images de marques solides – Les marques de logiciels persistent alors que leur contenu peut complètement changer.
- Le logiciel comme service – En moyenne les services comptent pour 40% des revenus des entreprises. Accelrys par exemple génère présentement 5% de ses revenus par ses services et vise 30%. Dassault Systèmes Services for America est la nouvelle division de Dassault Systèmes basée à Montréal. ESI par exemple vend 100% de ses outils de simulation sous forme de services.
- Des services de gestion des risques – Pour que le client puisse gérer les risques de solidification et d'augmentation de l'inertie des outils.

- La résolution des problèmes standard et complexes – Certains créent des standards comme Autodesk d'autres des systèmes complètement adaptés ou presque comme ESI.

Les stratégies dominantes

Les statistiques nous donnent les stratégies suivantes par ordre d'importance : (1) Une relation stable à long terme avec les clients, (2) l'accumulation du savoir-faire, de l'expertise et des compétences, (3) des opérations à grande échelle et (4) le contrôle de l'architecture centrale du produit. Voici d'autres stratégies très importantes obtenues grâce aux entrevues :

- Des plateformes fermées et intégrées – Structures, centralisations et concentrations des efforts sont nécessaires pour répondre aux besoins complexes.
- Consolider pour le leadership des plateformes – Une course pour la création de la plateforme de facto.
- Partager le leadership avec le client – Par exemple Dassault et Toyota ont développé l'application PLM pour l'industrie de l'automobile en partenariat. Le client se rend compte parfois que le développeur profite du besoin complexe pour créer des bons standards.
- La gestion du réseau de développeurs de tiers parties – Les joueurs PLM par exemple développent des compétences pour gérer des réseaux de plusieurs centaines de développeurs qui leur permettent d'ajouter constamment de nouvelles fonctionnalités.
- L'accès aux leaders de grands réseaux – Lorsque Agile a vendu son système PLM à CISCO, tous les fournisseurs de CISCO ont demandé de se connecter.
- Le développement de logiciels collaboratifs – Des fonctions de collaboration, de communication, de visualisation 3D, de PDM et de Concurrent Engineering sont constamment intégrées pour répondre au besoin de coordination des clients.

- Le développement sur des standards ouverts – La plateforme Eclipse par exemple est utilisée pour le développement des solutions PLM de Aile comme plusieurs autres développeurs. Des APIs sont utilisés pour connecter les systèmes.
- Les stratégies Top-Down et les stratégies Bottom-Up – Toutes les entreprises visent le marché PLM et des logiciels d'entreprises. Autodesk par exemple venant du bas avec des logiciels simples et Dassault venant du haut avec des logiciels complexes.

Les investissements en R-D sont très élevés, les petits joueurs investissent autour de 25% de leurs revenus en R-D alors que les grands joueurs n'investissent qu'autour de 18%. Les grands joueurs génèrent des innovations incrémentales alors que les petits joueurs des innovations plus radicales mais cela à différents niveaux.

En général, l'effort d'innovation total des entreprises est très élevé et représente approximativement 50% des revenus.

Une stratégie très importante est celle de la pénétration du marché de la construction avec des solutions de design, développement et de gestion de projets de construction. Certains l'appellent le BLM (Building Lifecycle Management). Alors que le secteur manufacturier en Amérique du Nord à augmenté de 300% en productivité durant les 40 dernières années, celui de la construction à diminué en productivité. Un effort d'informatisation est urgent et selon Autodesk, ce marché représenterait environ 3 trillions de dollars. Dassault Systèmes et Autodesk sont les joueurs les plus impliqués.

Logiques et dynamiques d'innovation

Grâce à la synthèse des activités de création de valeur, des stratégies d'innovation dominantes, des réseaux d'innovations importants et des compétences internes des entreprises (voir le corps de l'ouvrage pour les réseaux d'innovation et les compétences internes) les logiques d'innovation suivantes ressortent et viennent tester nos hypothèses :

- Les clients experts cherchent une plus grande performance, une plus grande variété de produits et des solutions pour la coordination du processus de développement de nouveaux produits à travers leurs chaînes de valeurs.
- Les architectes de systèmes comme IBM et leurs partenaires développeurs PLM comme Dassault transforment les industries en offrant des solutions de coordination.
- Les développeurs créent de la valeur pour leurs clients experts en accumulant leurs expériences de résolution de problèmes et leur expérience d'engineering.
- Les grands joueurs comme Dassault, PTC et SAP cherchent à créer des modèles standard et simplifiés de leurs outils. L'outil Pro/ENGINEER de PTC et le module Mendocino de SAP sont de très bons exemples qui fonctionnent sur Windows.
- Les grands joueurs développent des compétences pour la gestion des réseaux de petits développeurs et des compétences pour la résolution de problèmes de coordination pas de problèmes scientifiques.
- Les petits joueurs sont forcés de créer des partenariats avec les leaders de plateformes pour vendre leurs produits et se limitent de plus en plus à la résolution de problèmes plus scientifiques.

CONCLUSION

Des patterns d'innovation très particuliers ont été observés comme celui de la simplification et de la modularisation des outils complexes de R-D et Engineering. Les projets de résolution de problèmes complexes sont des opportunités pour innover et pour créer des designs dominants à plus grande échelle mais à moindre performance. Cette réalité semble contredire plusieurs des derniers modèles d'innovation comme celui des Disruptive Innovations de Christensen.

Pour résoudre le problème complexe du client, les développeurs d'outils ferment l'architecture de leur système tout en créant des interconnections avec les autres systèmes. Les architectures sont donc des architectures hybrides.

Les grandes organisations font face à de grands défis de coordination des activités de développement de nouveaux produits à travers leurs chaînes de valeur complexes et les outils PLM sont des solutions parmi d'autres. Ce marché est en pleine expansion et plusieurs nouveaux joueurs ont récemment apparu. Les joueurs PLM investissent plus de 20% de leurs revenus en R-D et développent des compétences de Engineering pour coordonner les principes scientifiques et les processus d'affaires de leurs clients.

La gestion de l'architecture de l'outil ou du produit est une compétence cruciale et le degré d'ouverture de l'architecture change d'un cas à l'autres. L'architecture d'un outil pour la NASA sera probablement beaucoup plus fermée que l'architecture d'un outil pour une PME qui fabrique des poignées de portes. Il est nécessaire de comprendre ce paradoxe pour innover.

Les organisations qui intègrent les outils devraient continuellement les améliorer et les maintenir flexibles pour pouvoir les adapter à de nouveaux besoins.

Les règles du jeux ne sont jamais les mêmes et pour mieux comprendre les logiques d'innovation spécifiques à la joute RDE ainsi qu'aux systèmes complexes, un modèle architectural d'innovation est nécessaire.

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API	Application Programming Interface
BLM	Building Lifecycle Management
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CRM	Customer Relations Management
CTO	Chief Technology Officer
DS	Dassault Systemes
EDA	Electronic Design Automation
ERP	Enterprise Resource Planning
HMI	Human Machine Interface
IS	Information Systems
MPM	Manufacturing Process Management
NPD	New Product Development
OEM	Original Equipment Manufacturer
OSS	Open Source Software
PDM	Product Data Management
PLM	Product Lifecycle Management
PTC	Parametric Technologies Corporation
RDE	Research Development and Engineering
SBU	Strategic Business Unit
SCM	Supply Chain Management
SI	Systems Integration
SME	Small and Medium Enterprises
SOA	Service Oriented Architectures

LIST OF APPENDICES

AVANT-PROPOS

The study explores realities and patterns of innovation inside one of the new economy's most complex and vibrant games.

It is addressed to entrepreneurs with challenging dreams and managers with high innovation targets. The technologies, strategies and innovation dynamics presented can help organizations in all fields choose better software and information solutions. The study is also addressed to software developers looking for alternative ways to develop and commercialize their software ideas.

Researchers could perhaps find the study appealing in that it opens up new research venues for understanding innovation, change and even evolution. Innovation researchers would hardly understand anything about innovation if they did not try to innovate themselves. The good news is that innovation exists everywhere.

INTRODUCTION

Why are Mozart, Archimedes, Da Vinci and Alexander so famous?

They all marked humanity with their revolutionary thinking, determined action and commitment to understand and improve the world. They respected other cultures and used their wisdom to enrich their work, languages and philosophies. They were lucky and also gifted with skills to empower and mobilize others; *they were innovators*.

The mass of innovation's technical and material side is constantly increasing but the human mind will always remain on top. In today's multinational organizations, technology creates great value and increases one's ability to innovate and thrive.

Innovations are cycles of progress and improvements, cycles of change and evolution. Innovation is an event that evolves in time. It is the beat of life inside human modern institutions such as the firm, the market and the government.

The management of innovation is a systemic management approach that enables the integration of the important elements of the firm's complex environments to make better strategic and operational decisions. The management of innovation is also the coordination of the firm's different organs and processes to enable its differentiation, the creation of its Competitive Advantage.

The new economy and the 'Information Revolution' stands on two of the 20th century most revolutionary inventions, the transistor (hardware) and programming (software); the heart and brain for every computer and server in the world. Programming and codification transformed all industries and created many new ones. It increased productivity, significantly accelerated research, development and engineering processes and made possible the storage and processing of much larger quantities of information.

This new technological paradigm and cycle is unfortunately the outcome of the last major wars, World War 1, World War 2 and the cold war. The emergence of electronics, software and telecommunications (the knowledge economy) has an important restructuring effect on all industries, all social institutions, politics, and of course the whole economy. According to Peter Drucker, the impact of the current information revolution driven by electronics and software is similar to if not stronger than the industrial revolution in the late 18th century driven by the steam engine (Drucker, 2002). Software, information systems and the Internet are as strong as if not stronger than Gutenberg's printing press in the 15th century in terms of inventing new societies and economies. The printing press resulted in reforming Christianity with helping the fast emergence of Luther's Protestantism in Europe. A little time after the fast diffusion of biblical texts emerged the first non-biblical book, Machiavelli's 'The Prince', and leadership knowledge diffused all along the 16th century.

Software is probably the major innovation of all radical innovations and its emergence is a great catalyst for all political and institutional shifts. Together, technological, political and institutional innovations are the new economy's driving forces.

The most important aspect of software is its use as a tool for researching, developing and engineering new products and technologies. Codification of scientific, production, operational and market data greatly accelerated the process of new product development and significantly reduced production and business processes costs. Software's first characteristic and strongest attribute is the 'Routinization' of processes.

Before the use of software for computing, processing information and managing databases, everything was written and archived on paper. Problem solving knowledge was very hard to reprocess efficiently, drawings and calculations almost had to be restarted from scratch for every single problem.

All research, development and engineering tools were built out of an accumulation of knowledge and experience and they still are. Before the use of algorithms, we used tables and charts.

For an illustration, take the German process engineering company Lurgi. The company is the world leading chemical and metallurgical process designer founded in 1897 with a proprietary technology strategy. According to the company's head of R&D, there is no problem the company hasn't solved. With more than 100 years of experience in chemical and metallurgical process engineering, Lurgi developed very powerful R&D and engineering tools that it sells globally through licenses. The codification of the firm's experience and knowledge greatly increased productivity in its reuse.

It is important to look at these tools from a historical perspective and understand their appearance and evolution.

Strategy and innovation authors such as Chesbrough have emphasized the need to better understand the close relationship between technological change and organizational structure. Looking at this relationship from the historical perspective of cognitive tools evolution is crucial for understanding today's knowledge based economy and even more crucial for understanding the modern way for managing innovation in the game of R&D and Engineering tools providers.

Technology, broadly conceived as the building of artifacts or procedures – tools – to help people accomplish their goals, predates recorded history. As amplifiers of human capabilities, tools may be classified in terms of whether the abilities they amplify are motor, sensory, or cognitive in nature (Sternberg R. J. and Preiss D., 2005). What we find relevant to the current study and to describing the R&D and Engineering Tools game are of course the cognitive tools.

There was no time when human beings existed and did not use technology to aid or amplify cognition. Most likely as soon as humans learned to count and measure, they created devices or tools to help them do so and to remember the results.

The creation of symbol systems and written language was certainly among the most important technological achievements of prehistory; there is perhaps no other technological advance whose effects on human history surpass the effects of this one.

Tools can amplify cognition either by facilitating reasoning directly or by reducing the demand that the solution of a problem makes on one's cognitive resources, thereby freeing those resources up for other uses (Sternberg R. J. and Preiss D, 2005).

4000 years ago the Ancient Egyptian symbol system and alphabet was considered a revolutionary cognitive tool for representing objects and concepts. The Greek alphabet and mathematical systems came right after and were defused with Alexander's empire. In Alexandria, Egypt, Egyptians used the Greek alphabet to improve their hieroglyphs system creating the Coptic alphabet. At the same time (3^{rd} century B.C.) and in the same place Archimedes innovated and created the greatest advances in mathematics ever known. Around the 7^{th} or 8^{th} century, the Hindu-Arabic mathematical system appeared and is now used as a universal standard.

Logarithms were invented in the 16^{th} century by the Scottish mathematician, John Napier, and brought mathematics to another level. In the 17^{th} century, Edmund Gunter, an English mathematician, invented a rule with a logarithmic scale that reduced problems of multiplication and division to those of addition and subtraction. A few years later, the logarithmic slide rule was born and made the measuring task much easier.

Many ingenious mechanical tools such as the abacus have been invented independently by various cultures in Egypt, Greece, China, Japan and Russia to assist counting and record keeping. It is said that the use of symbols and tools to assist counting predates the use of written language by many millennia.

A succession of computing machines developed by the French mathematician, Pascal, and Leibniz in the 17th century, the English mathematician Babbage in the 19th century and other successors, unfolded into the Electronic Digital Computer we all use today.

Babbage created a machine that he called the Analytical Engine around 1830 with a vision and functions that could not materialize with a mechanical machine. His vision had to wait for the appearance of the technology of electronics. By the middle of the 20th century, the technology had matured enough to the point that the creation of computing machines with stored programs was feasible. Events that helped mark the beginning of this era are the building of Howard Aiken's Mark I by IBM in 1944, completion of J. Presper Eckert and John Mauchly's ENIAC in 1946 (with 17,000 vacuum tubes), invention of the transistor by John Bardeen, Walter Brattain, and William Shockley in 1948, and the first commercial sales of electronic digital computers about mid-century (Sternberg R. J. and Preiss D, 2005).

Computers are used today for word processing, managing databases, communicating through emails, chat programs and VOIP (Voice over IP), searching for information on the Internet, but it is also used for computing, researching, developing and engineering tasks.

Extremely important attributes that information and communication technologies have added to computers or individual cognitive tools are the collaboration and coordination functions. Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) software tools are examples of such revolutionary tools that created group and enterprise cognition. The term *groupware* is often used to refer to these group information tools.

Before the wide use of software tools in the 1970s, concepts behind these modern tools emerged during the two world wars for designing and building boats and aircrafts. The first versions of the most used CAD/CAM/CAE software CATIA today was developed in-house by the French military company Dassault for military aircraft design and manufacturing. This software is used today in most manufacturing industries such as the automobile and aviation industries; it is also used in SMEs on Windows operating systems.

Concepts and techniques used in craft design tools were recently discovered by the scientific community and evolved into what is called drug and chemical design.

The first design schools appeared in the 1950s and introduced innovative design methodologies and theoretical frameworks. The Japanese took these methodologies and implemented them with efficient work techniques. They invented Concurrent Engineering, the Taguchi Methods, Just-In-Time, etc.

In the early 1980s, the Americans and Europeans reacted to the emergence of Japanese highly productive industrial production with several large digitization projects such as CALS (Computer-Aided Acquisition and Logistics Support), the US Military multi-billion program for a paperless American industry. The program's main purpose was making greater use of computer aided information technologies that enable process improvements in design, manufacturing and life-cycle support of defense systems and equipment. US military contractors were forced to develop integrated shared data based environments consisting of analysis tools, integrated databases, engineering design tools, manufacturing and logistics processes designed to utilize digital information. The contractors were also forced to use CAD/CAM/CAE methods to support design integration through shared product and process models and databases.

The outcome of CALS was the emergence of many data and process approaches in design, the appearance of the New Product Design School, the increasing demand for product differentiation and most notably the spin-off and birth of specialized software tools providers such as Autodesk, Dassault Systemes and PTC.

In this work, innovation is studied in the game of those software tools providers with a special focus on the value creation and capture process driven by these tools and increasing the innovation capabilities of firms buying them. It is a practical exploratory research on the way software companies manage their innovation and the role their software tools have in other industries' innovation. The study will show crucial innovation management issues in the new-economy's most innovative and effervescent sectors; the sectors we have clustered in the game of R&D and Engineering Tools Providers.

In the first chapter, a critical analysis of the theoretical framework for innovation management is presented including the Games of Innovation model used to structure the study. Other literature is explored such as literature on the economics of systems integration, software development and architectures and open and closed systems for innovation. In chapter two, the research hypotheses, questions, objectives and methodologies are presented.

In chapter three, an overview of the R&D and engineering tools game is presented covering existing R&D and engineering software tools, their nature and various applications, and the important value networks and industry structures related to the game. Chapter four is central in that a synthesis of the leading players' innovation strategies, practices, approaches and networks are carried out. In the end of the chapter the innovation logics and dynamics of the game are formulated.

In chapter five, a discussion is opened on the current consolidations and standardizations in the game and their effect on innovation, the importance of standard tools for average buyers, the importance of complex projects and their impacts on innovation, the scenarios where integration and closed architectures are necessary and create value and other scenarios where open architectures and modularization capture value.

In the conclusion the need for an architectural approach for understanding innovation in complex systems is presented along with three potential business opportunities for creative entrepreneurs.

CHAPTER 1: THEORETICAL FRAMEWORK

To frame and understand innovation inside the game of software tools development, four spheres are explored in this theoretical chapter; the software development and software engineering approaches, issues on open and closed innovation, innovation management models for complex systems and the Games of Innovation concept.

The management of innovation is a relatively new management concept. The subject is trendy and the academia is aggressively introducing innovation management literature such as the Innovator's Dilemma (Christensen), Crossing the Chasm (Moore) and Co-opetition (Brandenburger and Nalebuff).

This research is practical and exploratory first, theoretical second; it also constitutes an integral part of the Games of Innovation approach.

The Games of Innovation approach is a meso-level model for strategic management and industrial analysis. The concept is the continuity of past models such as the Schumpeterian model, Porter's model, the Resource-Based model, the Dynamic Capabilities model, the Network Effects model and the Value Net model.

1.1 INNOVATION MODELS FOR COMPLEX SYSTEMS

People, firms, governments and institutions use models for understanding their competition, industries and environments. These models or concepts are used to create contextual schemas and patterns to help formulate strategy and guide action.

The understanding of industrial dynamics, the context, is not sufficient if internal capabilities are ignored, both views enable the firm to formulate an innovation strategy which in turn helps create innovation management techniques and guide action.

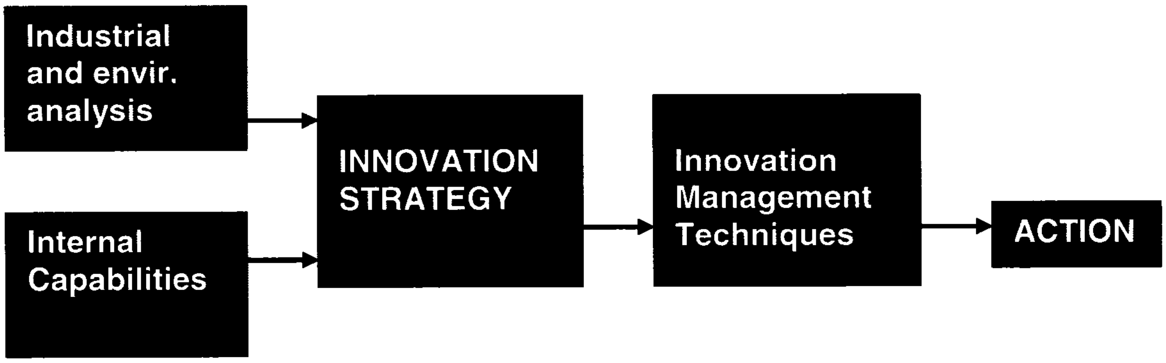

Figure 1.1 : Current Innovation Strategy Model

The models are essential for understanding innovation rules and dynamics and the rules and dynamics are essential elements to master before strategizing. The new economy is essentially a capitalistic economy that many authors tried to explain through their understanding of change mechanisms, authors such as Joseph Schumpeter, Christopher Freeman and Brian Arthur. The first to use innovation for explaining change is Joseph Schumpeter and his model is presented below.

1.1.1 Schumpeterian Innovation

Schumpeter revolutionized the economical and industrial analysis methods by bringing the dynamic dimension. He also reinterpreted the economical cycles focusing on innovation and the entrepreneur. Schumpeter found important links between new technologies and the economy's social system regulating them. His philosophical point:

1. The technological change destabilizes all sectors of the economy
2. Major structural adjustment crises follow the change
3. Social institutions have to transform

The innovation management part of his work is a revolutionary model for industrial and economical analysis; Schumpeter introduced the creative destruction concept. This process of Creative Destruction for Schumpeter is the essential fact about capitalism. The innovations are product lifecycles (S-curves) where the product matures to a dominant design followed by accelerated process improvements. In this creative and dynamic model for understanding change, the old incumbents (established firms) are replaced by new entry firms and their core competencies become core rigidities.

Another major concept in Schumpeter's model is the meritocratic view of market selection forces. For Schumpeter, innovation is only producer-driven. Shumpeter's model (creative destruction and meritocratic selection) is too simplistic for understanding today's architectural, modular, complex and network-based innovations. The model is still valid for many products but hard to apply in architectural and modular industries where coordination among players is a major competency for innovation and where innovation often starts in complex problem solving projects.

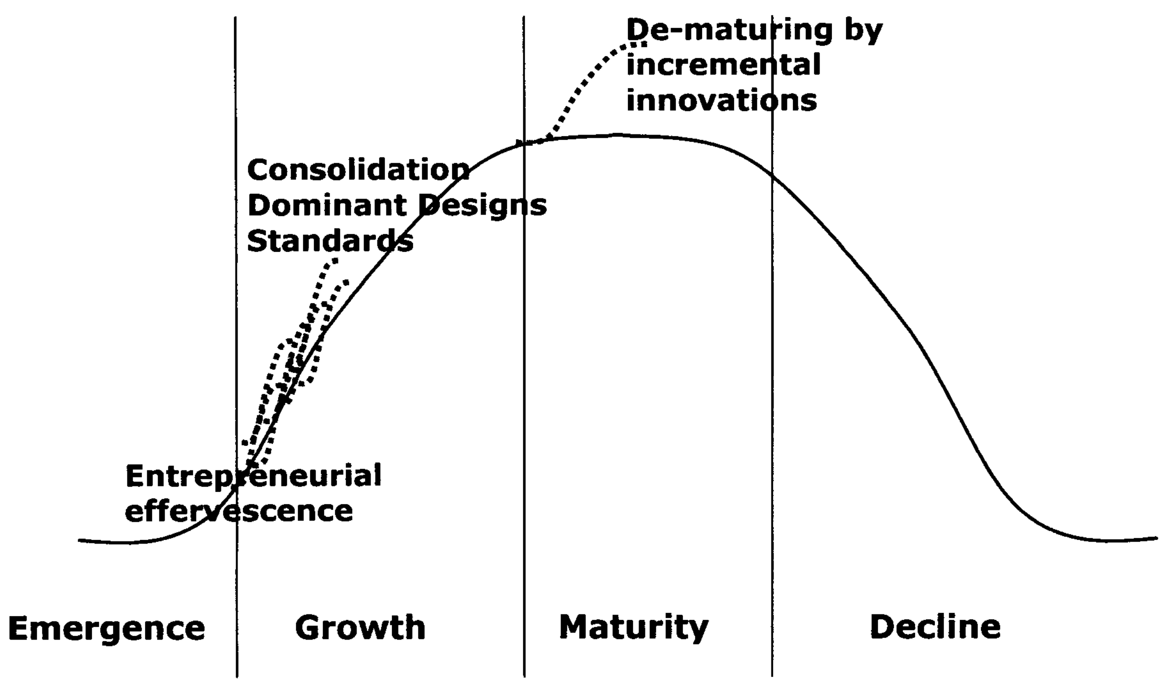

Figure 1.2 : Schumpeterian Curve

1.1.2 Porter's Five Forces Model

For Porter the firm's strategy is purely based on the industry structure and competition. His view of the world is very competitive (we are only competing and only competing for market share) and his mentality very military. The firm's main goal is to find a position in the industry where it can best defend itself against the competitive forces or influence them in its favor (Porter, 1980).

