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# THE EVOLUTION OF GAMES OF INNOVATION IN REGULATED COMPLEX INDUSTRIES: THE CASE OF AVIATION TRAINING

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Ce mémoire intitulé :

**THE EVOLUTION OF GAMES OF INNOVATION IN REGULATED COMPLEX INDUSTRIES: THE CASE OF AVIATION TRAINING**

présenté par : KAMEL Michael

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I would like to dedicate this thesis to
***Mrs. Nadia Rizk***, my aunt and friend,
whose love, and support greatly
touched me throughout my life.

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## SUMMARY

Innovation is instrinsically associated to risk due to the uncertainties involved with the adoption of novel ideas, technologies or methodologies. However, it is the inevitable direction of progress in all industries as science advances and human knowledge increases. Avoidance and suppression of innovation for the sake of preserving the status-quo has consistently proven to be a failing strategy. Management of innovation is the science investigating the creation of innovation, its commercialization, survival and evolution.

The complexity of the innovation process is directly correlated to that of its product technology as well as the complexity of the organizational design of the innovating industry. The massive volume of technological know-how in complex industries necessitates the close interaction of various players, government institutions, interest groups and industry forums. These factors add to the complexity of Porter's five-force model of competitive analysis. The necessary synergies between innovations made by several independent, sometimes competing, firms for the overall product innovation constitute the additional difficulty of innovating in such industries.

Another difficulty associated to innovating in complex industries are the high safety and regulatory restrictions placed on their technological evolution. The uses and effects of these products are often far-reaching and affect public safety. Governments, industry forums and public interest groups are usually monitoring the innovation process to ensure the protection of their respective interests. The other main challenge facing technological innovation in complex industries is the hefty investments involved, which exposes innovating firms to higher risks in the cases of obsolescence or failure of commercialization of these innovations.

Various theories emerged for analyzing the management of industrial innovation. Some of the earliest works on innovation management were made in the 1930's by J. A. Schumpeter. His famous studies of the capitalist economy and its modes of value creation and renewal gave birth to the famous "destructive innovation" concept. In the 1980's Michael Porter's "Competitive Advantage" series provided a revolutionary framework for analyzing the interaction of an economic entity, a firm or a nation, with the various players interacting with it. Nalebuff enhanced the interaction model by recognizing the cooperation – competition relationship

between players observed in many industries. The so-called “co-opetition” model emerged and the value net analysis followed to describe the, sometimes informal, interactions between the various players affecting their value creation potential. All three frameworks above though do not provide a sufficiently complex framework for analyzing the cooperation dimension of a firm with other players in its industry. This dimension could be the most complex to manage and detrimental for innovation success for the firm.

In 1944, Von Neuman introduced the famous Game Theory, which explained a firm’s strategic choices in terms of its decisions combined with those of other firms interacting with it. Game theory was recognized in the 1990’s as one of the most influential business theories in the century.

In the late 1990’s Miller *et al* introduced a new Games of Innovation Typology. Games of innovation are classes of innovation schemes and dominant industrial patterns that govern the rules of innovating and its commercialization. Eight main games of innovation were identified, covering industries ranging from consulting services to high-technology engineer-to-order industries. Identification of a particular firm’s game of innovation permits sketching its main innovation best practices and core competencies it needs for optimal performance in its environment.

In this study, the evolution of the mode of coordination of a complex industry was analyzed. The industry chosen was the aviation simulation and training, a highly regulated complex industry. The industry was studied in the 1990’s and it was found to exhibit features of the high-technology craft industry game of innovation. It was found to have developed a stable oligopoly that implements an ex-ante system of regulation-based pre-selection of innovations.

Changes to the coordination mode in the industry were observed in the new economy and a shift towards the tertiary sector was noted by some of its key players. A hypothesis was made in light of the observations and a grounded research approach was chosen to prove its validity. The hypothesis was that the industry has exhibited a transformation from a regulation-based mode of innovation coordination to a pedagogy-based mode. The transformation was lead by various external and internal forces and the final mode of coordination breaks away from the ex-ante selection of innovation to a supplier-user partnership mode of defining innovations. The role of regulators has therefore changed accordingly from the upstream definition of industry products to the downstream approval of the pedagogy-driven products and services.

The research work started by a comprehensive literature review of the various areas of innovation, strategic and services management as well as the industrial analysis theories reviewed above. Interviews of senior managers of key firms and institutions identified in the industry then followed and the inputs were collected and combined with inputs from the industry intelligence sources. A comprehensive data map was made as a result. The data was then analyzed and conclusions were then qualitatively drawn from the available data.

The transformation process of the coordination mode of innovation was found to start by the revolutionary digital computing and PC technologies. The digital revolution and the rapid leaps made in the hardware and software complexity fields caused significant improvement in the simulation quality while simultaneously reducing the costs of the necessary computing hardware. At a certain point, commercially available personal computers became sufficiently powerful to run the lengthy simulation algorithms and hence opening the door to desktop-based simulation stations. These portable simulators were quite promising for reducing the travel and living costs associated with pilot training while at the same time improving the quality of that training.

In parallel to the PC technology advancement, smaller firms were trying to enter the market and compete with the established oligopoly of key suppliers for market share. While full flight simulators (FFSs) had far too high barriers of entry, the flight training devices (FTDs) defined by the FAA in the late 1980's were reasonable targets. The small entrants leveraged their small overheads and flexible operations for producing lower cost devices that still met the regulatory requirements.

Several events followed these two movements, described above, causing a downturn in the global economy in general and high economic pressures in the aviation industry in specific. These circumstances pressured the industries on the supplier-end of the airlines further to become more efficient and reduce costs and prices. This effect favored the low cost FTDs trend and its adopted bottom-up design approach and hence alerted the higher-end producers of the need to venture into the growing low-end devices market.

Endogenously to the industry, a few key suppliers were adopting forward vertical integration strategies into the training services market. The non-cyclical stable service industry, contrasted to the highly periodic engineer-to-order equipment industry, lured several big players to start by either forming joint ventures with training providers or by wholly acquiring aviation training providers.

One firm was able to adapt to the above exogenous forces and adopt the forward integration strategy in time to capitalize on its move. This firm capitalized on its strategic position and introduced a new "*Advanced Curriculum*" capable of enhancing the effectiveness as well as efficiency of the aviation training in the industry. The standard migrated away from the dominant paradigm of value creation by producing regulation-compliant training devices. The new standard was to create value on the merits of its overall pedagogic value instead. The new proposed standard was developed in conjunction with various customers as well regulation authorities for ensuring its market applicability and acceptance.

The new curriculum shifts the focus of training equipment providers, to the pedagogic value of the training curriculum in which they will be used, rather than their stand-alone compliance with the prescribed regulations. As the standard amasses popularity, the strategic focus of the whole industry is being gradually transformed accordingly. Market and regulatory standardization of the new pedagogic platform will officially seal the transformation of the mode of innovation coordination in the industry towards the pedagogic value of the training equipment rather than their regulations-acquired value. The new mode of coordination is stabilizing to replace the ex-ante mode of innovation pre-selection that was observed in the industry in the 90's.

The observed shift in the mode of innovation coordination in the industry was due to a combination of external and internal factors and was lead by a key supplier of the old industry organization. This is against the conventional expectation of architectural innovations coming from outside of the industry and causing industrial reorganizations where old incumbents are driven out. In fact, the transformation happened within the constraints of the same game of innovation identified before. This was found to be in line with the games of innovation theoretical framework that indicates that a firm's understanding and mastering of the key success factors in its game of innovation are its most influential performance differentiators.

The hypothesis that the industry has exhibited a change in its mode of coordination has been proven by the analysis of the collected data. The new roles of the various entities in the new industry organization have been identified and their contributions to the value creation process defined. The resulting industry organization shows that while adaptation to external forces may be sufficient for surviving in a complex industry, leadership position is assumed when active reshaping of the industry game is done to favor the leader firm's core competencies and capabilities.