His model for understanding the environment and formulating strategy turns around the following five competitive forces: (1) Supplier negotiation power, (2) Buyer negotiation power, (3) Barriers to entry, (4) Threat of substitutes and (5) the Degree of rivalry.

This model is still a classic tool used in all management and MBA programs in the world but three major elements are lacking in the model:

1. Complex systems concepts
2. The importance of cooperative strategies and managing partner networks for innovation, or open innovation (open architectures)
3. Internal competencies and capabilities of the firm

1.1.3 Capabilities and strategic management

According to Teece, the Dynamic Capabilities Approach (DCA) is the answer to all questions on how to reach and maintain a competitive advantage for strategy (Teece, Pisano and Shuen, 1997).

They saw that the dominant Porter model for strategy formulation was not relevant in turbulent industries and sectors. They reacted to Porter's structured and military approach with an opposing approach. In the new economy, turbulent sectors are important hi-growth sectors such as the telecom, the biotech and the enterprise software. For Teece, structures in these sectors are changing too fast to limit strategy formulation to their analysis. The model presented by Teece is the following:

1. Market forces: Competitive forces and strategic conflict
2. Efficiency: Based on internal resources

In turbulent and uncertain markets, fast technological change and the firms' heterogeneous capabilities (which influence profitability) are crucial dimensions to understand for creating Competitive Advantages (CA); Porter's model is not complete in that sense. Shapiro's strategic conflict approach is based on the epistemological side of the Game Theory, it focuses (like the Porter model) on the competitive interactions between firms; the zero-sum game mentality (old game theory).

It is very hard to use game theory in turbulent sectors to predict rival reactions to rival actions and chose the best strategic move to make. Game theory enables you to make strategic moves but not to develop a Competitive Advantage (CA), which represents the core for strategy. In Porter's model, the industry structure determines the firm's strategy but in Shapiro's model, the rival's action can also determine the firm's strategy.

The other side of Teece's model is Rumelt's Resource-based approach defining the firm as: (1) a system, (2) a structure and (3) rare and specific resources enabling the firm to succeed. The resource-based approach is revolutionary in that it redefines strategy and adds to it a crucial dimension, the firm's internal resources (Teece, Pisano and Shuen, 1997).

Here is a comparison of the Porter and Rumelt models:

Table 1.1 : Dynamic Capabilities Model

Dynamic Capabilities Model	
Competitive model	Resource-based model
1. Pick an industry (based on its structural attractiveness) 2. Choose an entry strategy based on conjectures about competitors' rational strategy 3. If not already possessed, acquire or obtain the requisite assets to compete in the market	1. Identify your firm's unique resources 2. Decide in which markets those resources can earn the highest rents 3. Decide whether the rents from those assets are most effectively utilized.

The contribution of the Dynamic Capabilities model is important in that it improves strategy formulation in all industries or sectors whether turbulent and complex or stable and low-tech; you can't go wrong with understanding your internal capabilities. But the model is even more important in the new economy's turbulent and hi-tech sectors in that the firm should develop capabilities to (1) interact and respond very quickly to their environment, (2) develop agile innovation processes and (3) constantly coordinate and redeploy internal and external capabilities.

Dynamic capabilities are about developing core competencies and renewing them according to turbulence and environmental change. The model provides 3 measurement units for understanding the firm's core competencies and dynamic capabilities: (1) the processes, the (2) positions and (3) the paths:

1. Processes are managerial and organizational processes such as routines, learning practices, motivation systems etc.
2. Positions are characterized by the firm's Intellectual Property (IP), its position in the Value Network (partners, customers, and suppliers), its technological talents etc.
3. Paths are simply the firm's strategic alternatives.

In their view, the firm's Competitive Advantage is the hard-to-imitate and replicate portion of the firm's routines (processes) and positions. Many of these hard-to-imitate routines and processes are tacit and impossible to decode.

1.1.4 Disruptive Innovations

The concept shows how small firms with disruptive innovations destroy established corporations. The central argument is the difficulty for large firms with rigid structures built around their product architecture to venture into new applications with new business logics. The established firms with their rigid financial, supply-chain, human resource structures are typically destroyed and replaced by the entry firms.

This lifecycle approach, similar to Schumpeter's model, is neither applicable to complex systemic products nor to mature sectors where problem solving is the source of rejuvenation (Miller and Olleros, 2005). The lifecycle and disruptive approach is powerful for understanding non-architectural meritorious products, not networked complex enterprise systems.

1.1.5 The Value Net concept (Co-opetition)

This concept was described in the Brandenburger and Nalebuff book, Co-opetition.
The authors stress the Complementors concept and mention the symmetry that exists between Complementors and Competitors. The Value Net concept is a very powerful indicator of value creation and capture dynamics inside and across games.

The concept is very powerful for understanding industries; it presents a broader view of industries and their coexisting competition and cooperation relationships they call a game. The concept is powerful in that it complements Porter's competitive forces model with the cooperation element.

This framework also adds the informality dimension in cross-firm and cross-industry relationships. While Porter only focuses on the contractual relationships, the Value Net takes into account the non-contractual cooperation between firms.

In the new economy's complex industries and more precisely the RDE game, Porter's model is not complete enough. The Value Nets (Networks) are important in understanding and managing innovation for the following reasons:

1. Complementors are crucial players in the new economy, because of the complexity of value networks and the complexity of new products architectures.
2. The PARTS tool they created combines the Players, the Rules of the Game, Tactics and the Scope.
3. To become a player, the search for Complementors is crucial. To create the market (to innovate), cooperation is essential, especially during start-up phase. The point is that to create value, it is vital to cooperate.
4. The links governing relationships between players come from the Rules of the Game and companies who do not understand these rules can neither control them nor influence them.
5. Once the value network drawn, the company can develop tactics to : 1- increase its negociation power, 2- find a better position in the network and 3- change the rules and redefine the game's borders.
6. In reality, the game boundaries do not exist (Scope), we create these boundaries to understand things and to conquer them. We thus need to create many distinct games to understand and manage innovation. This explains the importance of the Games of Innovation theory.
7. An important point: The rules of the game are not only those of our formal industry, in reality we are all part of one large game. The links connecting our game to other games become new rules of the game. However, these rules are much more complex.

8. Companies who understand the rules of surrounding games and the rules linking the games together on top of understanding the rules of their own game are the top performers.

The model neglects factors such as regulators and the degree of expertise of customers and omits to truly explain the difference between suppliers and Complementors in high velocity sectors such as software development. It is also important to note that suppliers are very often Complementors in high velocity and complex industries. There will always be an entrepreneur in a network and network partners are usually suppliers and component providers not complementing partners. Players with comparative power seldom cooperate.

In addition, a larger game always exists and to change our game's boundaries in our favor, we have to have power in some bigger game. This is a great concept.

Understanding relationships between the firm, the regulator, the supplier and the client is crucial for understanding the mechanisms and dynamics in value creation and capture through the value chains. This is what the Games of Innovation approach will help frame.

1.2 OPEN AND CLOSED SYSTEMS FOR INNOVATION

The question of whether it is better to close or open products' architectures for innovation is taking more importance and models for addressing these issues were presented by many innovation authors.

In general, a product's architecture is closed when technical specs are not made public; it is open when a third party can use it to develop a complementary component.

In Chesbrough's view, open architectures offer exciting opportunities for firms to benefit from the creativity of local partners and suppliers through licensing agreements, joint ventures and other arrangements within the value network (Chesbrough, 2003).

In current innovation approaches, closed architectures are seen like direct causes for slowing innovation; closing a system does not allow the firm to benefit from the creativity, diversity and agility of potential partners, and the innovation process is slowed and dependent on the slowest unit of the value chain of a specific product. Generally speaking, most people think that open systems are necessary for innovation. This is only true in certain sectors and for a limited period of time. Cases for open architectures such as the PC case and the Telecom case created great value for consumers but it is impossible to conclude that innovation only takes place where there are open architectures.

It is said that a company not sharing a platform with many other players risks being isolated whenever something goes wrong with a major customer or whenever one of its products are outperformed by competitors.

Other disadvantages for closed systems are the higher risk for autonomous knowledge production and the negative outcome that results from locking customers in. The customer is locked in when limited to one closed system supplier. The lack of modularity prohibits other suppliers to connect to the system and bring added value. This view supposes that the customer prefers to choose an open system where he will have the power to decide when to bring new features and with which provider to deal.

While negative aspects of closed systems are emphasized, authors also mention positive aspects such as lower transaction costs (in Williamson's view), a higher industry concentration, easier IP protection, higher security, simple industrial organization and increased public safety.

As a commonly accepted advantage to closed systems, the reduced transaction costs come first on the list. If Williamson's model is applied here, modularity is counterproductive because for each change in the whole open system, transactions between all players are necessary. In closed systems, firms minimize the necessary investments for interactions and collective decision making.

In current projects of systems integration, the customer often deals with many different suppliers to design and build a new information system. This multiple supplier and open system strategy greatly increases transaction costs and the work duplication.

Open architectures and the coordination of large networks could greatly complicate and slow the process of innovation (Chakravorti, 2003).

1.3 SOFTWARE ARCHITECTURES

In this section, literature on software development principles is presented with a special focus on Open Source Software issues. An emphasis is carried out on the pros and cons of open software architectures for innovation.

1.3.1 Open Source Software (OSS)

In the software community, the Open Source movement is an important force vector and social movement acting on innovation whether positively or negatively. The open source community develops very flexible software that is totally open for anyone in the organization to modify or adapt to new needs. Open source codes and open architectures are very similar but not exactly the same; an open source code is an open architecture when it is adopted by many people and organizations but an open architecture is not necessarily an open source code.

Open source code is the C or Java code in its first written form. At the fundamental level, a computer only understands binary code because the electronics technology is based on electrical switches that are either on or off. Every computer program has to be translated into a configuration of 0s and 1s to be processed and once the program has been translated and tested, there is no need to keep the C or Java code. That explains why we only have access to Window's binary code. No one has the ability to decode a binary code and without the C or Java code, it is impossible to change or improve a software program.

C and Java languages are Third Generation (3G) languages that revolutionized programming. The first programmers directly used binary code to create their programs; this greatly limited what they could develop and the programs were very simple. The 3G languages are assemblies of 2G mnemonics, and 2G mnemonics (MOV for move, STA for store accumulator) are assemblies of binary sequences. It is crucial to know that pretty much all infrastructure software (operating systems, utilities etc.) that is running on all computers and servers in the world has been programmed in C.

The use of binary code for software distribution was a great value for proprietary software vendors. This is exactly what created the incentive for commercial software development (Feller and Fitzgerald, 2002). The authors emphasize two reasons for binary code adoption, (1) the binary mode occupies much less storage space and (2) more importantly binary code is impossible to decipher thus offers privacy and IP protection.

The open source movement is like communism. In open source communities, the software code is free and open for everyone and the largest open source project is ironically promoted by IBM.

The most important open source project nowadays is called Eclipse and is lead by IBM. Eclipse became an open source project when IBM decided to create a consortium through its own Eclipse Platform. The technology and source code will always remain openly available and royalty-free to the Eclipse ecosystem.

The ecosystem began with the following players: IBM, Borland, MERANT, QNX Software Systems, Rational Software3, Red Hat, SuSE, TogetherSoft3 and Webgain2.

Eclipse today has over 50 member companies and hosts 4 major Open Source projects that include 19 subprojects (website). Eclipse has also established a Board of Directors drawn from four classes of membership: Strategic Developers, Strategic Consumers, Add-in Providers and Open Source project leaders. The founding Strategic Developers and Strategic Consumers are Ericsson, HP, IBM, Intel, MontaVista Software, QNX, SAP and Serena Software.

The open source community is mainly pushing two Operating Systems, Linux and Apache. Their growth is particularly important in the server market where professional programmers and systems administrators constantly change and adapt the Operating Systems to their specific interface needs.

It makes no business sense for private software developers to distribute all their products in open source code. However, it is an opportunity for software leaders to use open source code for diffusing their closed and proprietary products.

The mission of the Free Software movement is bringing free software to the mainstream, this works in opening essential consumer software products like what happened with the Netscape browser.

Literature defines two categories of players in the Open Source Software (OSS) business, pure-play companies such as Red Hat, the most successful Linux distributor in the corporate market, and hybrid companies such as IBM, Apple, Sun Microsystems and SGI. The pure-play companies earn their money with distribution of OSS, training for the use of OSS and OSS applications development. IBM is the leading hybrid company with more than 1 billion $ injected in OSS. Hybrid firms use Linux and other Operating Systems in their solution offerings together with their own proprietary software tools.

Apple Computers has released the core of Mac OS X under an OSS license, SGI has ported Linux to SGI/MIPS machines and has open-sourced the XFS journaling file system, Netscape released Open Source versions of its client software, Corel Corporation offers Linux in addition of its proprietary products, Dell, Gateway and HP offer the option of factory installed Linux, Sun Microsystems is behind notable OSS projects like NetBeans and OpenOffice and IBM of course launched the largest OSS project, Eclipse.

1.3.2 Motivations for OSS development

At first, it seams that the major sources of motivation behind OSS are of socio-political nature; the social movement against Microsoft's monopoly on consumer software is the main OSS trigger. A common ideology is that software should be free for everyone!

The authors argue that the technological motivations for OSS, on the macro level, are for example the promotion of innovation and the leveraging of the OSS community for R&D (Feller and Fitzgerald, 2002).

While IBM leads the paradigm shift with the bundling of OSS in its large Enterprise Information solutions and pure OSS providers offer a consumer-driven service model for developing customized Operating Systems, complex and specialized software tools for R&D, Engineering or databases management will have to remain closed and proprietary.

It is recognized that software has no reproduction cost but has very high service and maintenance costs. The proportion of software development cost incurred in the maintenance phase represents on average 75% of the total development cost. But the 75% in maintenance is an average and in the RDE tools game, the proportion is somewhat reversed. In fact, the service/software ratio is changing and the services proportion is increasing.

In the OSS perspective, the proprietary and closed software model no longer makes any economical or business sense because the distribution of software development costs have changed and most costs are becoming maintenance and service costs. The increased maintenance cost is due to the current coordination problem facing multinational organizations with very large and complex networks of suppliers and partners. The ERP, PDM and PLM software providers emerged for solving the coordination problem.

The 'Bazaar' metaphor is often used to describe OSS in software engineering circles. A bazaar is a marketplace where a babbling and apparent confusion is reflected. Many recognize that given the complexity of modern software and information systems, the process of software development has to be centralized and proprietary.

1.3.3 The paradigm shift in software engineering

There are enough reasons for software developers to seriously consider OSS in their business plans. Many organizations shifted from UNIX to Microsoft to Linux.

The advantage of Linux is its modular code architecture built on the UNIX model and the possibility for developers to work independently on various modules, on the other hand modularity is exactly what represents a potential Achilles ' heel for OSS. To imagine how modularity facilitated the development of Linux, it is said that Linus Torvalds, the Linux founder, is managing the largest collaborative project in the history of humanity.

In vertical domains where software design is a function of specific domain knowledge that can only be acquired over time, OSS offerings are not suited anymore. Databases for example are not vertical domains; they fall in the horizontal general-purpose software category. In fact, OSS is slowly penetrating the database market with products such as mySQL.

OSS is much more a social innovation than a technical one (Feller and Fitzgerald, 2002). It is argued that Software Engineering principles are fundamentally overturned. For example, in the OSS process, there appears to be no formal design process, no risk assessment, no measurable goals, nor direct monetary incentives for individuals or organizations, informal coordination and control and duplication in parallel development.

While social perspectives are converging to software development models, engineering principles and business perspectives seem to diverge from generally accepted software philosophies. Software is changing from a means to an end; the means is in the engineering view and the end in the social perspective.

The threat in current wide-spreading software thinking is the negative impact social and open software could have on innovation-seeking businesses but the ones who saw the paradigm shift will embrace success.

Current innovation models for understanding innovation in complex systems and the models for understanding Software Development (Open Source movement) emphasize the benefits of open architectures and free software without considering the domains where closed architectures and proprietary software developers are crucial for innovation and for creating value for customers and users. Structure, discipline, centralization and monetary incentives are needed for crafting complex systems.

1.4 ECONOMICS OF SYSTEMS INTEGRATION

It is impossible to understand innovation inside the RDE tools providers without understanding the dominant economical and technological drivers for software tools development. One important driver and industrial organization model (or paradigm) is *Systems Integration.*

According to Pavitt (2005), there is a growing role of individual firms specializing in SI due to some technical change. The technical change is characterized by (1) the continuous increase in specialization in production of artefacts and knowledge and (2) the periodic waves of major innovations.

With their empirical research on SI, Akira and Takahiro, identified key industrial trends and show how SI is emerging as a new model of industrial organization. This model requires particular forms of corporate capability and new capability building strategies.

Although our understanding of the interaction between technological change and organizational structure has made many advances, our prevailing conceptions of these interactions remain fundamentally static (Chesbrough, 2003).

The design of elaborate artefact and the design of the process and organizational structures required to produce them *is a parallel thought* (Dosi, 2003). Dosi analysed the problem solving process required to integrate and design the organizational structure that enables the firm to elaborate its artefact.

They used the Model of Selection Dynamics and the AI concepts (Simon, 1987) to conclude with the following:

1. Problem solving by bounded rational agents must necessarily proceed by decomposing a large complex and intractable problem into smaller sub problems which can be solved independently.
2. The extent and efficacy of the division of problem solving efforts is limited by the existence of interdependencies.
3. The perfect decomposition which isolates in separate sub problems all and only the elements which are interdependent with each other can only be designed by someone who has perfect knowledge of the problem: near decomposable.
4. The best design is Near Decomposition: limited rationality (Simon)

In many activities, firms need to know more than what is seemingly required by current production tasks. Such knowledge is often a necessary requirement for firms to produce complex outputs, and even more so to prepare for future generations of products.

However, there are systematic divergences between firms boundaries revealed by the scope of production activities compared to the scope of knowledge bases which firms master.

According to Dosi, there is a tendency toward an increasing division of labour across firms, associated with the historical emergence of novel specialized industries. One can observe over at least a century the emergence of large multi-technology, multi-product corporations, characterized by varying degrees of vertical integration, but always embodying rich integrative capabilities among multiple components and multiple technological bases (Dosi, 2003).

Moreover, the growing division of labour across firms corresponds to a spreading modularity between components which ultimately makes up complex products. To remain competitive, especially in complex and turbulent sectors, firms must increase modularization while increasing integrative knowledge. Therefore, the system integrator has a crucial role in that: he masters interfaces, bridges learning trajectories, coordinates knowledge necessity and facilitates innovation.

In the framework of this research, the systems integrator is what links the enterprise software company to the industrial customer or user. The systems integrator is the key element for harmonizing software architectures with organizational architectures for process and product improvements.

The concept addresses a crucial paradox for innovating in complex enterprise systems. While modularity and specialization are crucial for component performance in complex information systems, integration and flexibility is essential for fitting the system to the organization's operations, innovation and strategy needs.

The SI and OSS economics share the following rationale: the large portion of software development costs (75%) is in the maintenance process. The maintenance process is the systematic effort for upgrading the system to the user's changing needs. The large maintenance costs and the difficulty in harmonizing the dynamic relation between the software system and the organization make economical sense for SI.

1.5 THE GAMES OF INNOVATION CONCEPT

The Games of Innovation concept is in process through the MINE project (ending in 2008) and the current work will contribute to shaping one of the concept's core games.

At a highly abstracted level, the Games of Innovation approach is similar to the Value Net concept in that it regards the world as a positive-sum not a zero-sum game.

The model's first axiom is the false hypothesis for a "One Best Way" in doing business and innovating. Every game has different rules and for every set of rules exist specific logics for innovation. Managers should understand the logic within their game in order to create sustainable competitive advantages and winning innovation strategies.

The Game of Innovation model captures the heterogeneity in the patterns of innovative activities across industries. Games of Innovation are meso-level systems with their own structures and dynamics (Miller and Olleros, 2005).

Another of the model's major characteristics is the hypothesis that value creation and capture practices are unrelated to industries and sectors. Games are industry-neutral and sector-neutral patterns of value creation and capture activities. On the contextual level, instead of just focusing on the competitive forces (Porter), the model also takes into account governmental and institutional forces acting on innovation.

Games of Innovation as high-level dynamic systems

The Game of innovation approach uses various levels of analyses to understand innovation.

The first and major level of analysis is the value creation for buyers. Necessary functionalities and performance attributes are never the same. The attributes and the ways to bring about value are specific to each game. Customers are different, their needs are different and their perception of value is never the same. Customers want novel products but mostly they want solutions to their particular problems (Miller and Olleros, 2005).

The second level of analysis is the dominant logic of innovation. Accepted rules about core capabilities for playing a specific game are created. In the RDE game for example the accumulation of engineering knowledge on specific vertical domains is a central rule for innovation.

Our understanding of innovation has been built on lifecycle views and the s-curves. According to Miller's model (2005), the automated s-curved perception of innovations is probably the most challenging obstacle for understanding innovation in complex and systemic products such as large information systems. According to the Games of Innovation approach, the dynamics of growth are a crucial level of analysis for innovation in that growth does not always follow the traditional s-curve pattern especially where collaborative problem solving is the source of rejuvenation (Miller and Olleros, 2005).

The fourth level of analysis, nesting into networks for innovation, is particularly important for understanding innovation in complex and systemic products such as enterprise software solutions. Where technologies are complex and open, the relationships for stakeholder coordination are more complex.

Dominant strategies are different from game to game. This fifth level of analysis characterizes the firm's master plan and evolutionary path. In every context, firms invest differently for maintaining their competitive advantage.

Organization of innovation activities is the sixth level of analysis. Innovation activities are either done in-house or passed to external players.

Good performance never means the same thing across games. As the seventh level of analysis, performance should be measured for every firm and compared to good performance in the game.

The concept suggests that games form dynamically stable systems within wide ranges of variations of contextual conditions and firms sometimes migrate from one game to another. This migration and transition process is the last level of analysis proposed by the Games of Innovation concept.

The Games of Innovation Model

The proposed model is made of two contextual perspectives; one is the vertical axis and represents the research, exploration and exploitation processes and the other, the horizontal axis, represents the value creation process for customers and the means for exchanging products and services.