## ABSTRACT

The study of industrial games of innovation usually involves modeling of the industry in question to understand its organizational design and dynamics. The dominant models in this area were traditionally based on the concepts of Schumpeter's destructive innovation, Porter's five-force competitive analysis (Porter 1980) or Nalebuff's value net (Brandenburger and Nalebuff 1995). Newer frameworks for analyzing industrial behavior include game theory and its derivative games of innovation theory. Innovation in the aviation simulation and training industry, which is a regulated high-technology industry, was studied as exemplary for that type of industries.

The aviation simulation and training industry emerged at the turn of the twentieth century and it was mostly demand-motivated at its onset. The increase in the volume and importance of aviation resulted in government regulation of the industry in the late 1960's. This has radically changed the innovation game of the industry into a regulation-based game. Previous literature described the regulation-centered innovation coordination as "an internally-coherent system of innovation". The new game had the regulatory frameworks at the core of the innovation process as they defined the market's acceptance and value capturing from innovative technologies. The evolution of these regulatory frameworks was almost entirely reactive to accidents and catastrophic failures that highlighted existing deficiencies in training methodologies or technologies.

This ex-ante regulator-driven system of innovation exhibited recent evolutionary changes towards being a pedagogy-centered service-based system of innovation. The forces behind this transformation were a combination of endogenous and exogenous ones. Technological opportunities, economic pressures and strategic transformation of industry leaders were the three main categories of these forces. The resulting mode of innovation coordination in the industry was a service-oriented pedagogical platform, lead by supplier-user partnerships and monitored by regulation authorities. A new stable equilibrium of innovation coordination is being reached by the industry, driven by its downstream-most service provision component.

# CONDENSÉ

## Introduction

La complexité de l'innovation est le résultat combiné des incertitudes impliquées à l'intérieur de diverses phases, allant de la génération d'idée au développement scientifique, à mettre en produit l'avancement scientifique et finalement à la création de la valeur du produit résultant. Dans ce travail, l'innovation dans les industries complexes est étudiée avec une attention spéciale sur l'évolution de ses modes de coordination. Une industrie complexe typique, qu'est l'industrie de simulation et de formation d'aviation, a été choisie pour cette étude.

D'ailleurs, le fait de revoir la « littérature » précédente appliquée sur cette industrie dite particulière, a révélé que les directives des autorités ont formé le noyau du processus dynamique d'innovation. Un oligopole stable de quelques fournisseurs a établi un système « ex-ante » de choix d'innovation basés plutôt sur les cadres réglementaires que sur la force méritocratique de choix du marché.

**Différentes théories pour analyser l'innovation :**

**L'Innovation selon Schumpeter :**

L'innovation comme l'a décrite J.A. Schumpeter, est bel et bien caractérisée par deux éléments principaux :

- Des vagues consécutives d'innovations destructives frappent souvent les industries matures et causent des changements drastiques dans leurs compétences principales, remplaçant les sociétés établies par des nouveaux débutants (Schumpeter 1934)

- La coordination d'innovation est basée sur la force méritocratique de choix du marché sur les produits innovants fournis par l'industrie.

**Modèle de l'industrie de Porter :**

Dans le modèle de l'industrie de Porter, la stratégie concurrentielle d'une entreprise est en fait l'essence de son rapport avec son environnement (Porter 1985). En d'autres termes, les rivaux des entreprises, les fournisseurs, les clients, les débutants et les produits de remplacement potentiels composent en réalité le réseau des rapports de ladite entreprise. Son but principal est donc de trouver une position stratégique dans l'industrie où elle (l'entreprise) peut mieux soit se défendre contre les facteurs de concurrence, soit les influencer en sa faveur (Porter 1985). Toutefois, le modèle de Porter ne s'adapte ni à l'associé ni aux rapports de sous-traitance, ce qui exige conséquemment le besoin de l'innovation concourante, et cela par le biais de divers joueurs afin de réaliser l'innovation du produit final.

**Le modèle co-opétition :**

Dans le modèle de la Co-opétition de Nalebuff, le concept de *filet de valeur* est employé pour permettre une vision de plus en plus large de l'industrie, et cela bien entendu à la lumière de ses rapports de concurrence et de coopération. Les deux dimensions de collectivité fournissent les principales forces affectant la performance et le positionnement stratégique d'une entreprise. Cependant, ces *filets de valeur* manquent des dispositions pour des interdépendances technologiques concourantes complexes, et cela entre les sociétés fonctionnant dans une industrie complexe.

**Joutes d'innovation**

Miller, entre autres, a constaté que les sociétés développent en effet les meilleures pratiques nécessaires au fonctionnement, et qui sont effectivement basées sur la nature et l'environnement de leurs industries respectives (Miller et Olleros 2004). Ces environnements imposent, d'une manière ou d'une autre, certaines règles d'innovation aux « joueurs ». D'ailleurs, le fait d'essayer de grouper ces divers environnements dans des positions logiques, donne lieu à huit jeux d'innovation qui influencent bel et bien la performance et la définition des meilleures pratiques de leurs joueurs. Les joutes identifiés sont :

***Joutes rapides***

1. Batailles pour l'architecture
2. Courses au brevet et aux bureaux de Régulateurs
3. Livrer Le Coffre-fort, Produits Science-Basés
4. Services de conseil

5. Systèmes de Recherche, de développement et de la technologie

***Joutes lentes***

6. Fournir les solutions réalisables dans des « Paquets »
7. Résolution des problèmes capital-spécifiques
8. Produits de Haut-Technologie adaptés aux clients.

La théorie de jeux d'innovation fournit véritablement un cadre suffisamment détaillé pour pouvoir analyser et comprendre l'innovation, et cela à travers un éventail de différents types d'industrie. En dépit des variations de la performance des entreprises dans chaque jeu, un ensemble générique et spécialisé de compétences s'avère commun à presque tous les joueurs.

## L'Industrie dans cette recherche

En réalité, l'industrie dans cette recherche – celle de la simulation et de la formation d'aviation – est vue comme une industrie réglementée et complexe. De ce fait, l'innovation de cette industrie doit donc suivre le jeu de *Produits de Haut-Technologie adaptés aux clients*.

## L'hypothèse de la recherche

Cette recherche a débutée par l'hypothèse démontrant que l'industrie de simulation et de formation d'aviation a été évoluée hors du système intérieurement-logique de l'innovation (dorénavant désignée sous le nom de *Mode de Coordination I*), et que le processus de l'évolution était fait par un hybride des forces et des facteurs. Le vecteur principal du changement de l'industrie est une évolution du mode de la coordination industrielle vers un mode de règlement-centré de produits à celui des services pédagogiques. Le changement s'est fait par une combinaison aussi bien des stratégies d'innovation rationalistes et incrementalistes des joueurs principaux dans l'industrie que des changements économiques exogènes dans d'autres industries et dans l'économie même. Un nouveau mode de coordination d'innovation se cristallisant et commençant à se stabiliser dans l'industrie (désignée dorénavant sous le nom de *Mode de Coordination II*). Le mode de la coordination dans cette industrie complexe s'est éloigné de innovation ex-ante régulateur-centrée en se lançant vers un mode pédagogique de partenariats des fournisseurs-utilisateurs.

**Méthodologie de recherche**

L'équipe de recherche a suivi une approche pratique de recherche pour comprendre les jeux de l'innovation de l'industrie ainsi que leur évolution en vue de répondre aux facteurs endogènes et exogènes. L'étude a été lancée par un examen de littérature des sciences économiques et industrielles, de la théorie des jeux, de la théorie de jeux d'innovation, du management stratégique d'innovation, de la stratégie de développement de produit, et l'industrie de simulation et de formation d'aviation.

D'abord, les joueurs principaux de l'industrie étaient identifiés. Puis l'évolution historique et les étapes principales de l'industrie ont été étudiées, cela en utilisant aussi bien les sources d'intelligence d'industrie que les rapports annuels et financiers des joueurs principaux. La littérature a été, de nouveau, employée pour comprendre la structure et la dynamique du *Mode de Coordination I*, et comment elle fut atteinte par le mode précédent de la coordination. La recherche pratique a alors débutée en interviewant la haute direction des sociétés participantes afin de pouvoir comprendre les facteurs derrière la transformation observée. La recherche a également rassemblé des données portant sur le nouvel arrangement de coordination d'industrie (*mode de coordination II*), l'image que les sociétés ont faite, et leurs stratégies dans le but de bien se positionner. Les forces derrière le processus de transformation ont été étudiées par le fait d'analyser tantôt les données de participants, tantôt les entrées de données. D'ailleurs, dans l'analyse de la transformation, la société, observée pour mener ce décalage stratégique, a été complètement étudiée voire analysée afin de bien accentuer ses compétences dynamiques qui étaient fortement nécessaires pour accomplir ce rôle stratégique. Finalement, le nouveau mode de la coordination a été décrit et un nouveau modèle industriel a été créé.

## Simulation et formation de vol

L'industrie de simulation et de formation d'aviation se compose en fait de deux industries qui sont à la fois distinctes et en corrélation : l'industrie d'équipement de simulation de vol qui fournit les produits de formation, et l'industrie tertiaire de formation d'aviation qui fournit les services de formation.

## Mode I de coordination: innovation conduite par les autorités

Conséquemment à la formation et à la stabilisation de l'architecture de l'industrie d'équipement de simulation de vol, sa nécessité à la sûreté du vol a été identifiée par les autorités de transport autour du monde. En effet, l'autorité de transport aérienne la plus influente autour du monde, le FAA aux États-Unis, a frayé un chemin vers l'application des conditions de formation annuelles minimums de simulateur pour des pilotes de ligne aérienne.

Les réglementaires ont identifié de divers niveaux de fidélité des dispositifs de formation de vol pour les diverses étapes du cycle de formation des pilotes. L'adhérence aux conditions minimum de chacun de ces dispositifs de formation est en fait ce qui a donné, à n'importe quel dispositif de formation, sa rentabilité commerciale de formation et par conséquent sa valeur marchande.

En raison des implications élevées de sûreté impliquée, les directives réglementaires étaient lentes dans le développement de leur réaction à l'évolution technologique. Peu et loin entre les révisions des directives qui ont été faits, or ceux-ci ont été la plupart du temps lié aux méthodologies de formation plus qu'aux technologies. Par ailleurs, l'innovation était très conservatrice au moment où elle a affecté l'interface utilisateur, et a été la plupart du temps concentré sur des technologies de fond transparentes au stagiaire ainsi qu'aux autorités. Ce meso-système de l'ex-ante choix des innovations basées sur les règlements, a eu comme conséquence une attribution efficace des efforts de recherches et de développement (Miller et Olleros 1993)

Ce cadre esquissé pour l'innovation, a mis en réalité les autorités au cœur du procédé de génération d'innovation, et cela dans l'industrie de formation d'aviation. Non seulement les fournisseurs ont adhéré aux directives réglementaires afin de pouvoir donner à leurs produits la valeur acquise de la qualification, les clients également n'ont pas créé une demande différente de ce que les autorités avaient dicté. Ces règles ont bien défini la structure des négociations qui se font entre les acheteurs et les vendeurs (Brandenburger et Nalebuff 1995)

## Les forces de changement

### *La révolution du PC*

En dépit de l'utilisation des ordinateurs analogues dans les conceptions premières des simulateurs de vol, cela n'a pas duré longtemps avant que le calcul numérique soit la technologie de noyau en simulateurs de vol. Cette nouveauté a provoqué en effet la technologie de CBT (*Computer-Based Training*) employée pour but de former des équipages d'aviation économisant localement les coûts de voyage aux simulateurs. La technologie naissante était quand même menacée d'une vague de destruction créatrice convertissant les compétences principales du noyau de fournisseurs en des rigidités coeurs, et les conduisant également hors de la nouvelle industrie (Leonard-Barton 1992)

***Les nouveaux FTDs***

Les sauts d'innovation faits dans le secteur de la capacité de traitement de PC, comme mentionné ci-dessus, ont incité bel et bien de nombreux petits fournisseurs afin de chercher, dans des *Flight Training Devices* (FTDs), des occasions de marché à coûts réduit.

Leurs appareils ont été construits de rien et ont été conçus à peine pour pouvoir répondre aux conditions de qualification des autorités régulatrices. Cette construction est faite, par conséquent, à des coûts significativement plus bas que ceux des FTDs traditionnels dans l'industrie. Ces produits devenus graduellement de plus en plus populaires dans ladite industrie.

Dans les années 1990s, éprouvant une diminution radicale dans la part du marché de FTDs aux nouveaux entrants d'industrie de bas-fin, CAE, une des entreprises principales dans l'industrie d'équipement de simulation, a lancé une nouvelle gamme de produits (*CAE Simfinity™*) avec le mandat d'exploiter ses vastes bibliothèques de modèles de simulation. Les conceptions de FTD ont été produites du fond, divergeant des conceptions classiques du CAE, avec les économies de coût et la conformité minimale nécessaire pour les qualifications régulatrices.

***L'intégration verticale en avant dans l'entraînement***

Simultanément au mouvement des fournisseurs clés de simulation de haut-fin en vue de couvrir la fin la plus basse de la gamme de produit, un mouvement d'intégration vertical en avant a été poursuivi par certains. En 2000, Thales Training & Simulation (TT&S) a formé des 50-50 partenariats d'entraînement avec Crossair ; une ligne aérienne régionale européenne, marquant son mouvement d'intégration en avant dans l'industrie d'entraînement (TT&S 2000). Dans la même année, le nouveau PDG de CAE a annoncé le mouvement "majeur, mais discipliné" de la compagne dans le marché de formation de pilotes (CAE 2000)

***Pressions économiques***

Les pressions économiques causées par des événements globaux mènent, en réalité, à une baisse économique. Ceci a mené, par la suite, au resserrement des budgets des clients clés et à l'augmentation des pressions exercées par les bons marchés sur les fournisseurs. Pendant que les façons révolutionnaires de diriger l'entraînement d'aviation s'étaient cristallisées dans les esprits de quelques visionnaires dans l'industrie, le besoin d'elles est devenu de plus en plus évident, notamment à la lumière de la lutte pour la survie que l'industrie entière l'a reconnue comme consécutive à ces mésaventures. La direction légitime de la transformation a été mise en question au commencement et jusqu'à ce qu'un accord implicite ait été atteint, cela pourrait être le mieux fait des fournisseurs innovateurs qui ont l'intérêt commercial en poursuivant telles solutions d'entraînement.

***Changer Le jeu d'affaires de l'industrie***

Les facteurs discutés ci-dessus ont préparé en fait le terrain pour un des dirigeants du secteur tertiaire d'entraînement afin d'introduire des méthodologies innovatrices pour rendre l'industrie de plus en plus efficace. L'entreprise, qui était le mieux disposée pour exploiter les forces mentionnées ci-dessus, et introduire et mener une nouvelle plate-forme d'entraînement, était l'entreprise capable d'apprendre de ces forces et aussi de s'y adapter. Le dirigeant potentiel devait s'adapter technologiquement à la révolution de PC, et opérationnellement à la production d'équipement bon marché. Il devait de même s'adapter stratégiquement en fournissant simultanément les produits d'entraînement et les services d'entraînement.

D'ailleurs, le changement majeur dans le jeu d'industrie était que CAE avait introduit une nouvelle trace d'entraînement dans leurs centres d'entraînement qu'utilisait le FFS avec le Simfinity™ IPT (*Integrated Procedures Trainer*), ce qui a éliminé conséquemment les nombreux équipements de formation (FTDs) antérieurement utilisées. La nouvelle trace d'entraînement a été nommée “le Programme Avancé” : annoncée pour être la génération d'entraînement prochaine.