The following figure shows the six games identified by our research team in October 2005:

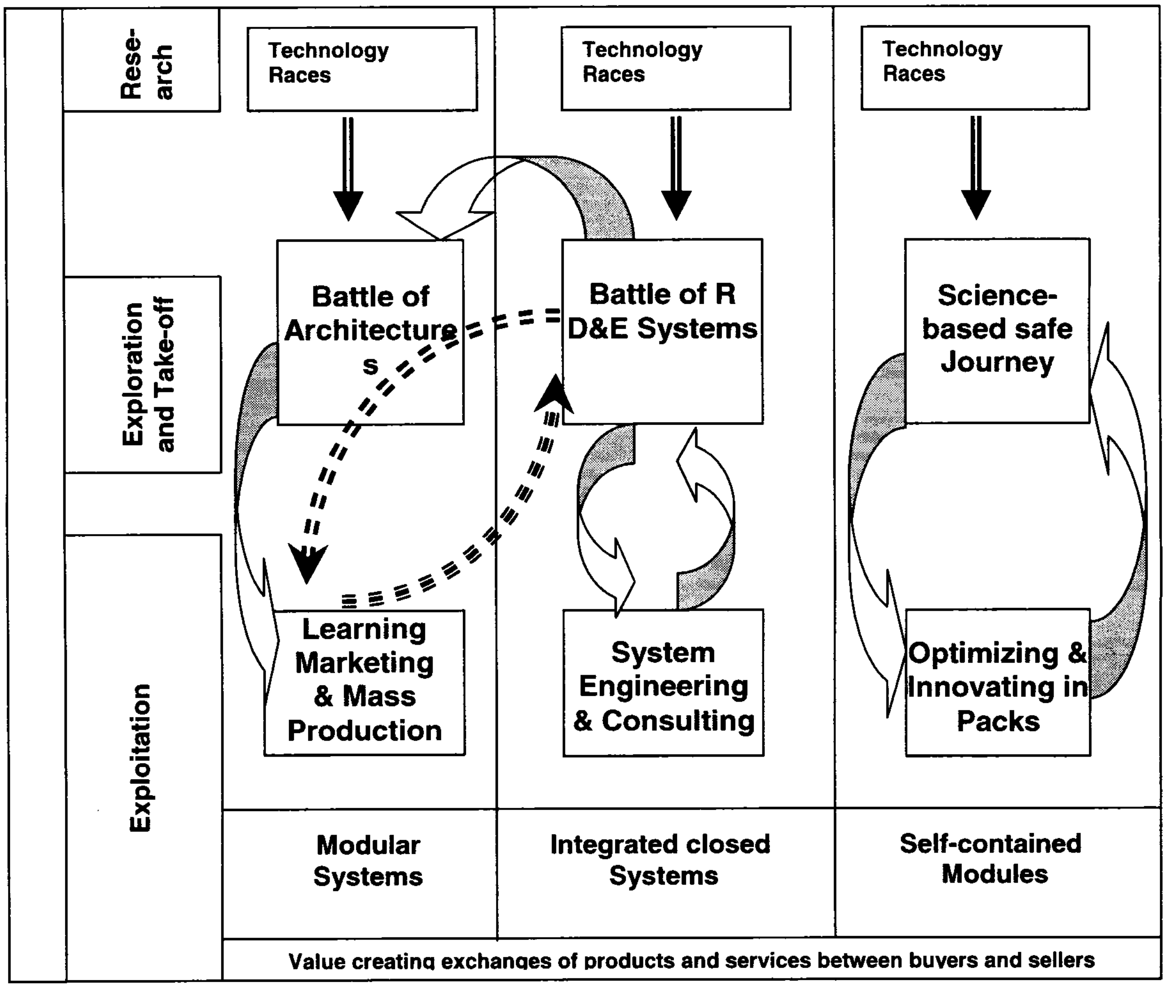

Figure 1.3: The Games of Innovation Model

The six games are; (1) Battles for Architectures, (2) Battles of R&D and Engineering Tools and Services, (3) Science-based Safe Journeys, (4) Learning , Marketing and Mass Production, (5) Systems Engineering and Consulting, and (6) Optimizing while Innovating in Packs.

The horizontal axis: Exchange relationships that create value for buyers

The model's horizontal axis is powerful in that product architectures become central in understanding value creation for buyers and innovation dynamics. This approach makes the measuring of value created and captured a little less complicated in systemic and complex systems.

The model suggests that "smart architectures" allow a firm to create and capture more market value more rapidly; these architectures balance out value creation and value capture concerns (Miller and Olleros, 2005).

The following three architectural categories are presented: (1) self-contained modules, (2) tightly-integrated systems, and (3) modular systems.

Patterns in the value-generating exchanges vary with the degree of expertise of the customer and the product's architectural category. When a product is a self-contained module, value assessment for making a good choice is much easier than assessing value in the case of systemic and complex modules. Self-contained modules are for example pills, watches, pencils and home appliances. Information regarding the merits of the product is available and easy to measure and the market space for innovations often pre-exists (Miller and Olleros, 2005). An important characteristic of self-contained modules is the straightforwardness in learning and using the product.

Tightly integrated systems on the other hand are the R&D and Engineering tools studied in the current work. The model suggests that value is created by offering complex solutions to expert buyers. When an aerospace company buys a CAD system to design new airplanes or when Unilever buys an ERP system to leverage its global supply chain operations, both the software company and the buyer work together to integrate the system and create the value. Recognizing and estimating the value of a system is often impossible in that implementation and configuration processes may take years to materialize with success being unpredictable.

The vertical time axis: Research, Exploration and Exploitation

The model challenges the lifecycle model and proposes a cyclical model that goes from research to exploration to exploitation and back. The hypothesis is that discontinuities very often start from technology races that emerge in closed systems and then unfold into open and socially accepted systems.

The passage from research and exploration to growth markets to exploitation may extend over many decades, many organizations and many industries (Miller and Olleros, 2005). The first period on the time axis, the research period, happens when entrepreneurs, corporate research and other venture groups develop divergent technologies. But institutional and financial support is essential to sustain entrepreneurial research activities in emerging sectors (Miller, 2000).

The second period, exploration, is a market take-off process that normally becomes problematic with systemic and complex products. Unfortunately many valuable and superior technological solutions are aborted during the exploration phase and never lead to the emergence of new fields (Miller and Olleros, 2005).

Exploitation is the third phase and could be seen as the penetration of mass markets and the reach of stability. In the exploitation period, firms are able to use economies of scale and scope of internationalization to reduce their unit costs and build routines for the launch of new products.

1.6 LIMITS OF EXISTING LITERATURE

The first limit is in understanding the impacts of large complex problem solving projects on innovation and the emergence of top-down dominant designs. There is too much emphasis on s-curves and the Disruptive Innovation concept.

There is an obvious lack of research on software and R&D and Engineering tools innovations. Software is core in information technologies and the whole 'Information Revolution' emerged with software.

There are very specific innovation logics in complex systems such as CAD, CAM, PLM, EDA and PDM systems that current models fail to capture.

There is an excessive focus on North American case studies. For instance, European, Scandinavian, Japanese, Chinese, Australian, Brazilian and Asian cases are important and should be studied.

The last limit is the absence of an innovation model for understanding socio-technical evolution through complex technologies and architectures. Organizational architectures are reflected on product architectures and cognitive patterns influence organizational evolution. The Games of Innovations model addresses the architectural dimension on its horizontal axis but a deeper understanding of architectures is necessary.

CHAPTER 2: HYPOTHESIS AND METHODOLOGY

The study is first about understanding value creation and capture through innovation in an industry-neutral and sector-neutral way. The studied entity is a game of innovation and a game is characterized by meso-level factors such as the customer's degree of expertise and the level of technological change, not the attributes and functionalities of the product. Hence, the industry and sector factors are less important. In the Games of Innovation approach, many industries could fall in a game category and many games could fall in an industry category.

As studied entities, Games are closer to markets than industries since every game is characterized by its own market dynamics. As we have already seen, the Game of Innovation approach suggests looking at product architectures for understating innovation.

2.1 RESEARCH HYPOTHESIS

Existing models for understanding innovation are not appropriate in the complex RDE (R&D and Engineering) Tools Providers game.

First, tools providers should tightly integrate and close their product architectures to ensure agility while trying to solve their client's R&D, Engineering and collaboration problems. Closed systems are crucial when architectural change is necessary. While controlling their product architectures, tools providers could open-up for smaller players to stimulate innovation and add functionality.

Innovation comes from a dynamic joint problem solution interaction with the client. Thus, competitive firms closely work with large buyers and systematically launch joint projects for developing innovative tools.

Second, the RDE game is an exploratory game with very high innovation investments and a very high velocity. To build their competitive advantage, firms have to invest a large portion of their revenues in R&D and innovation activities to integrate key scientific and engineering concepts in their solutions. The innovation logic and the rules of the game for all firms developing software or IT tools are very similar when these tools are bought by large and demanding customers; this includes customers in most industries.

Firms also spend about two thirds of their innovation time building-up organizational capabilities and strategies for innovation and spend about one third developing new products or services.

Third, software developers are going horizontal and adapting their products to various industries. Extrapolating niche market software to other surrounding markets greatly increases profitability. Our first interviews revealed that the once poor interconnections between tools providers in vertical markets (drug and mechanical design) are now growing and showing similarities in best practices. Consulting is a cross-industry business but what about tools development?

Innovation dynamics vary with the degree of expertise of clients and the necessary architectural adjustments they demand in their new enterprise software and information tools. Innovative tools are created through large cost reduction and quality improvement projects with large and demanding buyers. However, tools providers capture great value when standard modules are created and scaled down using stable architectures and sold on a large scale with minimal further R&D, Engineering and consulting investments. Tools architectures are sometimes crystallized into dominant designs and modules are created and directly sold to average SMEs, scientists and engineers. This is probably the central element in the current thesis and the anti-thesis to the latest innovation models.

Here is a summary of the above hypotheses:

1. To create value and solve their customer's complex problems, RDE tools providers tightly integrate and close their system architectures
2. To create their competitive advantage, RDE tools providers invest very large portions of their revenue in R&D and innovation activities and about two thirds of their innovation time building-up organizational capabilities for integrating key scientific and engineering concepts
3. Large and complex systems integration projects are opportunities for RDE tools providers to capture value and functionalities into their proprietary platforms. RDE tools providers along with systems architects transform complexity into standardized software tools and processes to sell to other buyers (typically smaller). The phenomenon changes innovation dynamics and triggers migrations from high performance games to low performance games. This is a crucial concept that existing dominant innovation models fail to address.

2.2 RESEARCH QUESTIONS

Considering 'innovation' as the central element for strategy and management in the new economy, our research questions are bind in the following manner:

1. Theoretical and more abstract questions on what model to use (to understand innovation), the firms' similarities in the RDE Game of Innovation and the logic of innovation
2. Meso-level semi-practical semi-theoretical questions on the above hypotheses

3. Business and practical questions on the firms' best practices and strategies

The abstracted macro-level questions are for example:

1. What is a good way (model) for looking at innovation in the new economy's most complex sectors?
2. Is the current two dimensional (value creation and architecture axes) Games of Innovation model complete and powerful enough for understanding innovation in the most complex and knowledge-intensive sectors?
3. What are the similarities and differences in the studied firms that could characterize and define visible boundaries for the RDE Game of Innovation?

The meso-level questions (hypotheses) emerged from both macro-level theory and what intuitively came out from the first business interviews.

The practical and micro-level questions used to test the above hypotheses are twofold:

1. Questions developed by Dr. Roger Miller and the MINE research team for studying all Games of Innovations, and found throughout the MINE Survey Questionnaire (Appendix). These questions helped collect my quantitative knowledge.
2. Questions specific to my hypothesis and objectives, specific to the RDE game of innovation. These questions on the other hand helped collect my qualitative knowledge.

Even though many questions used in the survey and the interviews were similar, they unfolded into different and complementary outcomes. The questions were similar in that they turned around the following issues:

- The context of innovation for the firm
- The firm's activities for value creation and capture
- The firm's innovation strategy (the competitive advantage etc.)
- How the firm is organized for innovation

- The firm's innovation network
- The performance of the firm

Specific questions on products' architectures (The model's horizontal axis) were emphasized during the interviews, questions such as:

- How do you keep your platform open?
- Who are you platform partners?
- How are your products interconnected with other software tools?
- Do you sell Linux-compatible versions of your product?
- What architecture is best for solving your customers' problems?

In the interviews we discovered what was not anticipated in the development process of our multiple-choice survey instrument.

Here are some additional questions:

- Will organizations buying and adopting those complex software tools (e.g. ERP and PLM systems) converge to an SAP or Dassault Systemes business model?
- Are tools developers bundling all customer processes in one large and increasingly complex platform? Are Engineering, R&D, Financial, Operational, and other Enterprise processes converging on standard platforms?
- Would organizations increase their innovation capabilities if their processes were programmed and locked on a platform?
- Is there a paradox in automating processes while seeking for agility and innovation competencies? How should organizations manage this paradox?
- What are the processes organizations should automate and the processes organizations should not automate?
- Should engineering processes (e.g. mathematics and physics), logistics processes (e.g. mathematics and statistics) and other processes in organizations be separated or united (integrated)?

- Are written languages (e.g. English, French or Chinese), mathematics (e.g. algorithms or arithmetic) and software programs (e.g. C++ or AutoCAD) different in nature? What can we understand in their similarities to understand innovation in software development (programming) and systems integration (languages, mathematics and software are all cognitive tools)?
- What differentiates IBM's systems architects from l'Académie de Langue Française? Intuitively, the academy promotes an old cognitive standard (French Language) while IBM architects unconsciously create the language for organizations.
- With the paradigm shift in software development (from software to service), will players integrate both development and consulting activities (including architecting activities)? Does it make economical or business sense for IBM and Dassault Systemes to merge or for IBM to buy Dassault Systemes (mergers and acquisitions are important indicators)?
- Is the continuous improvement in software (and system architecture) functionalities the logic of the game? What is the process for managing trade-offs in performance attributes (functionally normally comes at the expense of convenience and ease of use)?

The study should also help game players plan their strategies and design their business plans; the study is a 'Tool Box' mainly for the following three categories of firms:

- Firms (buyers) in all industries with a need for software tools and solutions
- Consulting companies helping clients (in all industries) choosing and integrating better software tools and solutions
- Providers of R&D, Engineering and Innovation software tools and solutions

In the illustration below, the arrows show information flow:

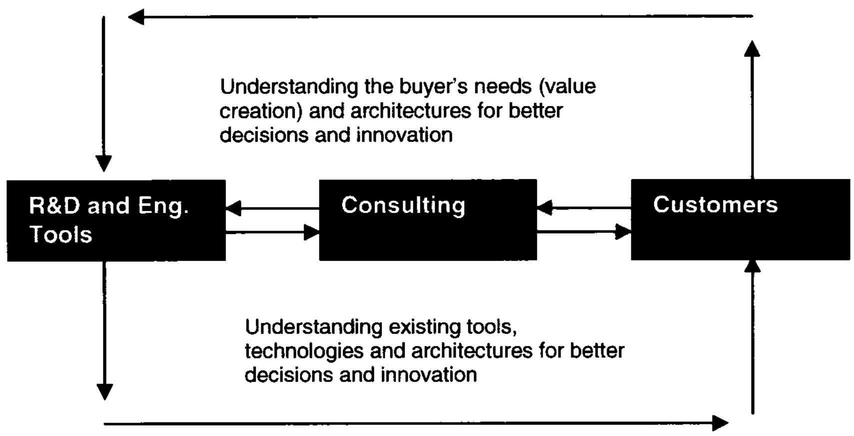

Figure 2.1 : The Stakeholders

The study should help understand existing interdependencies and value networks connecting: (1) tool providers (e.g. PTC) with other tool providers (e.g. MSC Software), (2) tools providers (e.g. PTC) with systems consultants and architects (e.g. IBM), (3) systems consultants (e.g. Accenture) with the buyers (e.g. Boeing), and (3) tool providers (e.g. Dassault Systemes) with the buyers (e.g. Toyota).

Our approach is systemic not reductionist; we thus try to get as many firms as possible in our survey sample instead of trying to get responds from many parties in the same organization. We also search for understanding the following:

- Impacts of complex tools on organizations (buyers) and the cost of the necessary organizational change
- Success factors for adopting and integrating the tools
- The value creation and capture patterns shared by tools developers (e.g. Dassault Systemes), systems architects (e.g. IBM or Accenture) and buyers (e.g. Bombardier, Boeing or Hydro-Quebec)

2.3 RESEARCH METHODOLOGY

With the hope to creatively contribute to the Games of Innovation concept, the practical and theoretical perspectives were addressed in parallel.

The literature review as seen mainly comprised the following areas: (1) Innovation Theory, (2) Industrial Economics, (3) Industrial Organization, (4) Strategic Management, (5) Software Development and Engineering, and (6) Cognition and Technology.

The theoretical and practical research development was sequenced to gradually explore answers to the research questions listed above. However practical and bottom-up research was emphasized to avoid getting stuck to traditional frameworks, naively following their traditional path.

The interviews and surveys already carried out for the MINE project do not exclusively fall in the RDE game but mainly R&D and Engineering tools providers are discussed in the study. For instance, exciting and very enriching interviews with very different firms were carried out in mainland China and Taiwan (Summer 2005). The lessons learned were very important and indirectly contributed to the study.

Let us focus on the way innovation data was gathered and analyzed for the current study. Surveys were carried out before the interviews and survey firms and interview firms were not necessarily the same. 31 firms completed the survey questionnaire and 10 interviews were carried out between Montreal and the Silicon Valley in California.

How firms were chosen

First, a database of interesting firms was built using various sources. Examples of sources are the Daratech database (that we partly bought) and websites of leaders in R&D and Engineering software such as Autodesk, Dassault Systemes and PTC. These websites are goldmines in that every firm lists all partner developers. The accumulation of lists of partners and lists of partners of partners resulted in a very large network of the leading software developers in the world. Firms for both the survey and the interviews were chosen from the database. The database contained the key contact persons such as Chief Technology Officers, R&D VPs, with their telephone numbers. For time and money constraints, I had to choose geographical clusters for the interviews. Not surprisingly the largest clusters appeared in California's Silicon Valley and Montreal. The table below shows the persons interviewed in each company and their positions:

Table 2.1 : Interviews

Interviews		
Firm, Location	Person	Position
Dassault Systemes	Jacques Roy	Engineering Director
Montreal, Quebec	Eric Van Houtte	Head of Knowledge Management
Engenuity, Montreal	Roanne Levitt	Director of R&D
Cadence	Aki Fujimura	CTO, New Business Incubation
San Jose, California	Ted Vucurevich	CTO
	Spencer Clark	VP, Chief Learning Officer
	Melinda Blair	Intern Program Manager
Autodesk	Jon H. Pittman	Senior Director, Strategic Research
San Rafael, California		Office of the CTO
Agile	Tal Ball	Sr. VP Agile Labs & CTO
San Jose, California	Chris Wong	EVP & Chief Product Officer
	Terri Pruett	Director, Corporate Marketing
SAP Labs	Foad Vafaei	Senior Product Manager
Palo Alto, California		Emerging Solutions, Office of CTO
ImpactXoft	Gian Paolo Bassi	VP & CTO
	Andrea Nassisi	Director of Product Management
Accelrys	Bill Taylor	VP Corp. Development and Marketing
San Diego, California	Nic Austin	VP R&D
Bricsnet	Ethan Farid Jinian	CEO
San Francisco	George Levy	VP of Marketing
	Hal M. Spitz	VP Engineering

Thanks to easy and low cost communication on the other hand, firms from many countries were contacted for the survey. Most firms contacted were European, American and Canadian. About 250 firms were contacted for the survey (in the RDE game), 50 on 250 accepted to answer the questionnaire and 31 actually responded. Luckily, the respondents were the leaders in the sample; the chance of getting a response was proportional to the firm's performance!

For instance we got answers from Autodesk, world leader in CAD software with AutoCAD, Synopsis, leader in EDA software, PTC and Dassault Systemes, leaders in PLM and CAD/CAM/CAE software and SAP, world leader in ERP software.

This table shows the respondents to the survey and their positions:

Table 2.2 : Surveys

Surveys		
Firm, Country	Person	Position
PTC	John Stuart	SVP Global Partners and Education
Dassault Systemes	Jacques Roy	Engineering Director
ESI Group	Tomasz Kisielewicz	EVP Engineering
Mercury Computer Systems	Paul Szulewski Bob Becker	Sr. Manager Product Quality SVP Engineering and Operations
MSC Software	Michael Hoffman	VP Corporate Strategy and Marketing
Numerical Algorithms	Robert Meyer	CEO
Autodesk	Jon H. Pittman	Senior Director, Strategic Research
Intergraph	Ryan Hobbs	Corporate Development
ELAN Software	Jean-Jacques Rigoni	CEO (PDG)
Synopsis	Raul Camposano	VP Technology and CTO
Quillion Group	Matthew Griffin	Managing Director
Avilar Technologies	Thomas Grobicki	VP Engineering
Impactxoft	Gian Paolo Bassi	CTO
General Ideas Software	Matthew Greeley	President and CEO
M3i	Karl	CEO
Barco	Johan Remmerie	VP Technology
CEA Systems	Tonny Dijck	Managing Director
Imagine	David Gagne	Product Director
Engenuity Technologies	Roanne Levitt	VP R&D
ISAH ERP	Hans Ophof	CEO
3dConnexion	Niraj Swarup	VP Marketing
Nexprise	Nail Sudin	CTO
SmartOrg	Don Creswell	VP Sales and Marketing
Moldflow	Peter K. Kennedy	CTO
Mclaren Software	David Parry	Senior Manager
SAP Labs	Nolwen Mahe	Research Group leader
Cocreate	John Alpine	Chief Technical Officer
SolidWorks	Kirk Haller	Research Director
Aegis Technologies, Xcellon	Larry D. Snyder	VP Products Division
MTS Systems Corp.	Don Krantz	CTO

The model

Using the Games of Innovation model, and the studied game's inherent characteristics, the following mental model was created to understand innovation and firms' strategies in the RDE game:

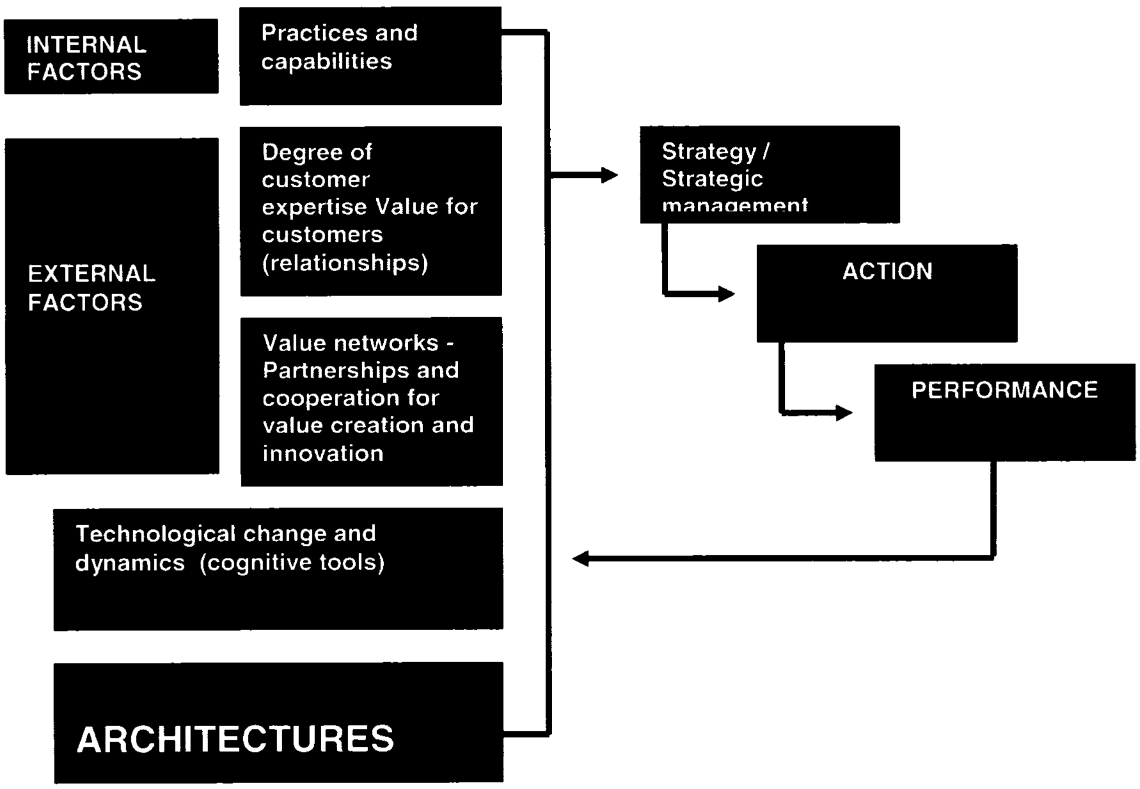

Figure 2.2 : Mental Model for Understanding Innovation

The model is a meso-level model in that macro-level and micro-level elements are conciliated for understanding innovation (a meso-level concept). Underlying meso-level factors are also carried out such as product architectures and technological change. Architectures are central in the model and represent the Game of Innovation's horizontal axis.

While micro-level questions address for instance the firm's capabilities, its internal organizational processes and routines and its HR management policies, macro-level questions address the rules of the game, regulations, competition and market trends.

CHAPTER 3: THE R&D AND ENGINEERING TOOLS GAME: AN OVERVIEW

Without software tools, new economy enterprises are simply handicapped. RDE tools providers lead technological trends with their new products and spend on average 25% of their total revenues on R&D; the highest ratio found in all new economy games.