## Le mode de coordination II: L'innovation conduit par la pédagogie

La nouvelle méthodologie a commencé graduellement à gagner une acceptation profonde autour du monde. Quelques lignes aériennes « no-frills » et régionales ont adopté l'idée et ont formé une équipe avec CAE, cela dans le processus de développement et de présentation aux autorités de règlement. L'efficacité augmentée d'entraînement a attiré, voire encouragé beaucoup d'autres pour acquérir des parties de la nouvelle solution d'entraînement afin de remplacer leur ancien équipement dit « démodé ». D'autres ont choisi, de préférence, de sous-traiter complètement leur entraînement chez CAE avec son réseau de centres de formation. CAE vendait soit le service d'entraînement de programme avancé (le programme clé en main) avec ses appareils d'entraînement associés, soit l'équipement spécifique de la nouvelle trace d'entraînement.

Le résultat s'avérait une nouvelle plate-forme d'entraînement qui accumule la popularité dans l'industrie. Les autorités régulatrices aussi deviennent de plus en plus prêtes à accepter le nouveau concept d'entraînement, surtout les solutions développées sans adhérant avec ses règlements. Ces derniers ont été maintenant re-interprétés et appliqués par le biais de leur valeur pédagogique, et non plus de leur texte littéral. Plusieurs de leurs anciennes interprétations ont été mises en question, tenant compte des nouveaux équipements d'entraînement et de la nouvelle méthodologie.

La nouvelle méthodologie d'entraînement et le défi des anciennes interprétations des cadres régulateurs ont transformé aussi bien l'organisation d'industrie que son mode de coordination d'innovation. Le système ex-ante de coordination d'innovation, contraint par les cadres de règlement, était graduellement remplacé par un système d'innovation pédagogie-centré dépendant lourdement sur la coordination entre les fournisseurs et les clients. Le rôle des régulateurs s'est déplacé en aval allant de dicter le contenu et le format des produits de fournisseur à approuver la solution, pédagogiquement basée, définie par le fournisseur-client. Bien que les outils de ce partenariat puissent être les produits de simulation, les critères de conception principaux deviennent la valeur pédagogique, et pas simplement la conformité avec les cadres de règlements.

## La Discussion

### *Est-ce que la destruction créative est nécessaire?*

Un point intéressant à noter dans le cas de la transformation de l'industrie aéronautique, c'est que l'innovation menée était bien révolutionnaire ; elle contredit la position stratégique de l'entreprise qui l'a menée. Contrairement à la sagesse conventionnelle disant que les révolutions technologiques viennent souvent de nouveaux entrants dans l'industrie, le dirigeant de la transformation dans cette industrie était le dirigeant établi qui a défini le design dominant (Abernathy et Clark 1985) Les tentatives créatives de destruction de compétences fondamentales de l'entreprise par nouveaux entrants ont été plus pesantes par son changement stratégique et sa capitalisation que par ses autres sources d'avantage concurrentielles. En fait, ceci va de pair avec ce que Tushman & Anderson (Tushman et Anderson 1991) ont discuté conséquemment à l'étude des industries de mini-ordinateurs, du ciment et du verre manufacturés aux États-Unis. Ils attribuent ceci à l'observation "que les vétérans peuvent exploiter toujours des forces en amont et en aval dans la chaîne de valeur suivant une discontinuité de procédé; seulement leur savoir-faire technique fondamental est renversé" (Tushman et Anderson 1991)

### *De la survie à la direction*

Pendant que plusieurs facteurs exogènes ont préparé la scène pour l'arrangement de coordination d'industrie pour la faire évoluer, une force endogène a été exigée dans le but but d'exploiter ces facteurs et de changer le jeu de l'industrie. Pour faire face aux forces exogènes, CAE a démontré une flexibilité significative, d'une part, sur son devant technologique, par son adaptation rapide à la technologie de PC, et d'autre part, sur son devant stratégique, par son adaptation opportuniste afin de fournir le FTD bon marché. Seule la flexibilité aurait pu garantir la survie de compagnie durant les moments agités. Le mouvement de manipulation de jeu d'industrie était ce dont on avait besoin afin de convertir la simple survie en un rôle actif de direction d'une nouvelle industrie. Brandenburger & Nalebuff élaborent, à l'intérieur de ce point du cadre actif, le jeu d'industrie que l'entreprise avait présentée plus que de jouer le jeu qui a été déjà défini (Brandenburger et Nalebuff 1995)

### *L'évolution dans le jeu d'innovation*

Il est remarquable de noter que l'évolution du mode de coordination de l'industrie a été encore au fond du même jeu d'innovation de ladite industrie, nommée Produits de Haut-Technologie adaptés aux clients. Malgré les forces externes et internes derrière le changement, ces mutations n'étaient en fait que des réorganisations des divers joueurs et leur relocation sur la chaîne de valeur industrielle, cela évidement dans les limites du jeu existant. Par conséquent, les compétences fondamentales ainsi que les meilleures pratiques dans l'industrie ont été, en fin de compte, préservées.

Ceci pourrait être considéré comme une observation évidente basée sur la théorie des jeux d'innovation. Cependant, la créativité destructrice, à la lumière du modèle d'innovation de Schumpeter, est supposée causer la dévaluation des compétences fondamentales actuelle de l'industrie et de la formation architecturale d'une nouvelle l'industrie. En réalité, ceci n'était pas clairement perçu dans cette industrie, c'est pourquoi, au premier coup d'œil, les deux théories peuvent sembler contradictoires. Or, un regard conscient et détaillé révèle, tout de suite, que cette théorie d'innovation de Schumpeter est en effet un cas spécifique de la théorie des jeux d'innovation.

L'innovation destructrice est, sans aucun doute, une des causes de l'innovation radicale dans des certaines industries. En ce qui concerne les industries complexes, les compétences technologiques ne sont pas les seules expertises de critique, et ne sont pas, non plus, déterminées pour l'entreprise lors du changement réalisé par les innovations destructrices. La compréhension du jeu d'innovation dans lequel l'entreprise est entrée ainsi que la maîtrise des compétences uniques exigées par ce jeu, sont bel et bien les différentiateurs d'exécution cruciaux (Miller et Olleros 2004) Ces compétences en question ne sont ni affectées ni dévaluées par l'innovation destructrice technologique, ce qui fait que les industries complexes, par conséquent, ne subissent plus les réorganisations ou bien les changements majeurs lorsqu'elles font face à ce type d'imagination destructrice.

## Conclusion

**Les implications théoriques :** les industries complexes ont besoin des théories de la gestion de l'innovation qui tiennent compte de la coopération entre les joueurs.

- Un mode stable d'équilibre de coordination dans une industrie peut être modifié en raison des forces exogènes et endogènes. La configuration résultante est dans le même jeu d'innovation comme l'original.

- L'industrie de simulation de vol et de formation a exposé un changement dans son mode de coordination de l'innovation d'ex-ante basé sur les règlements à l'innovation d'ex-poste basé sur la pédagogie.

- La destruction créative exogène n'est pas probable pour chasser les dirigeants d'industries complexes puisque leurs positions stratégiques ne sont pas seulement soutenues par la direction technologique, mais par plus d'une manière importante sur la compréhension de leurs jeux d'innovation.

- Le moulage actif du jeu d'industrie est ce qui fait la différence entre la survie et la direction en face des vagues de destruction créatives dans les industries de produit complexes.

- Pour qu'une entreprise puisse assumer son rôle d'agent de transformation, en suivant les forces de changement exogènes, il doit en effet maîtriser les meilleures pratiques ainsi que les compétences clés dans son jeu d'innovation.

**Plus de recherche :**

Il y a deux dimensions possibles pour augmenter la recherche résumée au-dessus. Celles-ci sont précédemment synthétisées :

1. Dans la dimension verticale, plus d'une recherche pourraient être accomplies sur les industries complexes similaires afin de confirmer la validité des observations faites dans l'industrie de simulation d'aviation et de formation.

Dans la dimension horizontale, plus d'une recherche pourraient être faites dans l'industrie de simulation d'aviation et formation pour inclure plus d'entreprises ainsi que d'autorités régulatrices. Cela peut révéler d'autres réponses intéressantes au sujet de la transformation du mode de coordination de l'innovation de l'industrie.