Functionalities and applications of existing R&D and Engineering tools, the profiles of tools providers and value networks will be presented.

Tools typically start as closed and tightly-integrated systems in vertical domains and evolve into standardized horizontal modules integrated throughout various industries and societies. For instance, the CATIA tool, the leading CAD/CAM/CAE platform, was developed by the software engineering team at Dassault Aviation for the virtual design and simulation of French military fighter jets. When the firm realized that its engineers had integrated core mechanical design functions and programs into one visual and user-friendly platform (for improving quality and delays), they decided to spin-off their software engineering team into an SBU they named Dassault Systemes. Today, Dassault Systemes generates more than one $ billion US of revenues annually. The PLM and CATIA platforms are sold in many vertical domains such as aircraft, automobile, consumer electronics and large infrastructure projects.

The CATIA tool evolved from a closed and specialized internal tool (internal to Dassault Aviation) to a semi-closed platform with many interconnected modules. The interconnected modules enable Dassault Systemes to propose adapted and affordable solutions for customers in various vertical domains with different needs.

Most RDE tools are built on engineering principles and aim at developing new products (e.g. design and simulation), improving product quality and coordinating design and development work (e.g. PLM and concurrent engineering tools). RDE tools are also cognitive amplifiers hiding thousands of complex principles and equations such as physics, mathematics, finance and life sciences. All principles and equations programmed into software tools are also processes, so RDE tools are complex architectures with thousands of programmed processes, nothing more.

3.1 R&D AND ENGINEERING TOOLS

RDE tools are mainly software tools built on improvements in computing power and IT infrastructures. The tools are embedded in hardware tools and given the relatively weak developments and low velocity in hardware technologies, (compared to software) the study only focuses on software innovation. Furthermore, advancements in semiconductor technologies have slowed greatly which limits miniaturization in processors. However, larger and more complex IC architectures are replacing the low-efficiency and high-heat assemblies of microchips previously used in PCs and servers (e.g. Intel's Centrino technology).

Software tools are cognitive and communication tools and similar to pocket calculators, alphabets, symbol systems and logarithms. Motor and sensory tools (e.g. Crystallography and Physical Crash Tests) are often used in early R&D and Engineering processes and usually contribute to developing cognitive and software tools.

Principles in RDE software tools were first discovered in the physical world. For instance, Newton discovered gravity accidentally in the physical world (not while reading Greek mythology) and used physical tools to carry out experiments for formulating a theory. Newton's theory (that was carried out physically) is embedded in all design and simulation software tools in the present day.

To capture innovation dynamics in software tools development, an overview of technology platforms (hardware and middleware) supporting these tools was carried out.

The following table shows important technology platforms partnerships with leading RDE tools providers:

Table 3.1 : Technology Platforms Partnerships

Technology platforms partnerships					
Dassault Syst.	PTC	Agile	MatrixOne	BEA	Alias
3Dconnexion	DELL	BEA	HP	HP	SGI
DELL	HP	Oracle	IBM	Intel	DELL
Fujitsu Siemens Computers	IBM	IBM	SGI	LANIT	IBM IntelliStation
HP	Sun	Microsoft	Sun	Sun	Apple
IBM IntelliStation	Unisys	Dr. Maier CSS	Software Platforms	ABG S.A.	Intel
Intel	3Dconnexion	Network Appliance	BEA Systems	Adobe Systems	HP Invent
Microsoft	3Dlabs	Sun	Microsoft	Advanced Microdevices	ATI
SGI	ATEC Advanced Technologies	Sinteg AG	Oracle		3DLabs
Sun	EMC	Technodat	IBM		nVidia
	SGI	xPLM Solution	Sun		

Most common hardware platforms are IBM, HP and Sun Microsystems platforms. For example, IBM offers three different hardware technologies (servers), IBM eServer, TotalStorage, and IntelliStation. However the IntelliStation platform was specially designed for peak performance and use with engineering and R&D software tools such as Dassault Systemes's software. On the other hand, the eServer technology was developed for efficient use of open source Linux and back-office applications.

Leading middleware products as application and integration infrastructures are IBM's WebSphere and SAP's NetWeaver platforms. It seams that the bases of competition on the middleware level are the security and scalability of infrastructures that allow building new business processes and leveraging existing processes cost-effectively. IBM argues that its middleware flexible platform leverages openness, interoperability and strategic integration through the SOA (Service-Oriented Architecture) approach.

Variations in software functions caused by shifting hardware platforms are negligible. Yet, middleware has a much more important impact on performance and functionalities of software tools integrated on the platform. While, for instance most functions offered in PTC's pro/ENGINEER software are available on most hardware platforms, computing speed and effectiveness could vary from platform to platform. Nevertheless, computing speed becomes a bottleneck when new complex software concepts are developed.

Here's an illustration of the four important levels of architectural change with regards to R&D and Engineering tools:

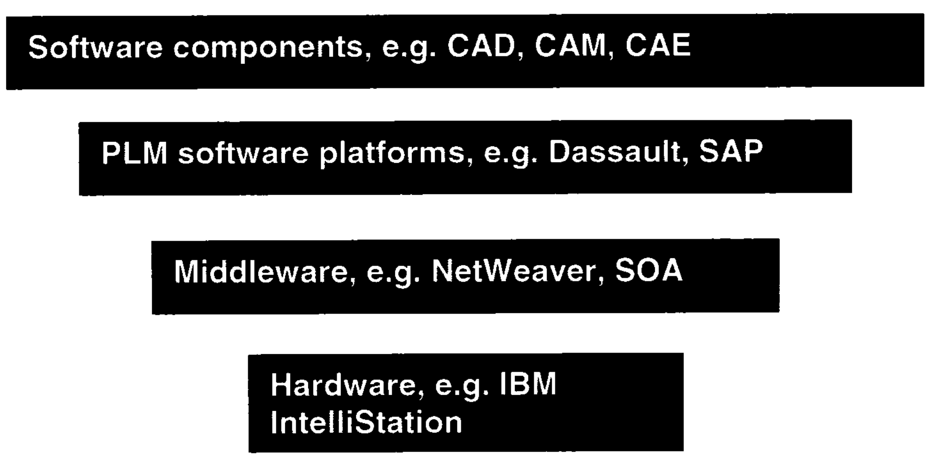

Figure 3.1 : The Four Architectural Levels

The RDE tools are on the two upper levels and architectures on each level are functions of the architectures below. Many small changes occur in the higher level developments whereas very rare but disruptive changes could occur on the lower hardware and middleware levels. Hardware technologies are decomposed into middleware architectures and middleware architectures into PLM platforms then CAD/CAE components. This phenomenon is similar to the division of a biological cell.

Every RDE tool has different functionalities and is better adapted to specific industries (vertical domains). Recently (in 2001-2002), the leading RDE providers, typically working for the world's leading manufacturers of cars and airplanes (e.g. GM, BMW, Toyota, Boeing or Airbus), assembled all software tools for design, simulation, manufacturing, engineering, data management and collaboration into one PLM platform (Product Lifecycle Management).

Today, PLM leaders are billion dollar companies sharing the world's largest manufacturing corporations and managing very large networks of partners; the leaders are Dassault Systemes (CATIA, Smarteam etc.), PTC (pro/Engineer), Autodesk (AutoCAD), UGS (Windchill), SAP and Oracle. Other RDE tools are EDA (Electronic Design Automation) tools used for the design and manufacturing of computer chips. EDA leaders are Cadence (interviewed), Synopsis (surveyed) and Intel (Intel develops its own proprietary EDA software).

Many players in the enterprise software game are merging with other complementary players and acquiring smaller component providers for their platforms. Some of these players are not necessarily R&D and Engineering tools providers; for instance, SAP, the ERP and SCM leader now offers PLM solutions integrating CAD/CAM/CAE components.

Value networks and industry structures were carried out, dominant, trend setting and archetype players were identified, some were surveyed and some interviewed. Products and solutions of these dominant trend setting players are presented below.

Any cognitive tool that increases and amplifies research, development and engineering capabilities is considered as part of the RDE tools ecosystem. Some tools help individual scientists and engineers carry out complex analysis and simulations thanks to the accumulation of programmed algorithms, scientific theories, experience and experiments, some tools enable collaboration, visual and user-friendly representations of models throughout the organization, and other tools enable the rapid transfer of design data to manufacturing and supply chain systems.

PLM platforms for example structure the product development process throughout the value chain and supplier network (Miller and Olleros, 2005). PLM systems also automate design, manufacturing and engineering processes and enable coordination and discipline in large engineering projects.

Yet, PLM and EDA platforms are not the only RDE tools out there. For instance, at Polytechnique of Montreal, one of the world's three fully integrated database computing systems in chemical thermodynamics was created and introduced in 2001. The software FactSage is the result of over 20 years of collaborative efforts between the CRCT (Centre de Recherche en Calcul Thermochimique) at Polytechnique and GTT-Technologies in Germany.

FactSage has several hundred industrial, governmental and academic users in materials science, pyrometallurgy, hydrometallurgy, electrometallurgy, corrosion, glass technology, combustion, ceramics, geology, etc.

Before introducing major RDE systems, I find it interesting to look at the following IT tools listed by the IRI (Industrial Research Institute) in Washington DC in their latest questionnaire on IT and innovation (the questionnaire was distributed in Nov. 2005):

- Idea generation tools such as brainstorming tools (e.g. ThoughtPath and Innovation Toolbox), mind mapping tools (e.g. MindMap Pro, NovaMind and MindManager) and knowledge management tools (e.g. Notes, Livelink and SharePoint).
- Concept development tools such as expertise directories (e.g. Livelink, Notes and database products), asynchronous group communication tools (e.g. Microsoft Exchange, Groove, Oracle Collaboration Suite and Notes), concept visualization tools (e.g. FlexSim 3D, Mathematica and SPSS), rapid prototyping tools (e.g. stereo lithography) and project management tools (e.g. Microsoft Project, TeamCenter and TeamPlay).
- Innovation tools such as BPM tools (e.g. Lombardi TeamWorks, Savvion and Fuego), CAD tools (e.g. AutoCAD, DesignCAD and ParaSolid), PDM/PLM tools (e.g. SAP, Smarteam and CoCreate) and project management tools (e.g. Microsoft Project, TeamCenter and TeamPlay).

The IRI questionnaire aims at understanding the role of IT tools in the innovation process. The problem with the first two categories is the weakness in automating idea generation and concept development. Too much emphasis on routine and Artificial Intelligence could become counter-productive for innovation; software is not a solution for every organizational problem.

RDE tools are used in many vertical domains such as the design and manufacturing of goods (e.g. cars, airplanes, ships, electronics, etc.), the design of infrastructures, plants, production processes and routed systems, the design of drugs and molecules and the design, construction projects, and engineering and management of financial systems. Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relations Management (CRM) systems are not neglected.

The following table shows functionalities of the PLM solution offered by PTC:

Table 3.2 : PTC Solutions

PTC (Parametric Technologies Corporation)	
Pro/ENGINEER Wildfire (PTC's PLM solution)	The PLM solution assembles modules for: (1) solid and detailed modeling, (2) simulation of dynamic and thermal behaviors of structures, (3) computer aided manufacturing (CAM), (molds and dies design for manufacturing, simulation of injection molding processes, verification of processed products (e.g. milled, molded, etc.), programming machine cycles for sheet-metal processing, etc.), (4) routed systems design (cabling and piping design), (5) improving the 3D appearance of modeled products (advanced rendering, reverse engineering, etc.) and (6) collaboration and workgroup data management.
Windchill	Enables collaboration and the control of the NPD (New Product Development) process for multinational and global organizations. Windchill works on Internet browsers such as Explorer and interconnects with Microsoft Office and most available CAD and ERP systems.
Pro/DESKTOP	User-friendly and simplified CAD software for learning and fast product design. The software is widely used in Engineering schools for training.
DIVISION	Enables collaboration and the division of design work early in the process.
CADDS 5i	This solution resembles the Pro/ENGINEER PLM solution and offers modules for: (1) drafting and modeling, (2) interactive surfacing, (3) concurrent assembly, (4) sheet metal design, (5) shipbuilding options, (6) wiring and schematic diagram design and (7) workgroup data management.
DIMENSION III	For plant design with integrated concurrent engineering capabilities.
Harmony	Optional interactive commands to integrate with Cadence Allegro, the leading EDA software presented below.
InterComm	Collaboration module adapted to EDA environments and used with EDA platforms such as Cadence platforms.

This table shows functionalities in Dassault Systemes' PLM solution:

Table 3.3 : Dassault Systemes Solutions

Dassault Systemes	
DELMIA	Manufacturing process simulation. This module enables the visualization and testing of the entire production process using virtual prototypes of the product.
ENOVIA	Collaborative design and 3D data management. The platform enables virtual product modeling and the management of product lifecycle data. Also considered as a knowledge management and PDM (Product Data Management) system.
CATIA	Modeling and products design. This is the leading CAD software worldwide and the core element of Dassault Systemes' PLM solution. The company argues that the CATIA or PLM V5 architecture is open and flexible and enables integration of revolutionary design and development concepts such as the Functional Modeling concept, developed by ImpactXoft (interviewed and surveyed), and totally integrated in CATIA only one year following Dassault's partnership agreement with ImpactXoft.
SMARTEAM (becomes a PLM solution when integrated with CATIA, ENOVIA and DELMIA)	SMARTEAM solutions manage the enterprise product data and other intellectual capital in a highly collaborative Web environment. The system is adapted to all industries and all organizations. SMARTEAM is mainly used by SMEs. SMARTEAM enables: (1) product engineering (creation of product technical data, systems engineering, requirements and know-how management, concurrent engineering, etc.), (2) supply chain management (supplier relations management, bids management, project collaboration management, etc.), (3) production support (quality assurance, optimization of industrial operations, meeting the industry requirements and standards, etc.), and (4) sales and services (bids, orders and contracts management, delivery and after sale support management, maintenance, assets lifecycle management, etc.)
SolidWorks	SolidWorks is a consumer products design software taught in more than 4500 academic institutions worldwide.
SPATIAL / CAA (Component Application Architecture)	This is Dassault's platform and trademark for enabling partners and customers to develop complementary applications to Dassault's PLM portfolio. All Dassault's products and modules are based on the CAA platform.

The two tables above show functionalities offered by two major PLM systems with the CAD and CAE tool as the core of the platform. The PLM platform offered by UGS is very similar. On the other hand, competing platforms with weaker CAD/CAE functionalities and perhaps stronger ERP, SCM and PDM functionalities are worth mentioning. Take for example Agile's platform. According to Agile's Chief Product Officer, Chris Wong, their PLM solution is a communication and collaboration solution that helps drive profits, accelerate innovation, reduce costs and ensure regulatory compliance throughout the product lifecycle. Dell's extremely productive web-based supply chain system is based on the Agile PLM technology.

Agile's Agile 9 solution manages the enterprise product record throughout the product lifecycle including engineering collaboration. The Agile e6 solution organizes product design assets to support globally distributed engineering teams. Agile also sells a simplified low cost PLM solution (Agile Advantage) for SMEs. The company recently acquired Cimmetry Systems; a Montreal based collaborative visualization company. Today, Cimmetry visualization tools are fully integrated in Agile's PLM platform. The Cimmetry solutions make rich and complex design information (CAD) available throughout the organization for technical and non-technical stakeholders including customers and suppliers.

Agile argues that while ERP systems manage the financial record, CRM systems the customer record, SCM systems the supplier record and HCM systems the employee record, their PLM system manages the enterprise product record. According to Agile, unlike employees, suppliers and financials, the product defines the firm's competitive advantage. This figure shows Agile's representation of its PLM solution:

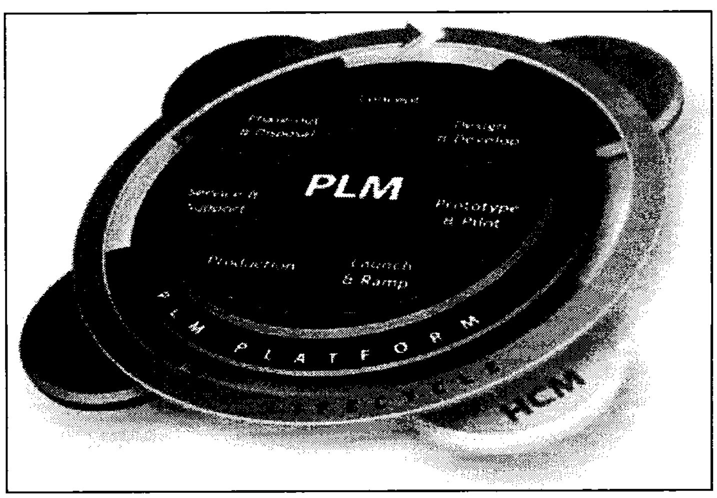

Figure 3.2 : Agile's PLM Platform
Source: www.agile.com

Agile's solutions as well as MatrixOne's solutions are closer to SAP's ERP, SCM and PLM platforms than PTC's or Dassault's CAD/CAE based platforms.

Here is a brief description of SAP's solutions for comparisons. SAP (interviewed) is the largest enterprise software developer in the world. All SAP solutions work on its technical foundation platform NetWeaver that integrates IT infrastructures and other software tools throughout the organization. Similar to NetWeaver are the Java 2, Enterprise Edition (J2EE); Microsoft .NET; and IBM WebSphere middleware platforms.

SAP is shifting to service-based solutions using the NetWeaver platform with its Enterprise Service Architecture (ESA) solution. SAP shifts to service-based solutions to offer its clients increased adaptability, flexibility and openness.

SAP's business solutions (mySAP) are: (1) mySAP Customer Relations Management, (2) mySAP ERP, (3) mySAP Product Lifecycle Management, (4) mySAP Supply Chain Management and (5) mySAP Supplier Relationship Management. All the above solutions help manage business processes not engineering and scientific processes.

According to SAP, mySAP PLM is an integrated solution for collaborative engineering, product development, and management of projects, product structures, documents and quality. Like Agile's PLM solution, mySAP PLM solution manages the product record or product information and enables collaboration with business partners through efficient user-friendly processes. SAP provides a single source of product-related information that only supports product innovation, design and engineering, quality and maintenance management and control of environmental issues.

All the tools mentioned above are scientific, engineering and business tools. CRM and ERP tools for instance are business tools, CAD tools are engineering and development tools and PLM tools bridge the scientific, engineering and business environments into one user-friendly platform. The scientific and engineering tools such as CATIA, Pro/ENGINEER and Cadence are used in industries such as the automobile, the aviation and the electronics industries.

The major scientific field these tools are drawn from is physics. However, other important R&D and engineering tools exist in fields such as chemistry, biochemistry, biotechnology and genetics. For instance tools for chemical simulation and petrochemical process design are developed by firms such as Accelrys and Lurgi, the German leading process engineering firm.

Drug design tools are used by pharmaceutical and biotechnology companies to simulate and design new molecules for solving health problems. Such tools are developed by firms such as Accelrys (interviewed in San Diego), Lion Bioscience, Arqule, Elsevier MDL, Cambridge Software, Tripos, CCG and Schrödinger. For an understanding, here are some of the major products developed by Accelrys:

- GCG Wisconsin Package for gene sequence analysis
- QUANTA for macromolecular X-ray crystallography
- Insight, including CHARMm, for protein modeling
- Cerius2 for modeling of drugs, chemicals, and materials
- Reflex for structure determination of molecular crystals
- CASTEP and DMol3 quantum mechanical simulation
- DS Gene - access, manipulate, and analyze DNA sequences
- CombiMat data management for high throughput experiment in materials science

Other tools exist for managing the financial records and banking transactions but will not be studied.

3.2 VALUE NETWORKS AND GAME STRUCTURES

For space and time constraints a summary of central value networks with the emphasis on central and leading game players is presented.

Value networks map industrial buyers in vertical domains (e.g. automobile assemblers, aircraft manufacturers and engineering consulting firms), consulting companies and systems architects (e.g. IBM, Accenture, CSC and CGI), software partners and module suppliers (e.g. ESI and MSC Software) and competition (e.g. Agile, SAP, Oracle and SGI in the PLM, ERP and CRM markets). Large and average PLM players, EDA players, ERP players and smaller specialized software developers are presented.
Here's a general view of typical value networks in the game:

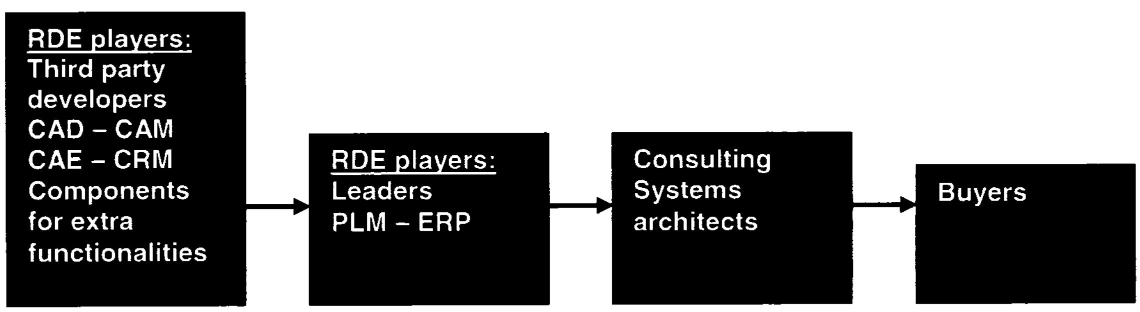

Figure 3.3 : Value Networks

According to Daratech and Frost & Sullivan (leading market research companies for enterprise software), three categories of information systems are appearing in technology sectors: upstream PLM systems (including CAD and PDM systems), MPM (Manufacturing Process Management) systems in the center and downstream ERP systems.

Figure 3.4 : PLM-MPM-ERP

The figure shows the importance of PLM, MPM and ERP architectures (not excluding SCM, CRM and other software systems) for the flow of ideas, organizational change and innovation. According to Daratech's speculations, the PLM market including software and service sales will reach 9.2 billion US dollars in 2007 with an 8% annual growth. For instance, Tecnomatix, a leader in the MPM business was recently acquired by UGS for integration and for reinforcing the company's competitive advantage.

Terminologies used by the players are not always consistent, for instance, while UGS offers a PLM solution integrating its Tecnomatix MPM component, PTC offers a PLM solution (Pro/ENGINEER Wildfire) integrating CAM components. CAM components offered by PTC are used in specific manufacturing processes such as molding and grinding which could restrict their applications to specific domains.

The table shows the networks of partnerships and alliances the three major PLM players have created to develop competitive solutions:

Table 3.4 : PLM Partnership Programs

Partnership Programs – PLM			
Player	Partner category	#	Program objectives
Dassault Systemes	Gold Software	46	Promote innovation and openness Establish partnerships Make E-Collaboration a reality
	Adopter Software	48	
	Technology	10	
	Service	11	
	TOTAL	**115**	
PTC	Platinum Software	11	Provide our customers with a complete Product Development System. Through alliances and partnerships with the world's leading software, services, Reseller and hardware companies, we are able to deliver a comprehensive suite of capabilities and process expertise to address the product strategies and business initiatives of our customers.
	Gold Software	34	
	silver Software	80	
	TOTAL	125	
	Strategic Hardware	4	
	Gold Hardware	7	
	Strategic Consulting	8	
	Gold Consulting	10	
	TOTAL	**154**	
UGS (The same partner could fall in more than one program)	Solutions	132	Partnerships are one of the reasons that UGS is a leader in solving complex product lifecycle management problems. Solutions Foundation Partners program aims at creating products to add functionality.
	Technology	70	
	Services	32	
	Sales	105	
	TOTAL	**279**	

3.2.1 Customers

Typical buyers of PLM systems are large and demanding corporations in all industrial domains, the following figure shows PTC's clients:

Table 3.5 : Buyers of PTC Tools

PTC tools BUYERS			
Airspace, Defense	**Automobile**	**Electronics, High-Tech**	**Heavy Industries**
Boeing Airbus Lockheed Martin NASA Raytheon General Dynamics BAE SYSTEMS Thales Rolls Royce Smiths Aerospace	ArvinMeritor Cooper-Standard Automotive Group DaimlerChrysler Ferrari Harley Davidson Hyundai Peterbilt Porsche SiemensVDO Automotive AG Toyota TRW Automotive Volkswagen/Audi	HP Samsung EMC Unisys Sun DEK Lucent Sanyo	Babcock Power Emhart Glass Machinery AGCO ABB SMS Mitsubishi Heavy Industries Otis Elevator Herman Miller Manitowoc York International

Dassault Systemes has a similar market with the following major buyers: Toyota, DaimlerChrysler, Nissan Diesel Motor, Kikuchi, L'Oréal, Schneider Electric, Boeing and BMW. Not surprisingly, PTC and Dassault Systemes often work for the same large buyers such as Boeing, Toyota and DaimlerChrysler. Wealthy and smart buyers prefer testing different systems and avoid getting locked on the platform of a single RDE tool provider. Other PLM players are Agile (interviewed), UGS, MatrixOne, Autodesk, SAP and Oracle.

According to CIMdata, UGS is the world leader in CPDM (Collaborative Product Definition Management) systems. The company also pretends to manage or create more than 40 percent of the world's 3D data. The following products are integrated in UGS's PLM solution: Solid Edge, Teamcenter, NX and E-Factory. UGS products are particularly present on the Formula One and mold design markets.

The following are some of the UGS NX platform integration cases:

Table 3.6 : Buyers of UGS NX Tools

UGS NX platform buyers	
Racing cars design	**Molds design**
▪ Andretti Green Racing: Indy Cars ▪ B·A·R: Formula One ▪ Jaguar: Formula One ▪ Joe Gibbs Racing: NASCAR ▪ RDS/PKG Engineering ▪ Swift Engineering	▪ FA MAX ▪ Millennium Mold Design ▪ Omni Mold ▪ Plast Competence Center ▪ Plasticos Catella ▪ Plastiken S.L. ▪ Talleres Fiestas ▪ The Tech Group

Providers of drug design tools and financial tools address a different clientele. For instance, Accelrys (interviewed), the world leader in drug and chemical design based in San Diego, works with pharmaceutical companies such as Merck, Novartis, Johnson & Johnson, Roche and Serono.

3.2.2 Consulting partners

RDE tools providers normally work with consulting firms and systems architects (systems integrators) for integrating their products. This table shows consulting partners for the major PLM players (not all partners are shown):

Table 3.7 : Consulting and Service Partnerships

Consulting and service partnerships				
PTC	**Dassault Sys.**	**MatrixOne**	**Agile**	**UGS**
Accenture BearingPoint Capgemini CSC Deloitte Consulting IBM Consulting ITC Infotech Lockheed Martin Commercial Sys.	Axiom Systems CSC Cenit AG Systemh. GSSL IBM Corporation Incat International MDTVISION PCO TECHNOLOGIES SCHLUMBERGER T-Systems Int. Volvo IT	Accenture Aces Int. Afek Systems AllStream Answerthink BearingPoint Capgemini CSC Ploenszke AG debis Divine, Whittman IBM Consulting	Deloitte IBM Permier Level Hitatchi Consult. Kalypso Magna Steyr PRTM Consult. Siemens xPLM Solution	Abbott Dev. Accenture ATK Procurement Capgemini CSC EDS Frazer Designers HP MAYA SEA Tata Consultancy

Leading consulting partners and systems architects are IBM, Accenture, BearingPoint, and Deloitte. Consulting and systems architecture services are horizontal and cross-disciplinary; for instance, IBM deals with buyers in the automobile, pharmaceutical and financial markets.

3.2.3 Third party developers

Third party developers are often excited to join the partnership programs offered by the large PLM players for the following reasons:

1. Possibility to integrate the same development (component) into different PLM solutions in different industries
2. R&D, Marketing and sales support
3. Hi-volume sales through important distribution channels and consulting partnerships

The figure 3-8 shows the importance of these developers for the large RDE players. Most third party developers are weak with regards to their PLM or ERP partners and only capture a small portion of the value created. However, some third party developers are significantly powerful and their tools (components) are the leading and sometimes the only solutions for specific problems. Obviously, these special component providers have created partnerships with all leading PLM players.

Inside the PLM and ERP battle for architectures, is a battle and struggle for acquiring the dominant component providers. The dominant component provider offers unique specialized functionalities and an acquisition would significantly increase the PLM provider's competitive advantage.

Here are major component providers with bargaining power and partnership contracts with the three leading PLM players (Dassault, UGS and PTC):

Table 3.8 : Dominant Component Providers

Dominant component provider	Capabilities
ABAQUS	Leading provider of software for Advanced Finite Element analysis
Alias	World leader for 3D graphics technology
Altair	Leading global product design consulting and technology company
Bleu Ride Numeris	Leading fluid flow and heat transfer simulation company
CD Adapco	A global provider of advanced computationally-based engineering solutions for simulating fluid flow, heat transfer, and stress.
Elysium	A leader in interoperability solutions
ESI Group	The world leading software editor for the numerical simulation of prototype and manufacturing process engineering in applied mechanics
Geometric Software Solutions	A leading provider of PLM solutions to the global mechanical design, manufacturing and industrial markets
ICEM	The world-leader in the development of advanced, 3D surface modeling, visualization and analysis software
MSC Software	MSC Software is the leading global provider of virtual product development (VPD) tools, including simulation software and professional services
Proficiency	An innovator in product data interoperability and engineering collaboration
Theorem Solutions	The world leaders in CAD/CAM product data exchange
VISTAGY	The world leader in as Composite Design Technologies
Wilcox Associates	Engineering consulting and tools company

ERP, CRM, CAD/CAM/CAE, PLM and SCM value networks are not independent domains. The research clearly shows that players are converging into one larger value network (the enterprise software value network) and starting to step onto each others feet. For instance, recently all established software players, whether CAD/CAM/CAE players such as Autodesk, Dassault Systemes and PTC and ERP and database players such as SAP and Oracle, and young emerging players such as Agile and MatrixOne are all working on their miraculous PLM platforms.

Furthermore, the leading business consulting firms such as IBM and Accenture also provide miraculous PLM solutions for their large and rich customers and Dassault Systemes's PLM platform simply becomes a component in IBM's architectural service-oriented solutions.

Recent mergers and acquisitions show important restructuring events in the industry. For instance, Oracle just acquired Siebel Systems in January 2006 to match SAP with CRM offerings, UGS recently acquired Tecnomatix to strengthen its CAM and MPM competencies, Dassault Systemes acquired ABAQUS the leading developer of Advanced Finite Element Analysis software, Agile acquired Cimmetry, the leading visualization software company based in Montreal and Autodesk acquired Alias, the media software leader in Toronto.

On the other hand, value networks in the chemical and drug design sectors are clustered around large pharmaceutical and chemical buyers. Accelrys for example was created through the merger of the following five small drug design companies: (1) Molecular Simulations Inc. (MSI), (2) Synopsys Scientific Systems, (3) Oxford Molecular, (4) Genetics Computer Group (GCG), and (5) Synomics Ltd. Interestingly, One of the five companies (Synopsys Scientific) was a division of Synopsis; a billion dollar EDA software company. Furthermore, Accelrys consulting, hardware and middleware platform partners are the usual consulting and technology corporations such as IBM, HP, Sun, SGI and Oracle.

3.3 ROUTINES AND AUTOMATED PROCESSES

Creating the software tool is the exploration phase of innovation (process innovation), using it is the exploitation phase.

Software by definition is a code, and a code is a set of algorithms, automated routines, loops and processes. Therefore, the code is written for a known concept that was mastered by the person in charge of its creation through experience and repetition (routine). We code what we truly and explicitly understand. The software tool could also be seen as a box of coded processes enabling people to compute, write, simulate, draw, manage the supply chain, send emails etc. As the Dynamic Capabilities model puts it, when explicit routines are coded, they no longer are a competitive advantage.

The output of a software tool was already imagined by someone else; the person who created the code. Furthermore, the limits of what your software could generate and enable you to do are the cognitive and imagination limits of the person (or the team) who designed it for you.

Software enabled innovations are extremely important but their concept scope is limited by the code's concept scope. Hence, software enabled innovations are of an incremental nature. However, little variations in a concept or a product are sometimes enough to create great value and trigger important change.

For Aki Fujimura, CTO at Cadence, for Cadence to be the leading EDA software company, two principals have to apply:

- Hire the best electronic designers on the market to develop the best EDA software
- Eat your own dog food, or use your own software products to run your operations and develop new software

The first point is extremely important because it clearly shows that the person who codes the software has to have a better understanding of the underlying concepts and technologies to create value for the person using the software.

This is one major competency for a software developer: The software developer has to have a better understanding of his client product's underlying principles than the client himself.

Take for example the CATIA CAD software. This software is typically used by mechanical engineers in various manufacturing companies. However, it was designed by PhDs in material science, physics, aerospace engineering (various fields) and engineers with several years of experience trying to solve a much more complex problem than what is faced by the mechanical engineers in the average manufacturing company.

From the industrial to the information revolution - In 'managing the Next Society', Peter Drucker (2002) presents an excellent historical perspective of innovation where he compares the 'Information Revolution' to the 'Industrial Revolution'. He started with the steam engine and the birth of the textile industry, introduced the steam train that changed the world, followed by Guttenberg's press and its role in diffusing Protestantism and 'The Prince', and ended his paper with software, e-commerce and the knowledge worker. Drucker pointed out a crucial element that underlies both revolutions and technological evolution; he calls this element 'Routinization' whish is ironically not considered as an English word in Microsoft Office.

Both the information revolution and the industrial revolution have only transformed processes that were here all along. In Drucker's own words: 'In fact, the real impact of the Information Revolution has not been in the form of 'information' at all. For instance there has been practically no change in the way major decisions are made in business or government. But the Information Revolution has routinized traditional processes in an untold number of areas'.

In Drucker's view, software and IT technologies are simply automating (routinizing) processes. This phenomenon increases productivity and makes space for more people to fit the system. While automation replaced physical routine work, software is replacing intellectual routine work. People at the buyer company will probably loose their routine engineering jobs replaced by the software tools but the event will force them to find better, more creative, and more challenging alternatives. More people indirectly fit the system because economies of scale in business and development processes are enabled by the software platforms and prices naturally fall.

To show that processes have not been changed at all with information tools, Drucker uses the example of stock market speculation. He argues that stock market speculation processes (now on the Internet using software tools) have not changed since the 1920s (Drucker, 2002).

CAD, CAM, PLM, ERP, CRM, SCM and EDA tools have also transformed traditional development, engineering and logistical processes into faster and more efficient software-based processes.

Software will never replace intuition - Henry Mintzberg (1989) and Herbert Simon (1987) have long discussed the importance of software and AI tools for management, innovation, strategy and governance. Mintzberg wrote the following: 'Nothing in management has frustrated me more than what has been called the "Rule of the Tool", the use of technique for its own sake (Give a little boy a hammer and it just so happens that everything needs pounding!)'. Mintzberg disagrees with Simon's view of intuition but agrees with the fact that effectiveness in management depends on the coupling of analytic and intuitive processes.

Minztberg's view of Robert McNamara's approach in politics and strategy is extremely appealing. He argues that the ill-conceived and fundamentally immoral war efforts were due to the application of modern analytical techniques (brought in by America's finest analytical talent, Robert McNamara) to the White House's non-programmed decisions.

Formal and programmed information is often too limited, it precludes much that is non-quantitative (e.g. politics, personality, etc.) and non-communicable (tone of voice, gesture, facial expression, etc.). One informal discussion can sometimes be far more revealing that reams of statistics. It takes time for events to become facts and more time for facts to be recorded, aggregated and to appear in periodic reports (Mintzberg, 1989)

To conclude on both Simon's and Mintzberg's work in analysis and intuition, the following is what was learned: the brain stores patterns, methods and values from experience using formal (alphabets, mathematics, models, statistics etc.) and informal (intuition) cognitive models (processes) and good judgment for management and strategy occurs when formal and informal cognitive processes are combined. Both analysis tools (software, methods, statistics, etc.) and intuition are necessary for innovation and strategy.

However, CAD, CAM, PLM and ERP tools are not analysis tools for management and strategy but analysis and information tools for research, development, engineering and operations (business and manufacturing). CATIA is a tool for simulating and designing mechanical and structural products and could only be used to generate variations of the initial product. The tool mainly reduces the technical risk of an innovation and only partially its commercial risk.

Tools for product and process automation - Placing software tools on a product-process axis would help understand differences in available software tools, for instance in CAD, PLM, ERP and CRM tools. Here is what a distribution would look like:

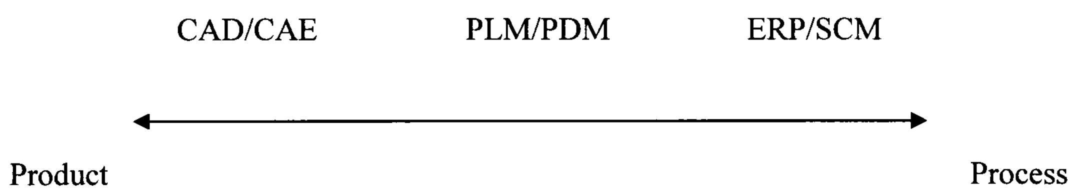

Figure 3.5 : Product-Process Axis

In the above graph, ERP and SCM tools enable the automation of business processes whereas CAD and CAE tools enable the automation of design and engineering processes.

Moreover, PDM and PLM tools link CAD and CAE tools with ERP tools. Product Lifecycle Management systems bridge scientific and engineering environments with business environments and greatly improve communication and coordination. All software tools have bits of product problem solving code and process problem solving code. The goal is to understand the clients' process and product problems and to craft the solution reflecting the exact complex need.

<u>Standard tools for cost reduction and incremental innovations</u> - Standard RDE modules are used for incremental innovations (product development). However, the process of developing new CAD, CAE and PLM tools for new applications is a creative problem solving process where only parts of the original software tool could be re-used and many new functionalities are programmed. The process also stimulates engineering teams and creative technical solutions are generated and programmed. Integration projects are also reengineering and restructuring projects.

The current project at Hydro-Quebec (the largest hydroelectric developer in Canada) for integrating CATIA in hydroelectric developments is the first of its kind in the world. Dassault Systemes works closely with Hydro-Quebec to capture hydroelectric engineering processes and integrate them into its CAD/CAM/CAE (or PLM) tool where new hydroelectric functionalities will appear.

Dassault Systemes will capitalize on the opportunity (very large governmental investments) to create a CATIA Hydroelectric module that other developers in other regions will buy for a much lower cost. Value is created for all players and even citizens who will end up paying less for the electricity consumption on the long run.

The Hydroelectric module will reduce design and development costs and world hydroelectric developers will probably reduce their prices.

Leadership in functionalities - Tools providers and systems architects lead when their buyers are organizations with the most complex problems. For instance, the team (developer and consultant) who creates NASA's tool for understanding the universe will probably find more functionalities than any leader in any industry would need or understand. In the car industry for instance, Dassault Systemes signed a contract with Toyota (automobile leader) for developing its PLM system and today holds the most powerful PLM solution in the car industry.

CHAPTER 4: MANAGING INNOVATION IN THE RDE GAME

As mentioned in the research methodology section, the MINE Survey levels of analysis are used to structure the synthesis work including interview data.

4.1 THE CONTEXT OF INNOVATION

Complex needs and higher performance - As seen in the previous chapter, the context of the game is characterized by a high pace of scientific and technological change and few large demanding customers with complex problems who continuously ask for higher performance. IBM is the undisputable leader in the battle for systems integration services and has created strategic partnerships with the leading engineering and scientific software providers such as Dassault Systemes and Accelrys.

From ERP to PLM - Database and ERP systems have created the largest enterprise software companies such as SAP and a standardization of ERP systems has rigidified organizations and triggered the need for more agile, communicative and collaborative systems such as the PLM. The PLM software is the fastest growing enterprise software market.

Open standards and OSS - RDE tools providers have adopted the IBM business model pushing open source standards such as the Linux operating system. The common path is from UNIX to Microsoft to Linux systems.

Battle of architectures and consolidation - According to Bill Taylor (VP of Corporate Development and Marketing) and Nic Austin (VP of R&D) at Accelrys, the industry is going through a battle of architectures and the competition is loosing out to the Accelrys scientific platform. Accelrys is the outcome of a merger of 10 scientific software companies and their new partnership with IBM will snowball the company's platform to the de facto standard. Agile leads consolidation in the emerging PLM sector with 7 acquisitions in the past 24 months.

Large projects and customer intimacy - Customer intimacy and partnering with consulting firms through large systems integration projects are necessary to structure, understand and solve the complex architectural and process problems that large producers face. Solving the complex problem is a critical force vector in the RDE tools game.

The PLM oligopoly - The survey data shows the two distinct categories of players, large players and small players. The smallest large player with 300 employees (Moldflow) and the largest small player with 82 employees (Imagine). This table shows large RDE players on the left and small players on the right:

Table 4.1 : Large and Small Players

Large firms	Staff	Sales MS	Large firms	Staff	Sales MS
EDAG	4200	600	ImpactXoft	26	4
Barco	4400	800	General Ideas Software	15	2
Mercury	650	185	Numerical Algorithms Group	65	10,5
Autodesk	2500	1200	M3i	22	3,5
Dassault Systemes	3200	1000	Imagine	82	8,8
Synopsys	4500	1000	Elan	50	5
ESI Group	500	75	Quillion Group	30	3
Intergraph Corporation	3800	540	Quality On-line	26	2
PTC	3045	660	ISAH ERP	80	7
MSC Software	1500	280	Avilar Technologies	17	3
Moldflow	300	60	Nexprise	35	4
Cocreate	400	75	SmartOrg	8	2
SAP	32200	9800	Mclaren Software	78	12
SolidWorks	500	200	Aegis Technologies, Xcellon	15	1,5
MTS Systems Corporation	1700	380			

ImpactXoft for instance partnered with Dassault Systemes to access its large distribution channels and sell its innovative Functional Modeling concept on a larger scale. According to Gian Paulo Bassi, CTO at ImpactXoft, the company tried to market and sell its innovative solution directly to large buyers but it was impossible. They tried for 4 years and then gave up.

Interconnections for solving complex needs - Around 40 contextual variables were used in the questionnaire to capture important contextual factors. Large and small players showed a similar pattern of contextual factors.

The table lists all crucial and non-crucial factors:

Table 4.2 : Important Contextual Factors for Innovation

CONTEXTUAL FACTORS (large players)	SCORE
Products must interconnect with other products or systems to have value for customers	6.2
Customers have very complex, advanced needs	5.8
Established competitors constantly attack each other's positions	5.7
Customers constantly push firms in our sector to innovate	5.5
The nature of our products makes brand names and reputation key competitive factors	5.5
Particular niches grow much faster than the rest of our sector	5.5
Customers provide significant expertise for the functioning and use of our products	5.3
New knowledge results from a gradual accumulation of experience inside firms	5.3
The pace of change in our sector is very fast compared to other sectors	5.1
External factors are forcing major transformations within the sector	5.1
The boundaries of our sector are undergoing major redefinition (e.g. convergence)	5.0
New competitors frequently enter the sector with innovative or low-cost products	3.6
Total sales of our sector grow very fast compared to other sectors	3.5
Our sector provides a strong contribution and feedback to academic research	3.4
Unexpected developments (novelties, reshufflings) occur frequently in our sector	3.4
Economic regulation (price, competition) is needed to ensure the viability of the sector	2.9
To collaborate in innovation is normal, even between direct competitors	2.9
Obtaining regulatory approval for innovations requires a long time and a lot of money	2.8
Regulatory approval is a critical prerequisite for commercializing any new product	2.5

In general the small player scores are lower (less confidant) but relatively similar. The table below only shows the differing factors. For instance the payoff from a successful innovation is huge compared to the investments for the small players but not for the larger players (where the factor was neutral). This is probably because successful innovations for smaller firms are usually component innovations. Moreover, the smaller firms are usually third party developers who use their partners' PLM and ERP platforms and distribution channels to sell their software. Hence, with minimal marketing and development efforts, smaller third party developers launch successful innovations. The table shows differing contextual factors:

Table 4.3 : Small Player Differing Contextual Factors

SMALL FIRM DIFFERING CONTEXTUAL FACTORS	SCORE
(4) The payoff from a successful innovation is huge compared to the investment	5.3
External factors are forcing major transformations within the sector	4.55
The boundaries of our sector are undergoing major redefinitions (e.g. convergence)	4.25

The principal contextual factor shows that products must interconnect with other products or systems to have value for the customers. However, competitiveness and new knowledge come from a gradual accumulation of experience. Customers are large and demanding buyers who push firms to innovate and competitors are constantly attacking each others positions. Reputations and brand names are key competitive factors.

Surprisingly, respondents disagree with the idea that collaboration is needed for innovation. Regulatory forces, academic research and IP protection are also negligible factors in the game.

<u>The need for coordination software</u> - There is a coordination problem and the market for coordination and communication software filling the gap between scientific, engineering and business software is huge. Agile, MatrixOne and Arena Solutions are the PLM companies with a business model aligned on such needs. Agile has recently delivered bottom-line results to over 500 electronics customers with a 500% return on investment within the first year.

4.2 VALUE CREATION ACTIVITIES

Solving complex problems and reducing the design, engineering and scientific processes costs are the way RDE tools providers create value for their customers.

Reduce costs by automating development and communication processes - For instance, Accelrys provides In Vitro solutions and scientific applications for the chemical and pharmaceutical markets to reduce discovery and development time and cost. The opportunities in design and discovery cost reductions with an integrated platform are huge. Customers are often large established companies desperately looking to reduce costs for better performance.

Systemic thinking - For Cadence, the customer is the electronic system design ecosystem and the company provides system level design technology and services.

Broadening the offering on a single integrated platform - Cadence leases its EDA licenses on a 3-year time basis and license prices vary from 2-3 thousand dollars to 1.5 million. The company has about 300 different EDA products used in many applications such as chips for TVs, cards and routers.

The balance - According to Aki Fujimura, at Cadence the goal is to find the balance in the customer's system and the Cadence platform. Cadence created a capability for managing change through the eco-chain they call 'The Backward Compatible Path'. Every time the company tries to do something new, the whole value-chain has to participate.

Streamlining scientific, engineering and business processes - For Accelrys, the pharmaceutical and chemical buyers need to change and streamline their development and scientific processes with business processes. The scientific application software is too fragmented and Accelrys is leading the race for developing the de facto scientific platform.

Solid brand names and reputation - Tools providers keep their product brand names solid while trying to keep the product content as fluid as possible for fast and agile change. For instance, the name of one of Cadence's major products, Redioso, remained the same but if you look at the content today and compare it to the content 5-6 years ago you will see two completely different products. The content adapted to changes such as changes in database and operating systems.

Software as service - When the buyer's needs are complex, software and services are bundled together. On average, 40 percent of revenues come from services in the RDE tools game. For instance, Dassault Systemes has created the Dassault Systemes Services for America division based in Montreal. At a certain point, companies reduce their R&D investments and focus on services and systems integration. Accelrys for example generates only 5% percent of its sales from services and wants to increase its services share to 25-30%. Agile service share is about 30%.

ESI group is the world leader in virtual prototyping and manufacturing process engineering in applied mechanics and has a complete service-based business model. According to Tomasz Kisielewicz, ESI' s VP of Engineering, 100 % of ESI's revenues are service revenues. The table shows the service share of revenues for some tools providers and their performance:

Table 4.4 : Players' Performance and Service Shares

FIRM	Services	Performance	FIRM	Services	Performance
Moldflow	15	73.41	MSC Software	30	55.16
Mercury	15	69.84	Synopsys	5	53.57
ESI Group	100	67.86	Elan	50	52.78
Autodesk	5	61.51	PTC	30	51.98
Imagine	40	59.92	Mclaren Software	30	51.19
SmartOrg	60	57.54	Intergraph	70	48.81
EDAG	70	56.35	ImpactXoft	30	43.25

For measuring performance, we have asked the firms to compare their innovation capabilities to the competition and to tell us about their profits growth and new product development productivity.

Risk management services - Software companies provide risk management services along with their systems to help customers manage the inertia and rigidity risk associated with every software system. Customers learned from the past organizational problems caused by ERP systems.