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# LIST OF ACRONYMS

| | |
|---|---|
| BOT : | Build-Operate-Transfer |
| CBT : | Computer Based Training |
| COTS : | Commercial Off-The-Shelf |
| CMOT : | Canadian Ministry of Transport |
| EASA : | European Aviation Safety Agency |
| FAA : | Federal Aviation Administration |
| FFS : | Full Flight Simulator |
| FTD : | Flight Training Device |
| IFR : | Instrument Flight Rules |
| IPT : | Integrated Procedures Trainer |
| JAA : | Joint Aviation Administration |
| SBC : | Simulation-Based Courseware |
| VFR: | Visual Flight Rules |
| WBT: | Web Based Training |

# LIST OF APPENDICES

## AVANT PROPOS

The strategic management of innovation is one of the most interesting fields in the new economy where the value of scientific and technological innovation for the survival, performance and competitiveness of firms has been firmly established. This thesis comes as a part of a series of works of literature emerging from the MINE research program lead by Dr. Roger Miller.

The aviation simulation and training industry is one of the 20 industries chosen by the MINE program leaders to study the management of innovation in the new economy. The industry is a global one that has exhibited surprising profitability despite the constant turbulence in its neighbouring airlines industry. One of the industry leaders, CAE, is also one of the prominent firms in Montreal, where the research program is being lead.

# INTRODUCTION

Peter Drucker defines innovation to be "the effort to create purposeful, focused change in an enterprise's economic or social potential" (Drucker 1985). Hirshberg defines it as the main factor on which the growth, stability and ultimate success of a business depend (Hirshberg 1998). Christensen defines it to be a change in one of the processes by which an organization transforms labor, capital, materials and information into products and services of greater value (Christensen, 1997). Regardless of the definition and perspective on innovation, it is undoubtedly associated with risk. In fact, innovation is intrinsically associated with the risk of introducing a novel concept, product or process.

The complexity of innovation is the combined result of the uncertainties involved with the various phases it entails from idea generation, to scientific development, to productizing the scientific advancement and finally to value creation from the resulting product. Each of these phases requires specific skills and competencies from the innovating firm. Acquiring and developing the specific set of required skills to carry an innovation from its preliminary phase to the mature product phase is the principal challenge of innovation management.

In this study, the innovation in complex industries is studied with a special focus on the evolution of its modes of coordination. A typical complex industry, the Aviation Simulation and Training Industry, was chosen for the study. Reviewing previous literature on this particular industry revealed a 'Customized High-tech Craft' industry where regulatory guidelines formed the core of the dynamic innovation process. A stable oligopoly of a few suppliers established an ex-ante system of innovation selection based on the regulatory frameworks rather than the meritocratic market selection force often thought characteristic of capitalist markets.

An array of exogenous industrial and economic factors started to shake the stable equilibrium in the industry. These resulted in a new 'flexibility' survival requirement for the industry incumbents. An opportunity was also opened for surviving firms to change the industry business game capitalizing on its core competencies and dynamic capabilities. One firm did seize that opportunity and introduced a new pedagogy-based standard in the industry. Amid skepticism from competitors and cautious scrutiny from regulators, the firm started an institutional process for promoting the new standard and widening its adoption. The new standard reshapes the coordination mode in the industry and moves it to a new stable dynamic equilibrium configuration.

In Chapter one of this thesis, the particular challenges and complexities encountered by innovators in complex industries are presented. This is followed by a presentation of the various theoretical frameworks available in the literature for studying and analyzing industries and finally a conclusion on the most appropriate framework for analyzing the evolution of innovation coordination modes in complex industries.

In Chapter two, the research hypothesis summarizing the observed shift in coordination modes in the sample industry is stated. This is followed by a listing of the various research questions involved to prove the aforementioned hypothesis. The research methodology and approach are then presented.

Chapter 3 of the document presents an introduction to the industry chosen for the study, namely the Aviation Simulation and Training Industry. An introduction to the objective, organization and dynamics of the industry is presented first followed by a definition for each of its two sub-industries. Next, the key attributes of the industry, based on available literature and this study, are presented. The subsequent section presents the historical emergence of the industry starting from the early attempts to simulate flight till the emergence of the first flight simulator that can be described as the grandfather of the modern day flight simulators. A synopsis of the key evolutionary technological milestones in the industry is presented. A similar synopsis of the organizational milestones is also presented, starting from the initial demand-driven industry coordination till the stable regulation-based meso system of innovation described in the 80's and 90's literature on the industry. The latter is termed *Coordination Mode I.*

In Chapter four, the transformation of the stable equilibrium Coordination Mode I is analyzed by presenting the combination of exogenous and endogenous forces leading to it. The sequence and effects of each of these forces is described and finally the resulting *Coordination Mode II* is described in details.

Chapter five contains the discussion of the results of the above transformation. The chapter starts by answering the question of whether creative destruction is the only way of evolution of innovation coordination modes in capitalist economies. A discussion of the similarities and differences between the initial and final modes of innovation is presented. Then some light is shed on the process of transformation and the strategic action required to convert mere corporate survival in the face of external threats to the controlled assumption of the leadership position in the industry. The following question discussed is whether any firm could have survived the perturbation effects of external forces and leveraged its core competencies to reshape the business game and introduce a new market standard.

The last chapter, Chapter six, presents the conclusions drawn from the above study and the theoretical learning made from it. The potential expansions of this study and further subsequent research opportunities were finally presented.

# CHAPTER 1: THEORETICAL FRAMEWORK

There are numerous difficulties associated with innovation in the corporate world. Many of these, as stated above, are associated with the mere uncertainty of the outcome of innovation. In times when productivity and fierce competition are straining the resources of a firm, investments for innovation may seem too risky to be attractive. A description of the various risks and challenges to innovation in general is not within the scope of this research and can be easily found in the literature on innovation (Stacey 1992; Tidd, Bessnat, and Pavitt 2001).

## 1.1 Innovation in Complex Industries

In complex product industries, such as flight simulation, telecommunication systems, and aircraft manufacturing, challenges facing innovation increase significantly. Some of these challenges are directly related to the complexity of the products while others are related to the often-complex industry architectures that evolve to address the technical challenges imposed by these products along various phases of their life cycles. The most common difficulties with innovation in these industries are:

### 1.1.1 Investments

Complex products require state-of-the-art manufacturing facilities, highly skilled labor and often expensive components and sub-assemblies. Their fixed costs of production tend to be very high given the heavy machinery and automation required in the process. Firms that invest in such products often expect a long Return On Investment (ROI) cycle often ranging between 4 and 10 years. Firms don't only commit capital investments but training and expertise acquisition costs that can be equally significant. The overall result is that firms make significant commitments into the setup and facilities required for operating in a complex product industry.

These commitments make the firms especially careful when evaluating the various alternative investment options and technologies. They also make the incumbent firms more reluctant to adapt to new technologies and innovations due to the high sunken costs in the old ones.

### 1.1.2 Coordination

Baksh *et al* (2003) classified manufacturing companies under the following continuum of production modes:

- MTS (Make-To-Stock)
- MTO (Make-To-Order)
- ATO (Assemble-To-Order)
- ETO (Engineer-To-Order)

ETO and ATO production schemes are usually used for technically complex products which tend to be highly specialized capital goods with specific, technical and precise customer requirements (Baksh and Abdul-Rahim 2003). Despite leading the design effort with the customer, ETO and ATO firms use subcontractors, suppliers and vendors for efficiently acquiring various components of their designs. The resulting architecture is a complex network of firms with various types of interrelationships. Innovating in such an industry cannot be adequately considered on a single firm-basis only. As the entire network of firms produce one final product, changes that any of the firms makes to its contributed components have to be accompanied by corresponding changes in the rest of the components. This imposes an innovation coordination requirement for firms operating in such complex architecture industries.

There is considerable literature covering the inter-firm cooperation modes in such an industry setting. Joint ventures, BOT consortia and partnerships are among the various architectural structures for coordinating firms to collaborate towards one common product goal. These architectures usually exhibit high levels of structural stability (Miller and Olleros 1993). These coordination modes will not be covered in details here, but it is evident that they add to the inertia of the industry and increase the efforts required to make any modifications to its path or configuration.