Complex vs. standard problem solving - Some players only work with large demanding buyers to solve complex problems while other players have created standards. For example, ESI group works closely with a few automobile companies to solve their complex crash test problems and Autodesk with only 5 percent of revenues from services is still profiting from its global AutoCAD licenses. The table below shows the important value creation activities from the surveys:

Table 4.5 : Important Value Creation Activities

ACTIVITY (General)	SCORE
Anticipating customers' emerging problems and expectations	5,89
Continually introducing products, versions, and features that match customers' needs	5,37
Transforming leading scientific and technical principles into usable products	5,26
Steering products and architectures into de facto standards with interface solutions	5,04
Aligning with dominant solutions to avoid disruption and uncertainty for clients	5,04
Ensuring reliability, safety, and security through engineering systems	4,93
Increasing product variety while keeping customization/manufacturing costs low	4,89
Controlling and opening architectures to induce suppliers and customers to innovate	4,74
Reducing costs and having progressively lower costs	4,44

4.3 DOMINANT STRATEGIES

As seen above, the interaction with the customer is crucial for developing the closed and proprietary RDE tool with the value added functionalities.

Closed integrated platforms - Closed platforms are more effective than open systems in achieving tight integration in design. Structure, centralization and concentrated efforts are crucial for solving complex problems.

Consolidation for platform leadership - RDE tools providers are racing for creating the de facto platforms in scientific applications, EDA and PLM. An oligopoly has appeared with leaders such as Dassault Systemes, Cadence and Accelrys accelerating in acquisitions and partnerships for platform leadership.

Sharing leadership with customers - Leading RDE tools providers have a strategy for sharing leadership with their customers for developing the best tools. For instance, Dassault Systemes reported that its PLM system developed in partnership with Toyota has reduced development costs by 43% and development time by 44 %. The updated new versions PLM and EDA companies launch every year or 6 months are the fruits of interactions with their demanding and innovative customers.

Managing third party partnerships - Cadence for instance is going in the systems business and a whole part of the company's business is focusing on partnerships. The company has created the X-Initiative for collaboration and managing their 40 major supply-chain alliances. Accelrys has created similar partnerships programs for scientific applications and believes that its platform is a ladder for third-party developers; it transforms their ideas into commercialized solutions. Agile on the other hand offers business solutions to many vertical domains and finds its new scientific and engineering applications in partnerships with third-party developers.

The access to leaders in large networks - Companies focus their marketing on customers with large networks of suppliers. For instance, Agile sold its PLM solution to CISCO and all CISCO suppliers asked for the same platform.

Collaborative software development - The large manufacturing industries have complex coordination needs due to disintegration and fragmentation. For instance, assemblers and OEM companies in the automobile, aviation, electronics and PC industries have hundreds of components suppliers and the component suppliers have their own supplier networks. The PLM concept is a solution for such a difficult coordination task. The large networks obstruct NPD (New Product Development) and corporations such as Boeing, GM and Dell find great value in PLM.

Develop on open standards - Players use logical and standard APIs to link their software to partners, IT systems and networks. For example, Agile builds XML gateways adapted to every industry and the logical interactions are extremely important in their partnerships wit the raw material data companies. The company also uses Eclipse as its open source platform.

Competitive advantages - Statistics carried out with the survey data show the following major competitive advantages of respondents:

Table 4.6 : Sources of Competitive Avantage

Sources of competitive advantage	Last 5 Y	Next 5 Y
Established customer base and reputation	6,068966	6,482759
Accumulated know-how, expertise, and capabilities	6,068966	6,344828
Scale and scope of operations (e.g. multinational)	4,896552	5,862069
Control of core product architecture or standard	5,413793	5,724138
Capacity for swift response (flexibility, agility)	5,068966	5,655172
Capacity to be first to market with any innovation	5,448276	5,448276
A portfolio of patents, copyrights, and trade secrets	4,62069	5
Capacity to be the lowest-cost producer	3,586207	4,068966
Barriers (regulatory, etc.) that protect our market	3	3,275862
Ownership of physical assets and natural resources	2,862069	2,931034

For instance, the accumulation of know-how, expertise and capabilities is the first source of competitive advantages for small players and the third for large players. The first competitive advantage for larger players is the established customer base and reputation. This explains the different roles small and large companies play. Smaller third party developers are rarely in direct contact with the customer, they deal with PLM, EDA and ERP companies.

High R&D investments - RDE tools providers spend very large shares of their revenues on R&D; firms spend on average 22, 25 % of sales on R&D. The table shows large players' expenditures on the left and small players' on the right:

Table 4.7 : R&D Investments

Large firms R&D spending over sales		Small firms R&D spending over sales	
EDAG	4	ImpactXoft	60
Mercury	20	General Ideas Software	30
Autodesk	18	Numerical Algorithms Group	20
Synopsys	25	Imagine	30
ESI Group	35	Elan	25
Intergraph Corporation	12	Quillion Group	20
PTC	30	Quality Online	15
MSC Software	18	Meditech-Bioflex	20
Moldflow	15	Avilar Technologies	20
MTS Systems Corporation	4	Nexprise	10
		SmartOrg	10
		Mclaren Software	18
		Aegis Technologies, Xcellon	50
AVERAGE	18,1	AVERAGE	25,23

Cadence spends about 20% of its revenues on R&D because their electronics customers are driven by continuous change and the company aspires to its customer's problems by trying to understand its customer's customer. Moreover, the advanced software business is not capital based and depends on investments in people.

Building innovation capabilities - As seen in the figure below, firms spend about 40% of their innovation time managing new product development and about 60% of their time managing BU innovation, building up organizational capabilities and making corporate strategy for innovation.

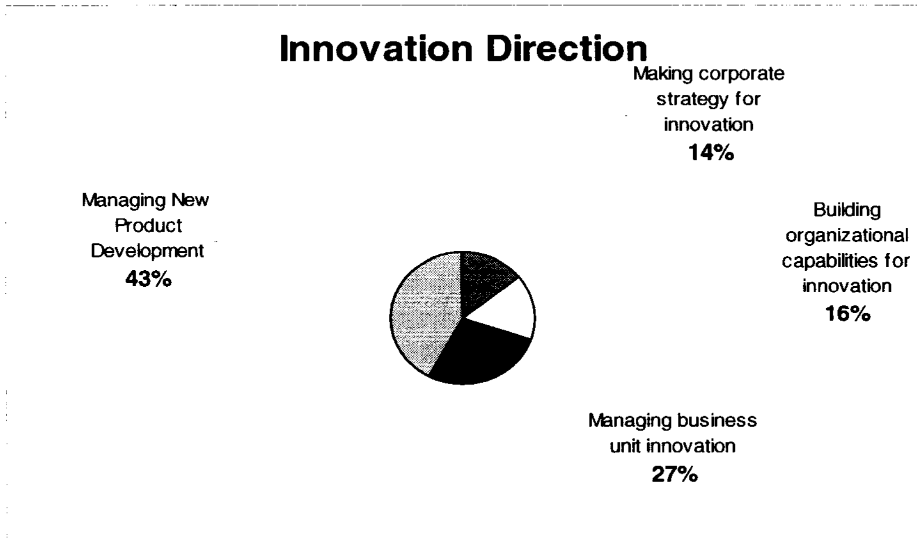

Figure 4.1 : Innovation Direction

<u>Engineering capabilities</u> - The major organizational capabilities are the scientific and engineering capabilities, the second are the marketing capabilities and the third are the innovation process and methods capabilities.

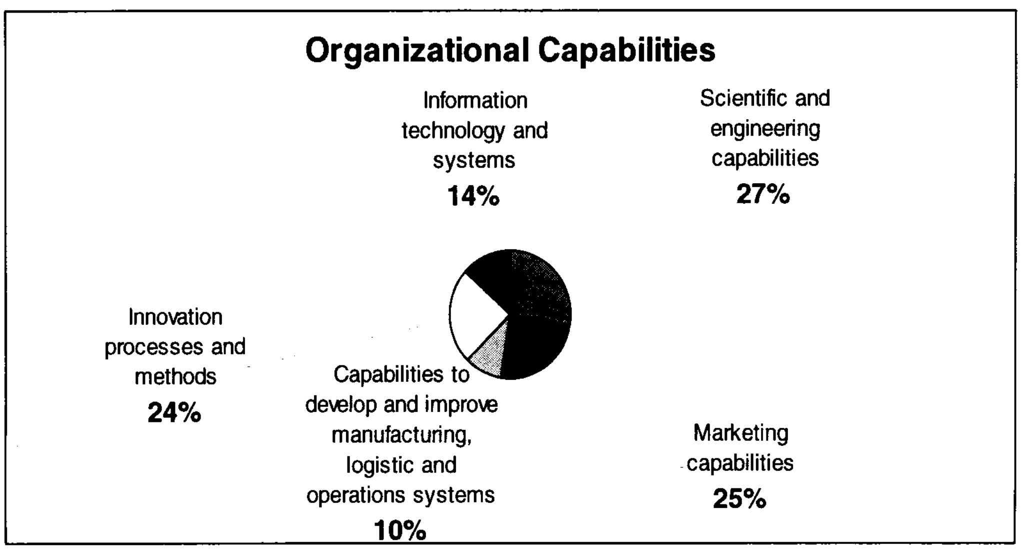

Figure 4.2 : Organizational Capabilities

R&D through corporate labs and projects - About 43% of innovation investments are allocated in corporate R&D labs and 22% of investments are allocated in functional departments and projects.

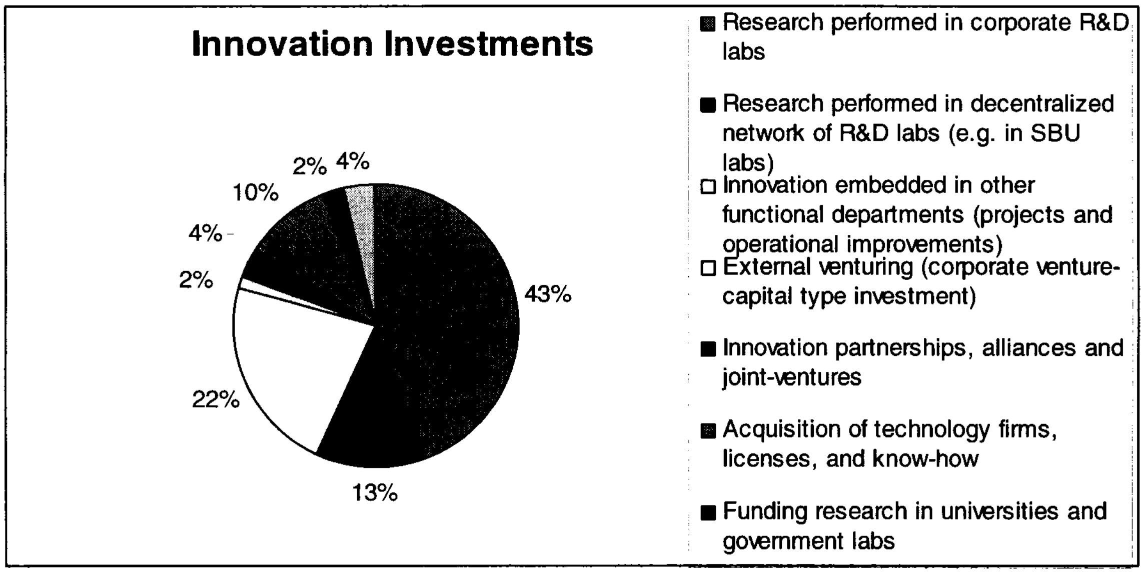

Figure 4.3 : Innovation Investments

About 38% of innovations are small incremental improvements and 29% of innovations are new platform developments.

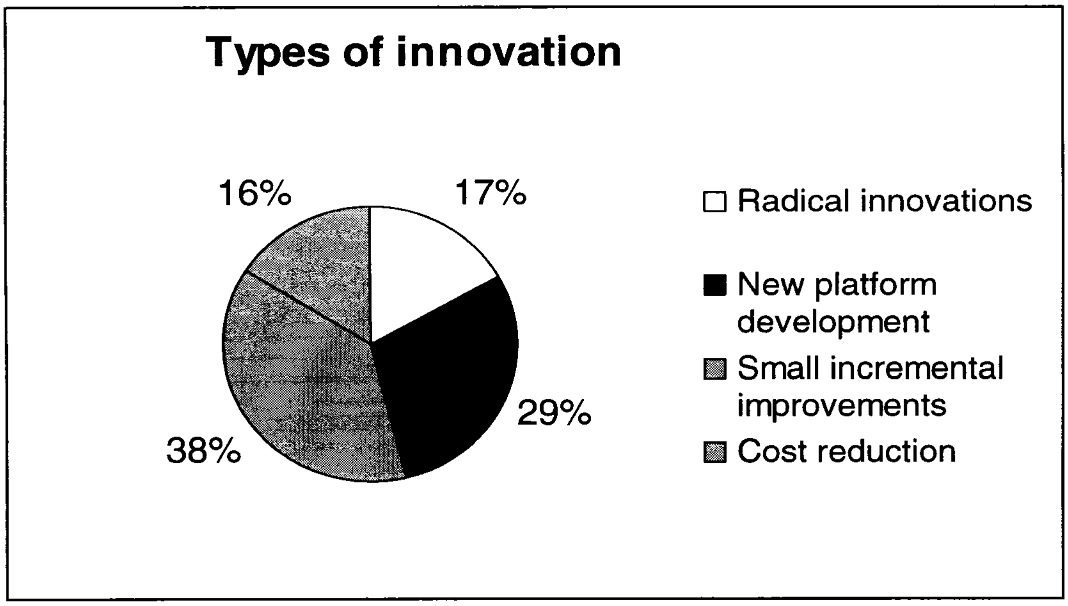

Figure 4.4 : Types of Innovations

Radical innovations for small players and incremental innovations for large one - The two figures below show the leading positions of small RDE tools providers in radical innovations and new platform developments.

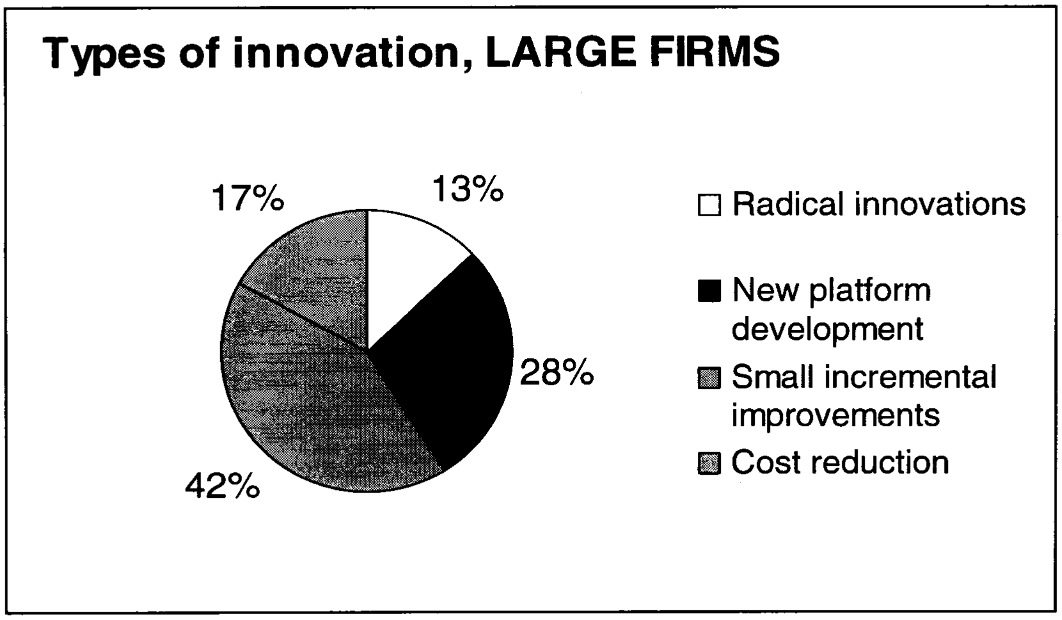

Figure 4.5 : Large Players Types of Innovations

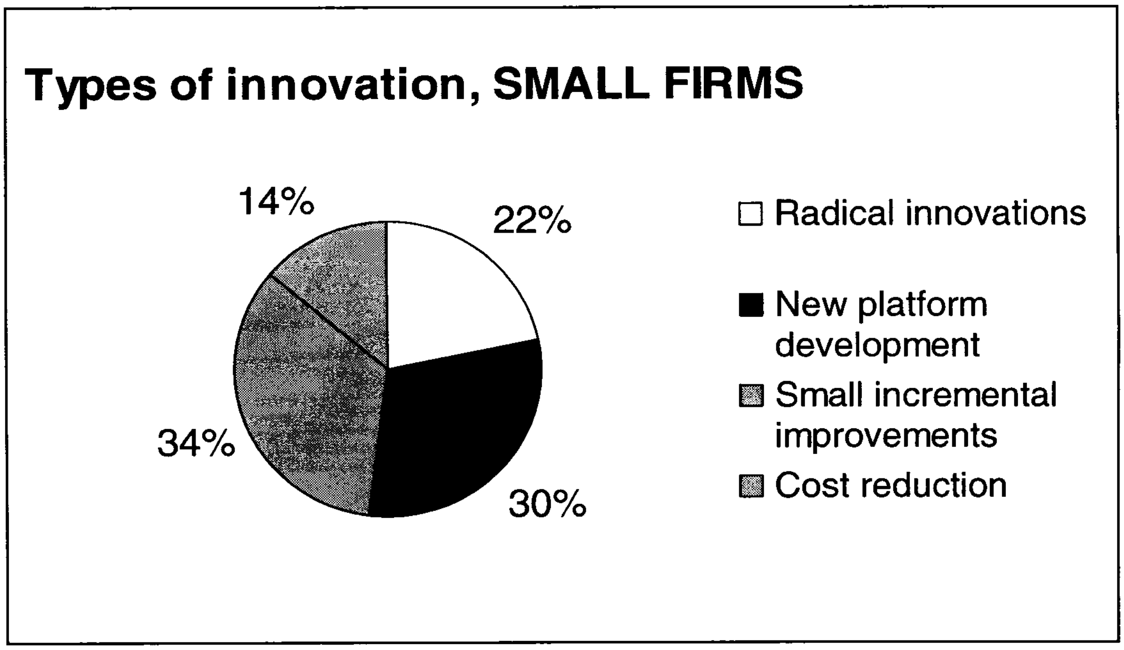

Figure 4.6 : Small Players Types of Innovations

The overall innovation effort represents approximately 50% of sales. Innovation expenditures are necessary to build engineering, scientific and marketing capabilities, to maintain the customer intimacy and to constantly come up with new versions.

Top-down and bottom-up strategies - Some players such as Autodesk have a bottom-up strategy for competing in PLM other have a top-down strategy such as SAP and Agile. Who will end up leading the PLM game?

The other RDE strategy: Autodesk's bottom-up approach - Autodesk has created the undisputable world practical software tool for engineers and designers globally. The company plays in the standard engineering software game and believes it could enter the PLM and enterprise level game by scaling-up its software products.

Autodesk has 7 different divisions and AutoCAD is its horizontal and cross-divisional platform. The following are the company's divisions: (1) the AutoCAD platform, the

PTD (Platform Technologies Division), the dominant Building Solutions division, the Infrastructure division (e.g. geo-spatial, traffic etc.), the Manufacturing division, the Media discrete division in Montreal, and all the Small groups. Autodesk also created a consulting division for entering the enterprise software market.

The competitive and innovation dynamics in every division are different but Autodesk created a strong link between these vertical domains with AutoCAD for the following reasons:

- There is not a perfect division separating the vertical markets
- Large buyers like Boeing usually need more than one vertical software application

For Autodesk's Director of Strategic Research, the ever growing customers of software companies such as Dassault Systemes are making it seem like they are trying to open their architectures. But this is not true; they only try to open their architecture for their very large automobile and aircraft customers! When GM acquires Saab or when Lenovo in China acquires IBM's PC division the software platforms needed for integrating diversified products on a very large scale makes Dassault Systemes feel like they have come up with the world standard for Product Lifecycle Management.

Autodesk is the most serious and dangerous threat to Dassault Systemes' current leading position in the PLM market. The company has not yet become a provider of enterprise software but works towards it. It has already launched data management and collaborative project management horizontal solutions.

According to Autodesk, it is very easy to scale up but scaling down is almost impossible; Dassault Systemes and SAP are trying to scale down in two different way but both ways are impossible. For instance, Autodesk could not work with SGI because the company had a high mentality.

In contrast with most RDE tools providers studied, Autodesk focuses on the broadest number of users instead on focusing on the highest complexity. The company is California State not Stanford or MIT.

Creating the booming construction digitizing market – PLM players are battling for the emerging digital construction market, the BLM (Building Lifecycle Management) market is part of it. User-friendly software tools for modeling, simulating and managing construction projects are needed. In the past 40 years, the manufacturing sector has gained around 250-300% in productivity while the construction industry has lost important productivity. The productivity losses are due to the weak links between the construction industry and the IT industry. According to Autodesk, the construction market for software tools is a 3 trillion dollar market and only 1.6 billion is spent on IT Technologies in construction. 30-40% of the costs are waste due to the under-deployment of IT technologies.

Dassault Systemes and Autodesk are two major players in this early market. The American Congress is creating a multi billion program for pushing digitization in the industry similar to the military CALS project for digitizing manufacturing organizations back in the 1980s. Such large national-level projects are once-in-a-lifetime opportunities for Dassault Systemes and Autodesk or even small entrepreneurs with a vision and good contacts.

The following graph shows the loss of information and the slow current construction process:

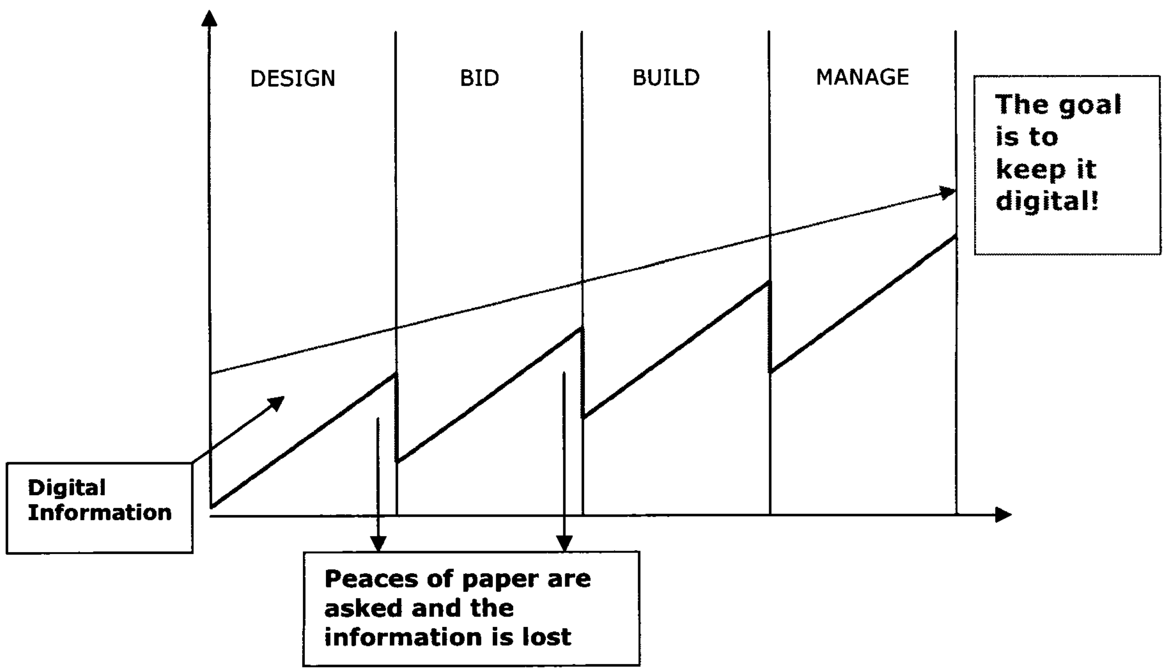

Figure 4.7 : Construction Process

Dassault Systemes is currently funding start-ups in construction technology such as Gehry Technologies. According to Autodesk, using technologies from airplane design systems in construction is not a successful strategy.

Hydro-Quebec, the major Canadian hydroelectric developer and one of the largest in the world is currently pursuing a large integration project with Dassault Systemes and IBM to use the PLM technology in hydroelectric construction projects. The project was initiated about a year ago and is still under development. The contract will enable the emergence of PLM systems in the construction industry.

4.4 THE FIRM'S NETWORK FOR INNOVATION

The matrix below was carried out using the survey data and shows that most innovation work is conducted in functional departments and through projects followed by central and corporate R&D labs. External partners, universities and contractual outsourcing are not very important for innovation. In the matrix, the sum of entries in every column equals 24 which represent the total number of respondents for the networks section of the questionnaire:

Table 4.8 : Innovation Networks

Innovation Networks	Technology development	Understanding and defining user needs	Product idea generation/concept definition	Industrial design and styling	Architecting and system engineering	Design and engineering of components	Prototyping and modelling	Design of the supply chain	Production process design/scale-up	Testing and validation	Regulatory approval procedures	Commercialization and spin-offs	**TOTAL**
In functional departments or projects	4	14	14	5	2	5	4	9	7	10	3	11	**88**
Central/corporate R&D lab	12	5	4	6	14	8	10	4	6	7	7	2	**85**
R&D labs of business units	7	2	4	4	5	6	7	2	2	6	2	6	**53**
Not applicable	1	0	0	6	2	3	3	8	7	0	10	1	**41**
With external partners (incl. universities)	0	3	2	1	0	1	0	0	1	0	2	4	**14**
Contractual outsourcing	0	0	0	2	1	1	0	1	1	1	0	0	**7**
	24	24	24	24	24	24	24	24	24	24	24	24	

Technology developments are carried out in central and corporate R&D labs. The understanding and definition of user needs, product idea generation and concept definitions are conducted through projects with expert buyers and functional departments.

While system engineering and architecting are central and corporate R&D activities, the design and engineering of components are activities distributed throughout the organization. The firms in the sample who also develop PDM, ERP or SCM systems carry out supply chain design activities through projects and functional departments. Commercialization of new products is conducted through projects, partnerships with large distributors and Marketing departments.

About 50% of R&D activities are carried out in corporate labs, 25% in domestic business unit labs, 15% through international business unit labs and 10% outside the R&D function. These R&D activities such as the research on future breakthroughs, the search for new business, new product development using existing technologies and architectures are shown in the following matrix:

Table 4.9 : R&D Networks

R&D Networks	Corporate labs	Domestic business unit labs	International business unit labs	Outside R&D function	
Perform research on future breakthrough products/technology	49	27	15	9.1	100
Venture into new business (either internally or externally)	48	25	13	14	100
Develop new products based on existing technology	46	34	13	7.2	100
Develop product extensions and derivatives of existing products	43	28	14	15	100
Technical, analytical, or product support advice to business units	45	22	18	15	100
Develop core competencies (expertise and organizational processes)	48	23	15	13	100
	47	**26**	**15**	**12**	100

For understanding motivations for choosing R&D and innovation labs locations we have used the following factors:

Table 4.10 : Factors for Lab. Location

LAB LOCATION FACTORS	SCORE
Proximity to sources of knowledge and expertise (e.g. universities)	4.5
Low cost of research (qualified personnel and facilities)	4.4
Proximity to markets and clients	4.2
Proximity to business units	4.2
Legacy of past acquisitions	3.7
Political and national pressures	2.5
Proximity to key suppliers	2.2

Tools providers base their location decisions on the quality of available scientists and engineers and the cost of research. The proximity to markets is also extremely important and probably more important to ERP, SCM companies than CAD and PLM companies. Some leading software developers afford higher research costs and base some of their labs in the richest places on the planet. For instance, SAP has chosen the following locations for its R&D labs: Montreal in Canada, Palo Alto in the Silicon Valley, Sofia in Bulgaria, Shanghai in China, Mougins near Cannes and Sophia Antipolis in France, Budapest in Hungary, Bangalore in India, Tel Aviv in Israel, and Tokyo in Japan.

The major external innovation contributor is the customer but other contributors are the scientific community, government agencies, universities and non-profit R&D organizations. The matrix below shows that industry and professional associations have no innovation role:

Table 4.11 : External Innovation Contributions

External innovation contributions	SCORE	Universities	Scientific community	Professional associations	Governement agencies	Industry associations	Financial institutions	Other business firms	Non-profit R&D org	Pres-sure groups
Scientific and technical knowledge	117	14	12	0	7	0	0	0	4	0
Helps identify potential partners and customers	116	5	6	0	8	0	0	0	4	0
Influences other parties to adopt new products	113	5	6	0	5	0	0	0	4	0
Helps learn about new markets and opportunities	110	3	5	0	11	0	0	0	3	0
Initial market and demonstration	105	5	6	0	3	0	0	0	4	0
Direction, vision and advice	98	5	11	0	8	0	0	0	4	0
Develops and promotes standards and norms	91	1	3	0	9	0	0	0	5	0
Capital and financial support	88	4	6	0	3	0	0	0	8	0
Facilitates collaborative research and innovation	87	8	4	0	4	0	0	0	3	0
Approval and authorization of technologies / products	76	3	7	0	2	0	0	0	2	0
Undertakes research and services on our behalf	66	9	3	0	3	0	0	0	1	0
External contributors' scores		**62**	**69**	**0**	**63**	**0**	**0**	**0**	**42**	**0**

According to Accelrys, the academia is often too far from business realities and commercializing code created in academic institutions could sometimes be frustrating.

However RDE tools players often provide universities with free software to create dependencies.

4.5 BEST PRACTICES AND INTERNAL CAPABILITIES FOR INNOVATION

The survey listed over 50 innovation practices. The following are the 5 best and worst practices for innovation, the highest and lowest scores:

Table 4.12 : Innovation Best-Worst Practices

INNOVATION BEST PRACTICES	SCORE
Rely on in-house experts and market research capability for the detection of trends	5.11
Our new product ideas are combinations of ideas from our previous projects	5.11
We track and react to the evolution of users' needs throughout the project	5.11
We extensively simulate the behavior of our product before building a full prototype	5.06
Interact with key suppliers and customers to figure out the evolution of the field	5.00
INNOVATION WORST PRACTICES	**SCORE**
From the beginning, suppliers play an important role in our innovation projects	2.89
We have a new venture group specialized in developing new internal businesses	2.89
Interact with numerous high-technology start-ups to probe ideas and technologies	2.61
Rely on specialized research and forecasting firms for the identification of trends	2.50
We have a policy of encouraging spin-outs led by our personnel	2.00

To capture differences in respondents, pinpoint clusters of firms or define sub-games of innovation, the RDE sample should be enlarged or the questions elevated. The CTO of Synopsis who answered the questionnaire on a Sunday night was frustrated about the details in the questionnaire; he thought it was too nitpicking!

Scientific capabilities for smaller players, and engineering, marketing and architecting capabilities for larger players - Larger players are increasing their marketing, sales, education and branding capabilities, and perhaps decreasing their scientific capabilities. The engineering capability leads in all RDE tools providers and even in scientific integrators such as Accelrys. The large players are also developing capabilities for project management and for managing large networks of smaller R&D focused partner developers.

Drink your own champagne - Tools providers drink their own champagne. In other words, they use their own products for internal design and development.

Speed to integrate the customer's needs - For instance, Agile claims to take half the time an ERP company takes to integrate customer needs in the system.

The use of standard programming - Players avoid re-writing code into their own language and use standard languages such as SOA (Service-Oriented Architecture) promoted by IBM.

Practices and performance correlate - In the survey, a few innovation practices show correlations with performance and help shape the RDE tools game of innovation. The third and fifth best practices above are showing a slight correlation with performance. Top performers consider the tracking and reaction to the evolution of users' needs throughout the project a crucial practice for innovation. The graph shows correlation:

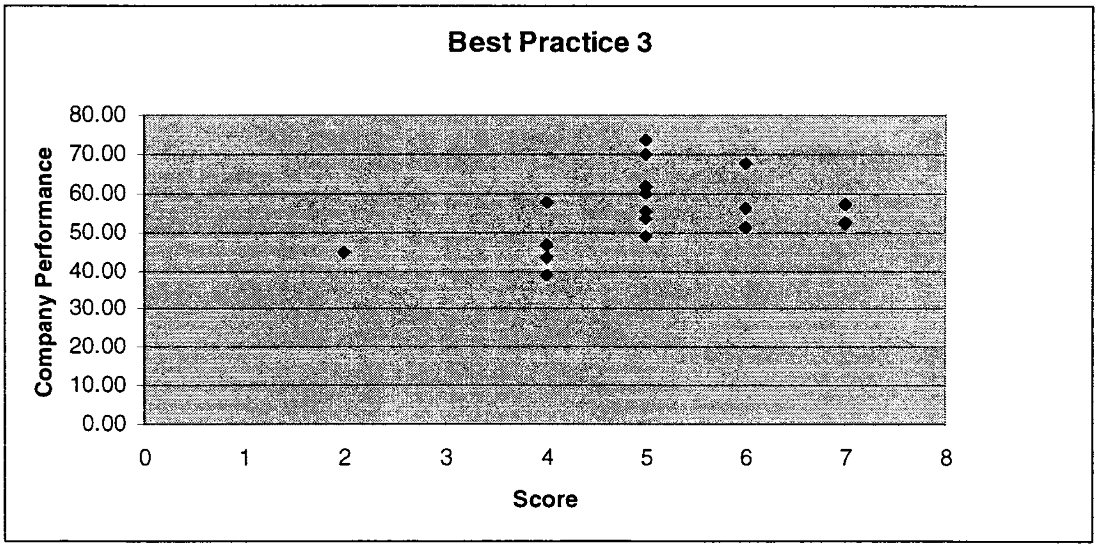

Figure 4.8 : Tracking the Evolution of Users' Needs

Another major practice showing correlation with performance is the need for interacting with key customers to understand the evolution of the field. Here is the graph:

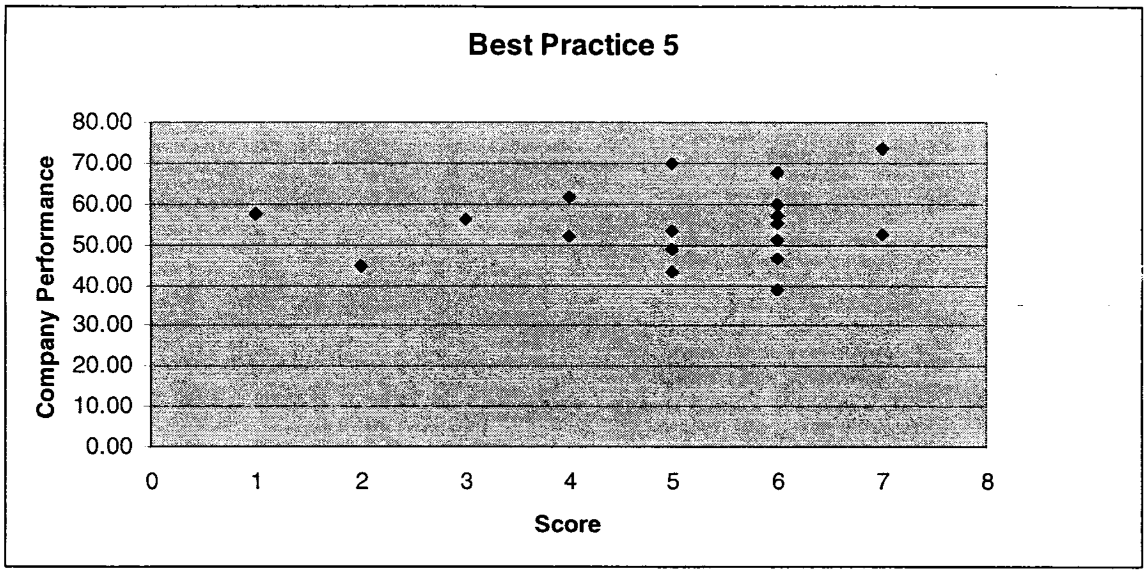

Figure 4.9 : Interact to Figure out the Evolution of the Field

Managing scientists and PhDs - RDE tools providers have created consortia and sabbatical programs for their scientists to feel comfortable and motivated.

4.6 INNOVATION LOGICS AND DYNAMICS

Every game has different innovation logics and managers should understand the logic of their game to innovate. The apparent innovation patterns in the RDE game are as follows:

- Expert buyers seek higher performance and ask for more productive and more collaborative software to leverage global operations and the product development task throughout their value chain. The experts are large demanding buyers such as Boeing, Toyota, Dell and Lucent Technologies.

- Chains of competitive pressures set the pace of innovation. For instance, Agile helps Philip Morris launch 6000 new brands a year.
- Systems architects such as IBM along with software developers such as Dassault and Accelrys transform industries by offering coordination solutions for reducing process costs and renewing the customers' innovation capabilities
- RDE players create value by integrating their accumulated knowledge of customers' problems, and accumulated engineering experience into closed and integrated systems and services.
- RDE players such as PTC, Dassault and SAP try to scale down their complex tools to standard engineering, design and supply chain management tools. They are trying to standardize and democratize their tools like Autodesk did. By scaling down their tools, the companies can reach larger markets such as SME, individual engineers and designers and university programs. For instance, scaled-down CATIA and Pro/Engineer tools are sold through 3-4 thousand dollar licenses. SAP is also introducing its scaled-down supply chain tool (Mendocino) with Microsoft.
- Large players are investing in capabilities for managing the third party developer network, marketing their platform and providing more systemic solutions.
- Small third party developers are forced to concentrate on developing their scientific and engineering capabilities leaving marketing and distribution to the larger PLM players.
- RDE players also try to scale their products horizontally to capture other vertical markets. Agile provides PLM solutions to the electronics and pharmaceutical markets and Dassault Systemes is aggressively getting into the construction business.
- Other players such as Autodesk are trying to scale up (instead of scaling down) their standard design and engineering tools to enter the PLM and enterprise software wealthy market.

- The social Open Source movement and the customer interoperability and flexibility needs are pushing the software companies to open up their architectures at the periphery but keeping the core architecture closed.
- Leaders are adopting the software-as-service business model for architecting their clients systems and adapting existing technologies to their customers' changing needs.
- Hardware, middleware and software technologies are co-evolving but innovations on the higher software component levels are much more frequent. For instance, smaller players showed larger R&D investments for discovering new components.
- There is a battle for architectures in enterprise software and PLM systems. Software leaders are merging and acquiring smaller players for stabilizing the industry and satisfying the customer interoperability, flexibility and coordination needs. Nevertheless, platform leaders are aligning to their customers' market and scientific dynamics. For example, Accelrys integrates all scientific applications needed in the pharmaceutical and chemical industries, Dassault integrates scientific applications needed in the fabrication of goods and Cadence integrates applications used in electronics.
- Innovations in terms of integrated novel engineering and scientific approaches and principles are slow. However, innovations occur in organizational and systems architectures integrating RDE tools, collaboration and communication software, and IT technologies.
- Innovations in RDE tools will not emerge unless a potential market exists. While North American and European manufacturing industries are closing down, new manufacturing industries are appearing in China where the need for RDE tools innovations is increasing.
- The software engineering capability is central to all RDE tools players. However, some companies such as Cadence and Accelrys are scientific integrators and other players such as Agile and SAP are business integrators. The customer is asking for the integration of both scientific and business platforms into one flexible platform.

- While scientific dynamics differ from an industry to another, business dynamics (or coordination dynamics) seem to converge. The CTO at Agile puts it this way: the company packages solutions in different ways but the dynamics are not really different from one industry to another. For instance, Agile sells its PLM solutions to car, aircraft, electronics and pharmaceutical companies.

Testing hypotheses – We have seen that open architectures are not a solution for solving the expert's problems. Expert buyers such as Boeing, Toyota, Dell, Sony and Siemens constantly ask for better and novel architectural solutions. These architectural solutions leverage global operations and the complex product development task throughout the value chain. Architectural needs are never similar from a buyer to another and wealthy buyers can afford custom made architectures and custom made RDE tools through complex projects. It is practically impossible to provide custom made tools with a standard open architecture.

For instance, complex development and coordination improvements needs at Ford could not be satisfied with Open Source free software or a standard off the shelf product. Thus, the need for integrated hybrid architectures enabling a structured, centralized and disciplined problem solving process, while at the same time interconnecting the system with other systems is crucial.

To attract large wealthy customers, RDE tools providers invest large shares of their revenues on R&D and innovation activities. But the high investments are not there to only integrate scientific and engineering concepts. The RDE tools providers constantly challenge their minds for solving the customer's design, development and coordination problems.

They constantly challenge their engineering capabilities to capture both scientific and business processes into their tools, not only scientific processes. Statistics and interviews clearly proved that RDE tools providers are highly motivated to research, develop and innovate to solve their customers' complex problems.

We have also discovered that RDE tools providers use large complex projects as opportunities to learn and capture key scientific and engineering processes, but also as opportunities to innovate and enable the mergence of dominant designs.

The learning is accumulated and integrated into their dominant platforms. For example, Dassault Systemes' current large projects with Hydro-Quebec and the American Congress will unfold into many standardized modules for designing, development and managing construction projects on a lower and larger scale. The scaling down of innovations is an anti-thesis to the current innovation thought and the dominant Disruptive Innovations model. Here is an illustration:

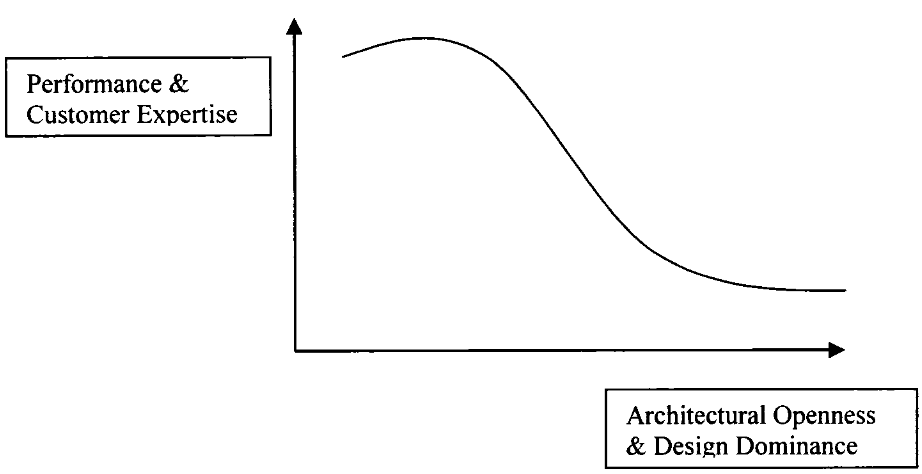

Figure 4.10 : Scaling Down Innovations

CHAPTER 5: INNOVATION DISCUSSION

The context of innovation and the innovation strategies, networks and logics mentioned in the previous chapter should open-up our minds about opportunities in the game as well as possible traps. Many great technical ideas emerge in R&D labs but only very few get adopted and value capture is not always in the hands of inventors.

The RDE tools game and the enterprise software game are emerging and innovation opportunities for large players and individual entrepreneurs are there. The question is how to lead the battle.

For a deeper understanding of innovation in the RDE tools game and through its whole value chains, challenges facing innovation should be understood and out-of-the-box patterns should be observed and linked to innovation patterns in the RDE game. The following are some key issues elaborated below:

1. Convergence and standard tools
2. Buying standard tools: the fate of average customers
3. Systemic thinking as a core competency
4. Complex integration projects create value and trigger new markets
5. Closed architectures and the software-as-service business model
6. Open architectures and the software-as-product business model

5.1 CONVERGENCE AND STANDARD TOOLS

As seen previously, products must interconnect with other products or systems to have value for customers and competition is loosing out to leading platform providers such as Dassault and Accelrys. Moreover, social and organizational needs for communication, collaboration and coordination are very strong and RDE tools have much less value if they did not interconnect with other software, standard operating systems and platforms.

The mergers and acquisition rates are high, for instance Accelrys was created with 10 mergers and leads the scientific software pharmaceutical and chemical markets. Moreover, Accelrys hired an electrical engineer to manage its R&D department and took MSC software's Marketing VP. This explains the systems convergence around dominant designs such as the PLM platform provided by Dassault Systemes and IBM. The Cadence platform is another dominant design. When software tools have similar applications and similar functionalities, network effects accelerate the adoption of a dominant design and the stabilization of the industry. Tools providers are clearly going horizontal with their platforms trying to consolidate all functions the customers need. Consulting partners such as IBM and Deloitte are totally horizontal and operate in all industries. These firms lead the information revolution and transform industries. There is a strong market pull transforming leading players from a vertical to horizontal position. This is a representation of the convergence phenomenon:

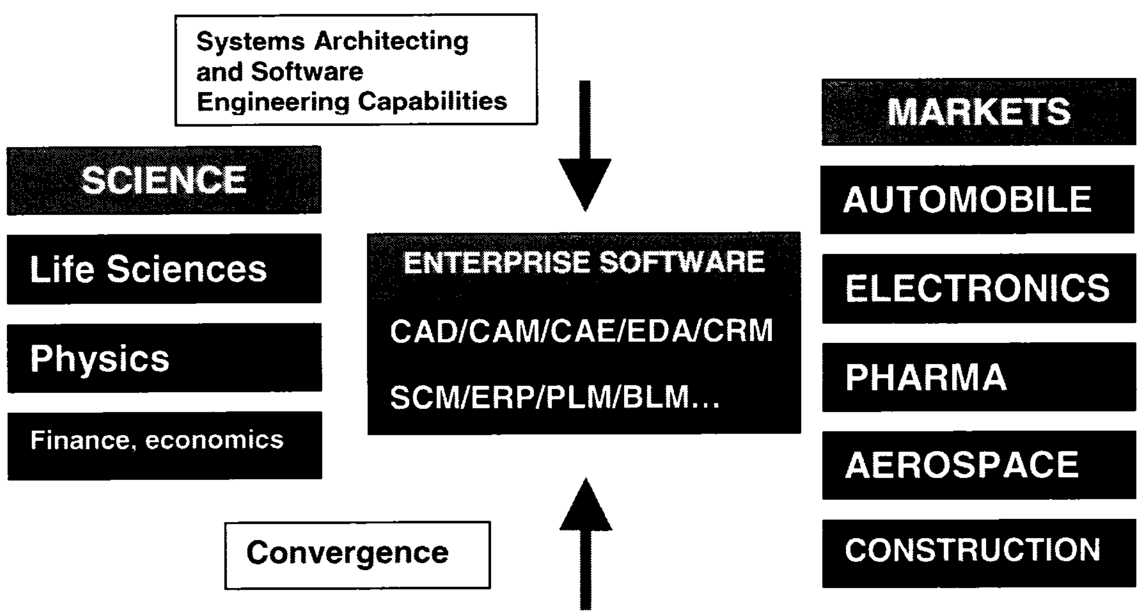

Figure 5.1 : Convergence of the Game through Engineering

Interoperability and coordination needs are slowing scientific and engineering innovations.

Coordination is slowing innovation - If you look at innovation from the perspective of small scientific developers, your perceptions of innovation dynamics will change completely. The interview with ImpactXoft, who invented the innovative Functional Modeling concept and spends about 50% of its revenues on R&D, clarified this fact. It took almost 20 years for ImpactXoft to convince Dassault Systemes that the concept would revolutionize the mechanical design process and over 12 months for Dassault to integrate the concept into its user-friendly platform architecture. The company is trying to bring back to engineers their old creative environment that was lost with rigid and primitive software tools and information systems. According to the company's CTO, the meritocratic selection of software tools is rare. Customers normally select a tool because they have heard of it not because they understand its underlying principles and functionalities.

Global economy effects on innovation - According to ImpactXoft, the industry is very slow, there is very little innovation and there has been nothing new in the past 6 years! Innovation is very slow because no one in North America wants to invest in engineering, design or manufacturing. Everything is clearly going to China where new PLM, CAD and EDA players are emerging.