### 1.1.3 Regulation

Networks of complex product manufacturers often operate under the direct scrutiny of regulatory authorities for ensuring their compliance with minimal acceptable standards

(Baksh and Abdul-Rahim 2003). The high capital investments and the often far-reaching safety and economic effects of such products necessitate some form of government or industry forum intervention in a monitoring position.

Regulators influence both the supply and the demand side of the product by dictating the design specifications of the product. Since the most important requirements for complex products are often the functional aspects rather than the aesthetics (Baksh and Abdul-Rahim 2003), regulators effectively make the top-level product designs for the producers and consumers leaving them the details to define.

This restricted framework of design further challenges the process of innovation and shifts it to the sub-assemblies or embedded-technologies levels only. The high risks associated to the investment costs are further escalated by the risk of innovation rejection by the regulators.

### 1.1.4 Safety

For some of these complex product industries, public safety is a major concern, which increases the strictness of the regulatory guidelines and may even introduce another hindrance to innovation, namely legal liability. For the North American aircraft manufacturing industry for example, compliance with the FAA guidelines are not only essential for airworthiness certification, but also to guard against huge potential lawsuits in case of catastrophic failures. The same applies to the flight simulation industry where negative training of pilots can result in significantly large lawsuits in case it results in an aircraft accident.

As seen above, innovation in complex product industries is faced with many challenges and risks that sometimes result in a stable oligopoly structure where ex-ante selection of innovations is done by all the product stakeholders. In the following chapter, we will sketch and evaluate the various theoretical frameworks available for understanding the innovation coordination process in complex product industries.

## 1.2 Industrial Analysis Techniques

The dominant modeling techniques of industrial organization and coordination tend to revolve around a few breakthrough concepts in industrial economics, strategic management and industrial dynamics. Many industrial analyses are made by applying these models to the studied industries and using the resulting patterns to explain individual firm strategies or industry behavior. Some of these models are:

### 1.2.1 Schumpeterian Innovation

Innovation, as described by J.A. Schumpeter, is characterized by two main features:

- Consecutive waves of destructive innovation hit industries and cause drastic changes in their required core competencies (Schumpeter 1934). These waves are intermitted by product life cycles where the product matures to a dominant design paradigm, followed by a phase of accelerated process improvement (Teece 1987). The Schumpeterian reorganizations usually result in the entry of many new entrants and exit of old incumbents whose core competencies served as core rigidities (Leonard-Barton 1992);

- Innovation coordination is based on the meritocratic selection force of the market on innovative products supplied by the industry.

Both characteristics mentioned above converge to a "hands off" approach, of letting firms embark on a variety of innovative projects before exposing them to the selective forces of the market. Figure 1.1 summarizes the inter-relationship of these two phenomena: meritocratic selection and destructive creativity. This model may be valid for low cost consumer goods but not the highly coordinated complex products industries. In these ETO industries, the market selective forces of the innovation are often at play before the project contract is awarded, namely at the technical Request For Proposal (RFP) phase. Customers of such products are well informed and highly technical in their approach and they are often aware of the available technology and the required innovation to be done by their selected equipment supplier (Baksh and Abdul-Rahim 2003). For such a complicated industrial organization, Schumpeter's underlying assumption of producer-driven innovation fails to hold, rendering his framework inadequate to model and predict the modes of coordination of innovation in complex product industries.

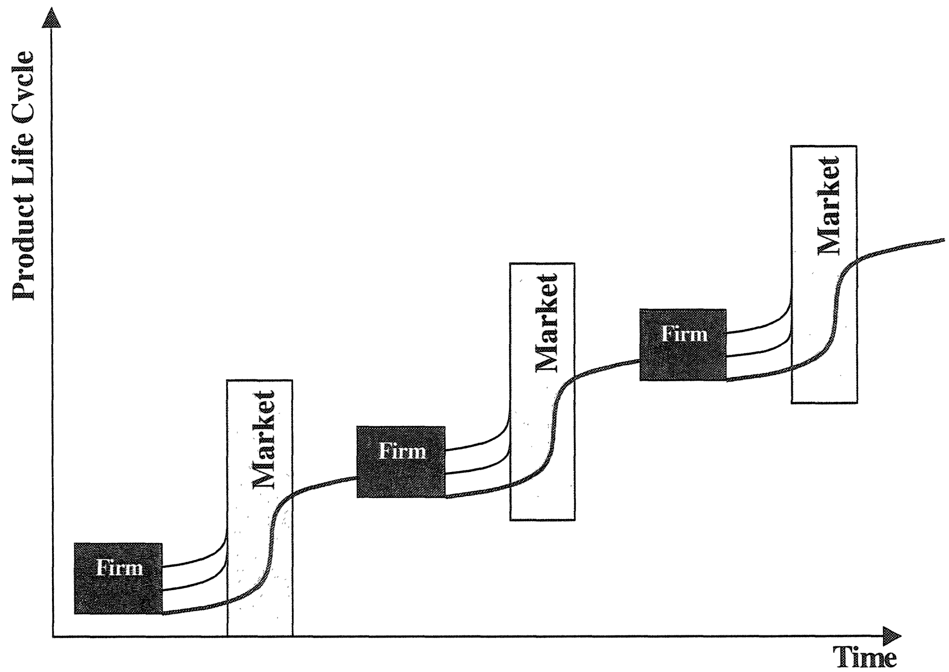


**Figure 1.1: Schumpeterian Mode of Capitalist Innovation**

### 1.2.2 Porter's Industry Model

In Porter's industry model, a firm's competitive strategy is the essence of its relationship with its environment (Porter 1985). This relationship can be described in terms of the firm's rivals, competing with the firm for market share and profits, at the core of the firm's focus circle. The firms' suppliers, buyers, potential entrants and substitutes compose the rest of the firm's relationships network, lying at the periphery of the firm's industry. 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 1985).

Figure 1.2 illustrates Porter's *five-force* view of the industry from the competitive advantage perspective.