The graph illustrates the transition:

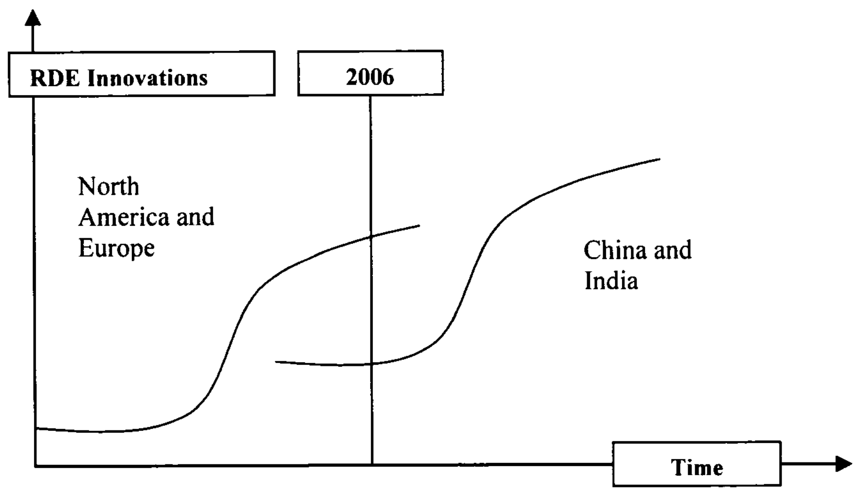

Figure 5.2 : China's Emerging Market

Leading RDE tools providers will face disruptions in the future and their platforms will turn into commodities. The players will have to change and adapt their business models.

There new necessary cultural and business parameters in the PLM platforms are disrupting established players but on the other hand new scientific parameters emerge such as nanotechnology parameters in scientific software.

This showed us that manufacturing companies in North America and Europe are trying to figure out new creative ways to face the manufacturing crisis caused by China. Buying PLM, EDA and ERP systems is one way to increase performance and the current goal is development and logistics costs reduction through process automation and coordination not the discovery of radical innovations.

Standard systems may greatly rigidify the tool provider as well as the buyer - Both RDE tools providers and buyers face problems of inertia (Miller and Olleros, 2005).

The entry barrier is the accumulated knowledge and the RDE players with the necessary knowledge for certain domains will gain stability and probably lead the battle of architectures.

Furthermore, when the buyer unlearns old development and engineering processes and spends hundreds of millions to learn to use the new RDE tool, the organizational inertia grows and switching to new systems with new integrated concepts and innovative parameters would be too expensive.

RDE tools and information systems will remain for decades in companies with only small incremental changes not for ROI reasons but for cognitive, coordination and return on learning reasons. Once people in the organization have found their secure positions around a new system, changing the parameters would necessitate a revolution. Moreover, buyers develop very close relationships with their RDE tools providers and social forces reinforce the organizational architecture.

Developers, as a result of accumulated knowledge are locked into their learning paths in and around their systems (Miller and Olleros, 2005). The disruptive innovation concept could be extrapolated here explaining the transformation of core competencies build around the RDE system into core rigidities.

<u>The risk in the 10 million lines of code learning investment</u> – Developing a complex integrated engineering system is a painful and long task that could take years to accomplish. The firm with its employees could get locked in the product and unlearning of the product could cost the firm a bankruptcy. This phenomenon of getting locked in a product with 10 million lines of code is also true on the buyer's side. Buyers develop capabilities as a function of the 10 million lines of code and unlearning the knowledge often means getting rid of a core capability.

RDE tools are often taught in engineering schools and scientific faculties and engineers develop a dependency on a certain commercial product even before getting a job. Think of CATIA, AutoCAD or Pro/Engineer, all these products are mandatory in many engineering classes. The problem here would be the excessive dependency of engineers on those tools.

Tightly integrated RDE tools have taken so much time to develop, their learning is so difficult and their market is so important that engineering schools have no choice but training their student on these proprietary systems. Unfortunately, organizations no longer employ engineers if they have no experience on a specific software tool such as AutoCAD or CATIA. The threat is when engineering schools teach their students the routinely and systematic use of what was already engineered in software tools. This makes engineers dependent on what they learned in using the tool not in the ends for using it.

If you want to hunt a dear, you learn how to use a spear but if you want to hunt a tiger you have to think of the spear's limited functions and invent a better weapon. The problem is when hunters keep on sharpening the spear thinking nothing out there could replace it; this would be the end of the world!

If we train hunters to use spears what happens if they face a tiger? Well it's sad to say but they will get processed in its digestive system and the tiger will have found its proteins for the day. It is more or less the same thing with engineering systems and everything else in this world. The bad news is that elder hunters keep sharpening their spears and end up getting killed but the good news is that junior hunters see the horrible event and force themselves to stand-up to the threat; they end up solving the complex survival problem.

This complex survival problem is now across organizations and across public institutions. One who has the wisdom to foresee his evolutionary path should challenge not only the status quo but his mind and imagination. To accomplish this purpose one should jump in the world's most complex problems and actively contribute to solving them.

5.2 BUYING STANDARD TOOLS: THE FATE OF AVERAGE CUSTOMERS

When a company buys a standard tool, the company should realize that the tool was originally crafted for another purpose and for other needs. This is critical for innovation. Leaders have created their own tools for R&D, Engineering and innovation. For example, Intel, the undisputable leader in electronics and computing hardware has its own EDA tool for designing chips. Cadence and Synopsis, the two EDA leaders sell their tools to Intel followers such as VIA Technologies in Taiwan.

The best tools for R&D and Engineering have emerged in critical situations and through large investment projects. The CATIA tool, world leader for CAD/CAE and concurrent engineering, was developed by the French military producer Dassault Aviation for designing faster and more effective fighter jets.

Can we plan innovation? Innovation isn't an easy task and it is very hard to plan. How easy is planning to constantly restructure your company and fire the employees who master your current products and technologies to facilitate new technology adoption?

5.3 SYSTEMIC THINKING AS A CORE COMPETENCY

From the engineering capability to the systemic thinking capability - The core competency in the RDE game is the Engineering practice. Most human resources in the researched firms have an engineering or computer science background. On the other hand, people with scientific backgrounds, biologists, physicians, material scientists, or financial backgrounds are less common.

Moreover, RDE tools providers are not leading the game, the game leaders are the systems architects and systemic thinkers such as IBM and Accenture. Nevertheless, RDE tools providers are starting to understand the rules of the game and investing in their systemic thinking capabilities.

Bridging mentalities for technology transfer and innovation - It is obvious that innovation is faster when the client has similar mentality, mind frame and professional background.

The cognitive and socio-technical perspectives are important for understanding the value and technology transfer from an organization to another. Note the difference among the following scenarios:

1. Engineers develop a software tool for engineers to use in aircraft design
2. Engineers develop a software tool for chemists to use in molecular design
3. Engineers develop a software tool for bankers to use for bank transactions

The economy in the RDE game is first an economy of engineering knowledge and process accumulation. The third party developer sub-game is an economy of scientific knowledge accumulation.

Innovation is not only slower when the school of thought is not similar it is even slower when the technical knowledge and intellectual level of the buyer who integrates the system is lower. The limited access to manufacturing technologies and qualified human resources for production and business process automation is a major problem in developing economies that impedes innovation.

Integrating a tool or adopting the imported technologies may be a step in the right direction, though, if well mastered. Technology has an environment-specific element and includes an underlying tacit knowledge dimension. For instance the CATIA tool was initially developed for the design of aircrafts. Mastering the adoption of technology, with all of its dimensions, enables its adaptation to the organizational local needs and eventually its advancement.

The wider the gap in technological development and the more discrepant the cultural characteristics, the more difficult it is to transfer technologies. For example, Cadence would find it easier to transfer its EDA technology to a chip designer in the Silicon Valley than a chip designer in India.

5.4 COMPLEX INTEGRATION PROJECTS CREATE VALUE AND TRIGGER NEW MARKETS

Markets for RDE tools emerge when providers and the expert customers have found together the solution for their complex organizational or technical problem. For instance, important mechanical design functionalities are programmed in the system and user friendly modules are created. The module is refined to fit the needs of less demanding buyers in other industries. When development and engineering solutions are programmed and scaled down, a product is created and could be distributed on a larger scale. However, value creation and capture dynamics vary when the RDE tool provider has found the standard development or engineering solution.

Large investments for technological upgrades in product development, supply chain management or concurrent engineering create opportunities for internal engineering teams to improve their software engineering skills and develop powerful development and engineering tools. The tools greatly improve productivity and automate routine development and engineering work.

Engineers who were fortunate enough to participate in those large creative and brain draining processes sometimes discover new opportunities and applications for the system. For instance, Dassault Systemes is a spin-off from Dassault Aviation.

As previously discussed, large military projects such as the CALS project in the US create many opportunities for visionary and entrepreneurial engineers with smart ideas for new software applications. When large and wealthy buyers like Boeing see the potential in such propositions, they ask for more and large tools are created.

Even for Autodesk, who claims to democratize design and engineering practices, its open architectures and standards such as AutoCAD or Inventor (similar to Solid Works) started as closed systems then migrated to open systems. The architecture opens up because it is coupled with smart APIs at the periphery and a strong partnership program for third party developers who add their own value. However, the core of the architecture always remains closed and third party developers stay at the periphery.

Here is an illustration of PLM architectures:

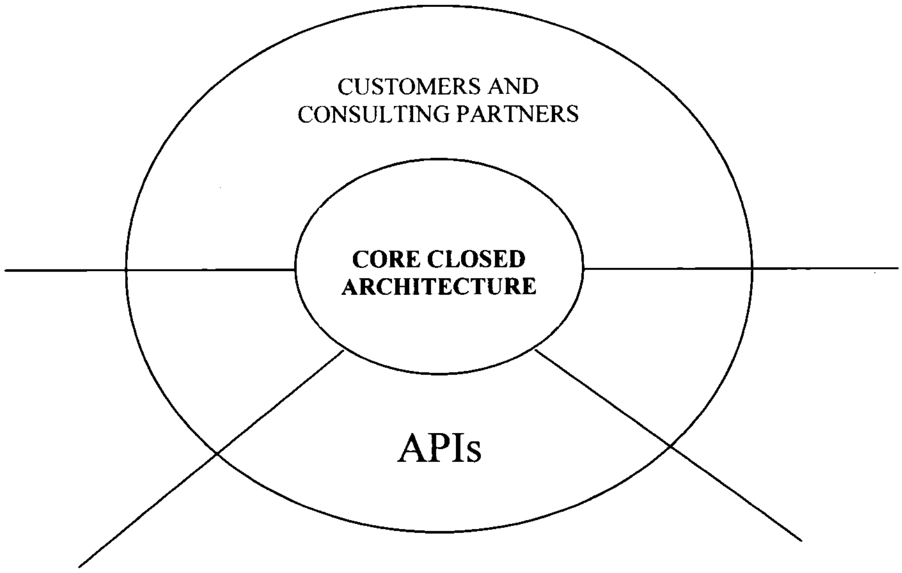

Figure 5.3 : Hybrid Architectures

5.5 CLOSED ARCHITECTURES AND THE SOFTWARE-AS-SERVICE BUSINESS MODEL

To avoid commoditization, the service business model for providing software tools makes business sense. The Japanese software providers for example completely rejected the modularization option and went into consulting. However, standard modules with standard design and engineering processes make business and economic sense for small and medium enterprises who could not afford buying consulting time.

For constantly solving complex coordination problems, tools should be based on a flexible architecture to constantly integrate new scientific concepts as well as new business processes. Flexibility comes with integration and central control.

As a cognitive amplifier, software becomes a powerful tool for consultants to develop and use with their clients. The software engineering practice becomes very important in consulting companies for automating unnecessary work routines. Mastering software and systems engineering becomes a competitive advantage for consulting firms. ESI Group for instance is a pure service company that provides specialized simulation tools for the automobile industry. The complexity of tools should be transparent to expert users who ask to adapt large parts of the software to their specific needs.

5.6 OPEN ARCHITECTURES FOR MODULARIZATION AND THE SOFTWARE-AS-PRODUCT BUSINESS MODEL

When man had less time for fishing, he replaced the fishing spear by a fishing net and caught more fish faster, when he realized he had too much fish, he went on selling it. When man saw the great potential in fishing nets, he went on hiring net weavers and fishermen and caught fish for his whole community. The fisherman created a modular architecture and captured more value. SAP called its middleware platform 'NetWeaver' for the same reason.

Autodesk democratized design and engineering tools, Accelrys is applying its technology to biological systems and Engenuity in Montreal wants to take its HMI technology used in airplane cockpits through many other industries.

There is no best way for managing architectures and either closing the architecture or opening the architecture could create great value and wealth. The question is how complex the problem is. In some cases, value can only be created if a complete new architecture was developed, in other cases the same core architecture could be used with changes at the periphery and finally, using a standard tool could solve the problem.

The crafting of standard modules from accumulated complex problem solving experience changes the rules of the game. For instance, Dassault Systemes and Toyota created a CATIA module for the automobile industry that smaller players buy and integrate with minimal architectural change. Modular systems are created when tools providers create scaled-down versions running on desk top computers and sold to small and medium sized firms.

The transition from closed to open architectures was already observed in industries such as the PC industry with IBM opening the architecture and telecommunications systems using SIP protocols. Telecom systems architectures opened to insure interoperability of standardized components. In both the PC and the telecom industries, great value was captured by society and other component providers.

The following are the observed reasons that trigger the opening of architectures:

1. The RDE tool provider sees the value in packaging the development and engineering principles and processes learned through complex projects in standard modules
2. The advances in RDE tools begin to overshoot market expectations and customers' real needs and new competitors start to develop lower costs and flexible products.
3. When competition comes up with advances and more functionalities, the buyer asks for interconnecting the system with the competition's new modules (consolidation)
4. Communication, coordination and information tools are often more important than RDE tools for buyers and since the RDE tools providers are not competitive in providing these tools, the customers ask for interconnecting other tools
5. When proprietary tools monopolize markets, competitive and regulatory pressures are used for democratizing the standard and widening the architecture, that was the case with IBM and the PC and is currently the case with Microsoft and OSS

CHAPTER 6: CONCLUSION

Innovation management and strategy models such as the Schumpeterian Innovation, the Porter's Five Forces, the Value Net, the Disruptive Innovations and the Resource Based models are important and contributed to shaping this study. However, their applications are too narrow and many innovation patterns go beyond their scope.

We have explored the game of R&D and Engineering tools providers to improve our innovation and strategy understanding and many interesting patterns appeared.

Large multinationals are facing important challenges for managing new product development and operations through their complex supplier networks and tools such as Product Lifecycle Management will solve this development coordination problem.

The RDE players invest a large percentage of their revenues on R&D and innovation activities; among the highest R&D investments in the world. They invest in their engineering capabilities to integrate their field's scientific concepts and business dynamics.

We thought that scientific capabilities were much more important and realized that capabilities for coordinating science and business came first.

The social and coordination problems are as complex if not more complex than technical and scientific problems and the current PLM and enterprise software technologies are solving the coordination problem arising in the global economy.

The information revolution is changing all industries. Earlier, automation replaced physical routine work but today enterprise software and RDE tools are replacing cognitive and intellectual work. With a powerful RDE tool only one engineer could do the work of 10 engineers or more and with collaborative and concurrent engineering tools even more productive development is possible. Visualization and media tools along with standards such as the 3D XML standards will push communication, development and Product Lifecycle Management to a higher level.

We have found that the solving of complex problems through corporate and governmental large projects triggered very important technological cycles. Complex problem solving through systems architectures and enterprise software solutions creates new markets and technological cycles.

Furthermore, software tools should not be taken for granted and the threats behind the adoption of standard tools should be known. The tool is not the rule but a means for automating routine work and coordinating people. As the Dynamic Capabilities model puts it, routine is not a competitive advantage and innovation should not depend on tools.

6.1 MANAGING ARCHITECTURES FOR INNOVATION

The architecture is a major strategic lever. Expert buyers have difficult needs and hybrid systems are crucial for satisfying these needs. The game evolved from closed systems to hybrid software architectures interconnecting with other systems at the periphery. Hybrid architectures are characterized by their high flexibility and intensity. The intensity here is characterized by an accumulation of experience and knowledge on certain scientific fields or business models.

We have seen that innovations not always start as primitive ideas in small research labs but they often emerge from large political, national and corporate projects. For instance, Military projects often trigger large scale innovations.

While RDE tools providers are crafting solutions for their customers' complex needs, scientific, engineering and business processes are created, mastered and automated with the tools. Software dominant designs emerge through such problem solving processes.

The closed portions of the architecture are exclusively kept for in house developments and the open portions enable the contribution of third party developers, consulting partners and customers. Acquisitions and partnerships provide new capabilities that are recoded and re-architected to fit the software.

The trend of openness in software contributes to architecting platforms to which components and other solutions could plug-in. They can plug-in if they are scientifically and technically integrated.

As previously said, leading RDE tools providers have a strategy for sharing leadership with their customers for developing the best tools. Customers are the most significant members of the innovation network and the development of integrated products requires mutual interactions between the tools providers and expert customers.

There are integral consistent models on the inside of the architecture and open standards on the outside. For example, one of the last evolution in IT and software systems is the notion of plug-ins.

The shift to hybrid architectures is inevitable and internal changes are really difficult. Everyone in the company needs to understand the logic for opening the architecture and everyone needs training. But there is always a limit for openness.

Mechanisms (e.g. the Open Access program at Cadence) are necessary for enabling customers to plug other important tools for interoperability. Cadence like Dassault Systemes and other tools providers are taking advantage of their open platforms (e.g. Open Access) to sustain a large share from the customer and the third party developers.

6.2 THE RULE OF THE TOOL

Tools and systems should be evaluated and buyers should understand all underlying principles and specifications of the software tool or platform. Every single detail should be discussed.

When we discover a technology (or tool) that makes sense in solving an apparent problem, other problems emerge and the tool no longer solves the new problems. Intuition becomes the tool for solving the most complex problems in the world; not super computers nor PC clusters. However, intuition becomes a powerful tool only when it comes from prepared minds. The prepared minds (in my opinion) are those who have accumulated both technical and social knowledge.

6.3 MANAGING THE PARADOX

Would the solution then be to open 50% of the architecture and close the other 50%? Problems are never similar and every single client and project deserves a different architectural approach. The challenge here is closing parts of the architecture while at the same time opening other parts. One should craft a business model considering both the software-as-service model as well as the software-as-product model. There rule for the openness-closeness paradox is a slide-rule, one should create the capability for quickly finding the right point on the slide-rule for solving his customer's problem.

Another important paradox to manage is the tool as the rule paradox. Software tools are not the only solutions for the customer's problems. For building innovation capabilities, the customer should find the balance in using the tools and automated processes and using tacit and organic processes. Managers should develop their capabilities to use the tool and use their intuition at the same time.

6.4 FURTHER RESEARCH: AN ARCHITECTURAL APPROACH

According to the Co-opetition approach, there's always a larger game. This is true but there's always a smaller game too (from a scientific standpoint)! This simply means that the rules are never the same but what seams to be true is the existence of an evolutionary balance.

As seen in the study as well as along the horizontal axis of the Games of Innovation approach, every product and every service has an architecture. As seen in Christensen's Innovator's Dilemma and Solution, the product's architecture is similar to the organization's architecture. We have seen in this thesis that architectures could open-up and close in different ways. For instance, AutoCAD is open but proprietary like Windows, Linux is open but public. A highly specialized computer tool developed for NASA would be totally closed like an original hand made peace of furniture. On the other hand, a democratized design tool such as SolidWorks used by amateur designers would have an open architecture like a standard IKEA chair.

Nevertheless, architectures exist everywhere, not only in products. A few centuries BC, the Greeks created the Greek alphabet with an architecture that enabled the quick integration of other cultural concepts and advancements from around the world. Our own languages today are based on many of those concepts. Our biological cells also have architectures enabling healthy cell divisions. As seen previously, RDE systems are based on middleware architectures and middleware architectures are based on transistor architectures, etc. Moreover, the Intel processor architecture is based on Intel's organizational architecture.

When humans were hunters, lived in huts and conducted their social life around camp fires, they had cutting edge technologies (cutting edges), they had jobs (hunting the animals, preparing the weapons, building their houses) and they had a social life (gathered around the fire to eat and celebrate). When the number of tribes increased and larger societies emerged (with an unimaginable number of battles and carnages) humans suddenly came up with more complex technologies entailing more complex managerial jobs and a division of labor.

The underlying architectures and coordination mechanisms in our technologies, factories and information systems also exist at work and throughout our social lives. When you think of architectures in supermarkets (Wal-Mart), consumer electronic superstores (Best Buy), airports, banking systems, transport systems, highway networks, you see the link and continuity with architectures in software tools, electronic chips, communication technologies, mathematics, and symbol systems.

Technology triggers massive institutional and social change but at the same time, society triggers major technological change. For instance, the software community reacted to Microsoft's monopoly and created the Open Source movement and most actual software developments work on open source platforms. Moreover, Wall Street reacted to SAP's monopoly of the ERP and enterprise software market and created a vacuum for all emerging PLM companies.

When the tool's architecture has the necessary parameters for creating or nesting a network backed-up by aggressive marketing and PR, the architecture opens up and a dominant design emerges.

Architectures exist for balancing a very complex set of elements and an architectural continuity exists throughout our cognitive, social, technological and environmental patterns (probably biological too).

Further research for developing an architectural model is necessary and would surely improve our innovation and evolution understandings.

6.5 BUSINESS OPPORTUNITIES

The enterprise software and Product Lifecycle Management games are emerging and millions of opportunities exist. Practically, entrepreneurs with smart ideas, commitment and good contacts could launch integrated exploratory projects to eventually modularize and access very large and wealthy markets.

Looking at the history of successful technological entrepreneurs could show us the light. For instance, the founder of Anderson Consulting (today Accenture) also founded Seibel Systems and Siebel just got acquired for 4.5 billion dollars by Oracle. One prepared mind saw the need for CRM tools and ended up leading the game.

There are three clear successful paths for innovating in the enterprise software and RDE tools games:

- Find innovative ways with hybrid architectures to address the need for coordinating scientific, engineering and business capabilities.
- Develop PLM systems with Chinese partners to address the booming Chinese industry and make sure to embed critical cultural and environmental parameters. Develop the system from scratch.
- Find partners in the construction and software industry to launch software solutions for the design, development and management of construction projects.

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APPENDIX A: MINE ISSUES FOR DISCUSSION

MINE PROJECT

MANAGING INNOVATION IN THE NEW ECONOMY

ISSUES FOR DISCUSSION

1. **Value creation for customers**

    - Key dimensions as perceived by customers
    - Key dimensions stressed by your firm
    - Activities: engineering, productizing, interacting with customers, architecture alignment

2. **Vision of business environment and sectoral innovation dynamics**

    - Value net and key drivers of innovation
    - Sources of market uncertainty and unpredictability
    - Nature of technology and scientific problems and of their evolution
    - Key competitors and their strategies
    - Major recent changes in the business environment

3. **External Knowledge network for Innovation (Ideally draw map of network)**

    - Key concrete knowledge sources (in interviews and secondary sources)
    - Partners and alliances (ample data in corporate documents)
    - Other key stakeholders and influences (regulators, venture capitalists etc.)
    - Innovation leaders and success stories

4. **Corporate and business strategy**

    - Key sectors and markets in which it is present (describe in terms of games)
    - Competitive strategy (positioning and roles in game; other major thrusts)
    - Key platforms, competencies and capabilities and their development
    - Recent major transformations (turnaround, migration, mergers etc.)

5. Innovation strategy

- Vision/image of innovation (value creation; sources; success factors; risks; management principles, role and relation to other functions)
- Key policies for investments (e.g. 10% sales from products launched in the last year etc)
- Incentives (e.g. options for key scientists)
- Allocation of funds (between divisions/markets, etc.)
- Policies for the management of the portfolio of innovation projects

6. Building corporate capabilities for innovation

- Differentiation of innovative activities (key areas, problems and activities)
- R&D function structure (central lab; unit labs – number and type of personnel)
- Decision, steering and portfolio management committees
- Internal networks and communities of practice (e.g. innovation forums, task forces etc.)
- Other integration and knowledge sharing practices (inter-project, inter-unit etc.)

7. Key innovation management practices

- Knowledge, idea and opportunity management
- Portfolio management
- Project management
- Value capture and market shaping

8. Innovative performance

- Implicit and explicit self-assessment
- Rating by industry experts and press (from secondary data)