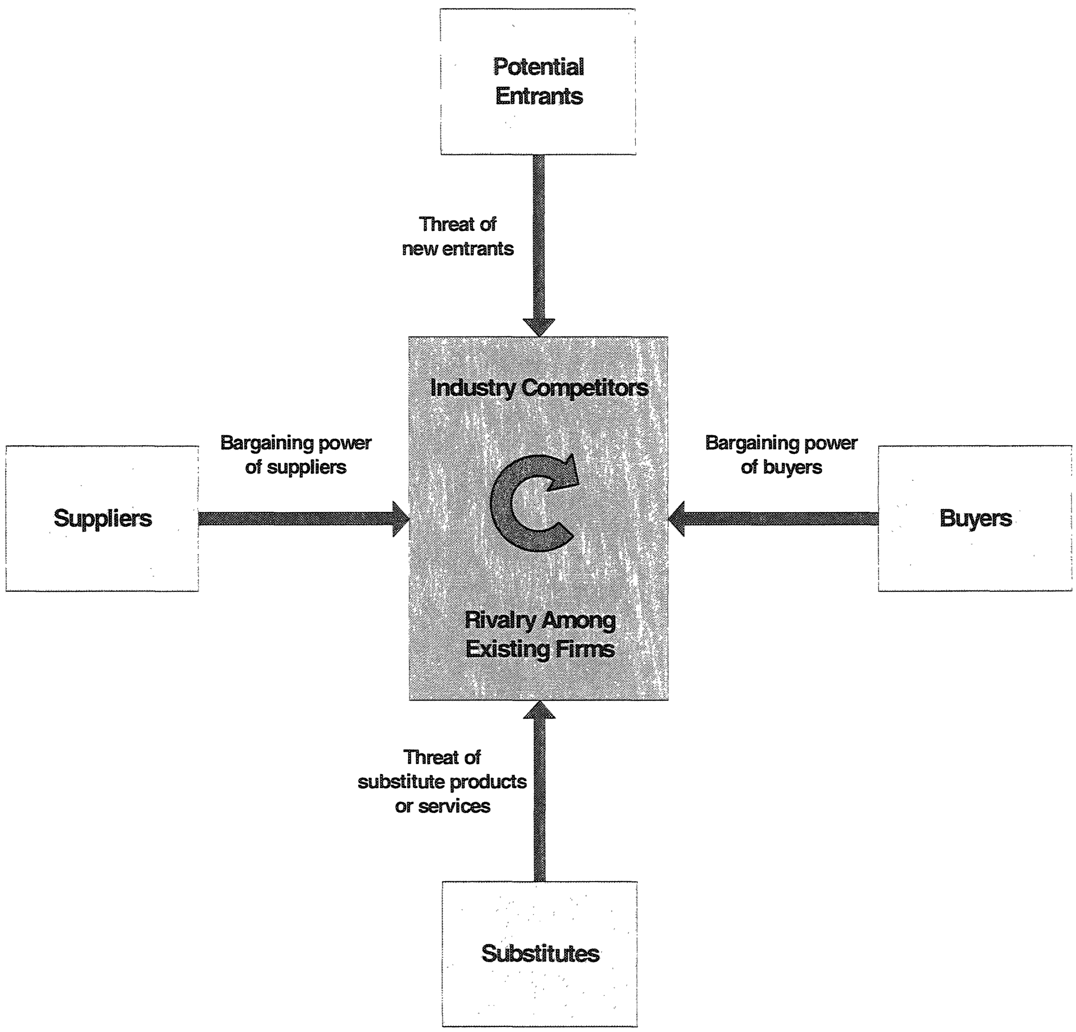


**Figure 1.2: Porter's five-force Industry Modeling**

Porter's five-force model was and continues to be a classical tool for strategic analysis. The model's unit of analysis however is the entire entity producing a specific product. It therefore treats a complex network industry as a single vertically integrated firm and proceeds to analyze its interactions with the various entities surrounding it. This black box treatment of the industry does not give sufficient insight into its organizational structure or its mode of innovation coordination. Porter's model does not accommodate for the partner and sub-contracting firms whose relationship with the integrator firm are more complex than a supplier-buyer relationship (Porter 1980).

A Porter supplier provides sub-assemblies or product components based on design specifications provided by the design firm. The supplier is not assumed to be innovating simultaneously with the buyer or at least not in any way that can affect the latter. A classical example would be a furniture manufacturer buying screws from a supplier firm. Any innovations upstream at the supplier side may be process-related or for producing new products for new markets. This will be transparent to the furniture manufacturer though. For complex product industries, however, the inter-relatedness of design between the various customized components result in the need for concurrent innovation by various players to achieve the final product innovation. These complex relationships are transparent to Porter's analysis framework as they are all considered to be within the unit of analysis.

### 1.2.3 The Co-opetition Model

In Nalebuff's co-opetition model, understanding the industry is done using the *Value Net* concept (Brandenburger and Nalebuff 1995). The value net representation of the industry relationships is more than a new nomenclature for the same interaction model. It provides a broader view of the industry and its coexisting competition and cooperation relationships forming its Game (Neuman and Morgenstrom 1944). The value net framework complements Porter's competition-based view of the firm with the cooperation dimension. Both dimensions provide the principal forces that affect a firm's performance and strategic positioning.

The Value Net framework also introduces the added dimension of informality in the inter-firm relationships. While Porter's analysis focuses on the contractual relationships between the firm and its external environment, the Value Net takes into account the non-contractual implicit cooperation between firms for value creation. The latter model is therefore more appropriate for platform-like industries where cooperation between competing players is instrumental for the overall platform innovation.

For complex industries, Porter's model, which does not account for complex non-competition informal linkages, becomes too simplistic to understand the industry coordination. The co-opetition model, on the other hand, provides adequate provisions for considering the opportunities and threats resulting from the firm's partnership arrangements and technological platform interdependencies. A graphical illustration of a value net is shown in Figure 1.3.

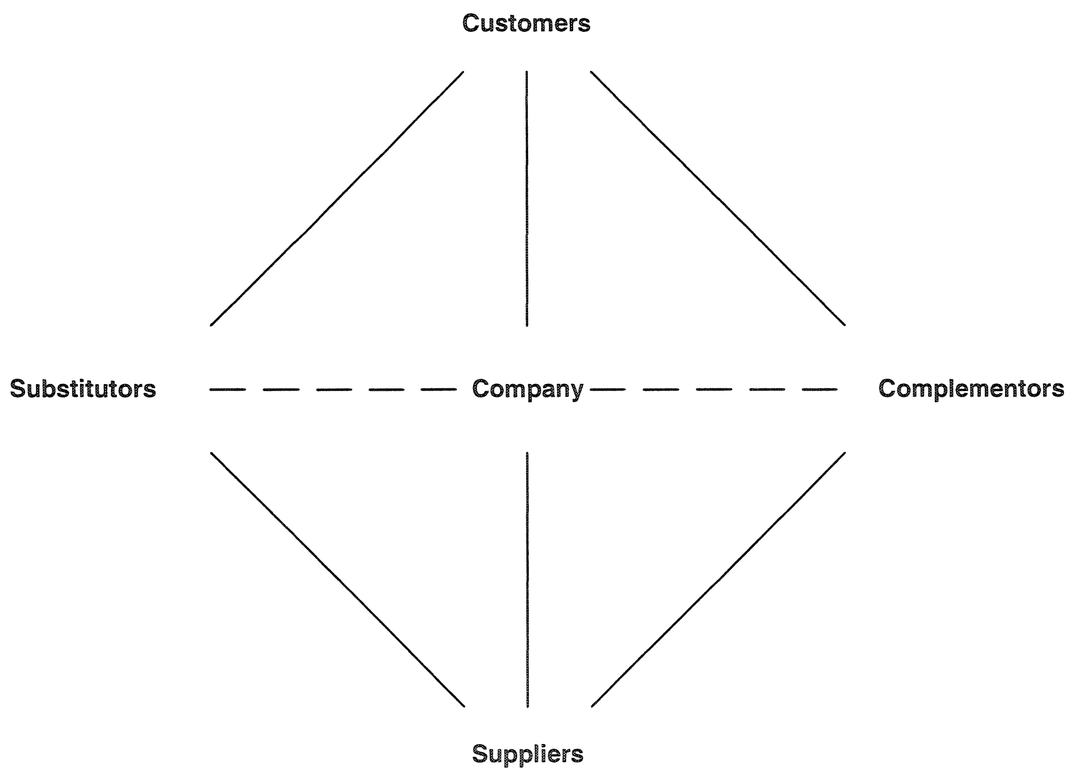


**Figure 1.3: Nalebuff's Value Net**

While value nets make provisions for other relationships than competitors, namely complementary products, they still lack the necessary levers for capturing the entirety of all the factors shaping the evolution of complex industries. The value nets model focuses mostly on complex relationships with competitors and complementors while those with suppliers, customers and regulators are not clearly accounted for. This renders the model insufficiently detailed for complex industries where the latter three types of relationships have a special importance in the value creation and capturing processes.

### 1.2.4 Games of Innovation

In a study aimed at identifying the effective R&D strategies to manage for growth and the best practices for maximized value-capturing from innovation, Miller *et al* (2004) found that firms develop the necessary best practices depending on the nature and environment of their respective industries (Miller and Floricel 2004). Attempting to group these various environments into logical sets resulted in eight *games of innovation* that influence the performance and best practices definition of their players. Firms in each of these games share similar activities in each of the following four vectors: (1) processes for productizing knowledge, (2) mechanisms to interact with clients, (3) processes to align and stabilize design architectures and (4) engineering processes to ensure cost reduction, safety and reliability (Miller and Floricel 2004). The pace of scientific change and market dynamism in each of the games was the criterion of classifying them into slow and fast games.

A quick synopsis of the eight games of innovation identified is as follows:

***Fast Games***

1. *Battles for Architecture*: value creation is done by aligning solutions and modular components to emerging architectures and therefore reducing uncertainty for clients. This game is common in industries with fast technological change, low degrees of regulation, and a combination of individual laymen and expert corporate clients. An example is the software industry.
2. *Races to the Patent and Regulatory Offices:* value creation is based on productizing academic research and managing the consequent regulatory approval process. This game is common in industries where scientific change is high-paced and heavy regulations are in place for protection of public interest and intellectual property rights. An example is the pharmaceutical industry.
3. *Delivering Safe, Science-Based Products:* value creation is based on productizing academic research and delivering it effectively, reliably and safely. This game is common in industries with moderate scientific and technological opportunities, heavy

regulatory frameworks and high risk from public interest groups and regulators. An example is vaccines industry.

4. *Systems Consulting Services:* value creation is based on offering systemic architectures, based on dominant standards, and offering their integration with the necessary tools and procedures. This game is common in industries with a moderate pace of technological change, expert clients and little or no regulation. Example industries are engineering consulting and project management consulting.
5. *Research, Development and Engineering Services:* value creation is based on transforming learning from customers as well as academics into products and services. This game is common in industries with very fast technological changes, short product life cycles and a few large expert customers. An example is firmware software tool builders.

***Slow Games***

6. *Delivering Workable Solutions in Packs:* value creation is based on investments in intellectual property management and cooperation between customers and partners for delivering large-scale and problem free solutions to industrial customers. This game is common in industries with slow scientific and technological change and lack of regulation. An example is firms that build multi-organization customized industrial solutions.
7. *Asset-Specific Problem Solving:* value creation is based on finding ways to use existing technological assets and knowledge more efficiently. This game is common in industries with a high capital intensity but slow scientific pace. An example is firms specialized in R&D work for traditional industries such as mining and petrochemicals.
8. *Customized High-Tech Craft:* value creation is done through:
    i. Understanding the needs of expert clients
    ii. Delivering customized solutions yet aligning them with clients existing technologies.
    iii. Increasing the reliability of systems and reducing costs

    This game is common in industries with a relatively slow pace of technological change, high product complexity, expert customers and high regulations. Synchronization of inter-dependent moves of various players is the basis of innovation. An example is the flight simulation industry.

The emerging concept of *Innovation Games* provides a sufficiently detailed framework for analyzing and understanding innovation generation in a wide range of industry types. Despite variations in firms' performance within each game, a generic and a specialized set of competencies were found to be common to almost all the players within a game.

For analyzing complex industries, with the challenges described above, multiple player coordination and synchronization can be conveniently accounted for in the innovation games approach to understanding industry dynamics. In fact, a significant portion of complex industries falls within the *Customized High-Tech Craft* game.

### 1.3 The Industry in this Research

This study was done, using the aviation simulation and training industry, as a typical regulated and technologically complex industry. Innovation is this industry falls within the *Customized High-Tech Craft* game of innovation. Unique features and attributes of this industry will be presented throughout the text. However, most of the observations made and the conclusions drawn are, unless otherwise mentioned, applicable to most (if not all) industries exhibiting the two main traits identified earlier: *regulation* and *technological complexity*. These observations and conclusions may therefore be cautiously extrapolated to other similar industries such as telecommunications and aerospace (Tidd and Hull 2003).

# CHAPTER 2: RESEARCH HYPOTHESIS & METHODS

## 2.1 Research Hypothesis

In 1993, Miller and Olleros reported the findings of their studies on the flight simulation industry as an exemplary high-technology craft industry. Their research interest was aroused by the observation that this industry was consistently improving in efficiency performance over the years. The global oligopolies of this industry were studied as well as their coordination with the other players in the industry. The required dynamic capabilities and core competencies of the industry were also studied for understanding the dimensions and pre-requisites of high performance in it. The resulting industry sketch depicted it as an internally coherent system of innovation that implements a meso-system for *ex-ante* targeting and development of innovations within the prescribed regulatory frameworks.

A decade later, the same industry was observed to exhibit signs of evolution from the first identified innovation coordination mode. This observation has lead to this research, aiming at investigating these changes, finding the forces behind them and finally making a similar sketch of the resulting final coordination mode.

Based on the above-mentioned observations, this research started with the hypothesis that indeed the industry did evolve out of the internally-coherent system of innovation (henceforth referred to as *Coordination Mode I*) and that the evolution was lead by a hybrid of forces and factors. The main vector of change in the industry is an evolution of the mode of industrial coordination from a regulation-centered training products mode to a pedagogy-centered training services one. The change was lead by a combination of rationalist and incrementalist innovation strategies of key players in the industry as well as exogenous economic changes in other industries and in the global economy. A new mode of innovation coordination is crystallizing and starting to stabilize in the industry (henceforth referred to as *Coordination Mode II*). The mode of coordination in this complex industry has migrated away from the regulator-centered ex-ante innovation towards a pedagogy-centered supplier-user partnership lead mode.

## 2.2 Research Questions

In an attempt to systemize the proof of the above hypothesis included in this document, the research will attempt to answer the following questions:

- What is the aviation simulation and training industry?
- How did the industry emerge from its early start phase until it reached Coordination Mode I?
- What was Coordination Mode I?
- What were the factors and forces behind the evolution of the industry from Coordination Mode I to Coordination Mode II?
- What is Coordination Mode II?

The answers to these questions are presented in a similar order in the chapters and sections that follow.

## 2.3 Research Methodology

The research presented in this paper is a part of the MINE (Management of Innovation in the New Economy) research program[1].

The research team followed a grounded research approach to understand the games of innovation of the industry and their evolution in response to endogenous and exogenous factors. The study was initiated by a literature review comprising the following areas:

[1] MINE is an international research program studying the games of innovation and their evolution in more than 20 industries worldwide. The program is lead by the Jarislowsky Chair of Innovation and Competitiveness at the École Polytechnique de Montreal and incorporates academics and students from Canada, the USA, Italy, France, Brazil and the UK. The research proposal of the MINE program is attached in Appendix D.

- Industrial Economics
- Game Theory
- Games of Innovation
- Platform Leadership
- Strategic Management of Innovation
- Services Industry
- Product Development Strategy
- Aviation Simulation & Training Industry

The research progress was sequenced to gradually explore answers to the questions listed above. First, to define the industry, a value chain encompassing all of its key players was constructed. Then the historical evolution and key milestones of the industry were studied using industry intelligence sources as well as annual and financial reports of the key players. Literature was again used for understanding the structure and dynamics of *Coordination Mode I* and how it was reached from the previous mode of coordination. Field research was then started for understanding the factors behind the observed transformation. The research also collected data about the new industry coordination scheme (*Coordination Mode II*), the participant firms' perception of it and their strategies to reposition themselves with respect to it. The transformation process was explained as a sequence of factors that played together, some rather deliberately orchestrated, to achieve a new industry coordination scheme. In the analysis of the transformation, the firm that has lead this strategic shift was also thoroughly analyzed to highlight its dynamic capabilities that were necessary for fulfilling this industrial strategic leadership role. Finally, the new mode of coordination was described and a new industrial model created.

The detailed description of each of the steps highlighted above is as follows:

1. A linear value chain linking the various groups of firms in the industry was constructed. This chain showed the major players in each of the nodes of the value chain as well as their interactions. Figure 2.1 shows this value chain:

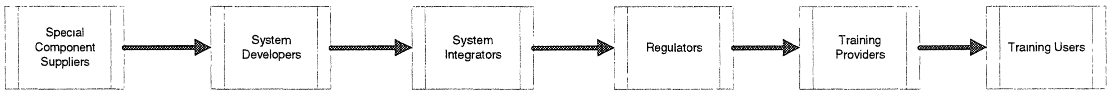


**Figure 2.1: Linear Value Chain of the Aviation Simulation & Training Industry**

2. A database was constructed with a record for each of the firms in the industry containing its pertinent strategic information, product scope and historical events that impacted its strategic position. This database was populated through the following means:
    a. Public-domain information about the companies (from sources such as their web sites and annual reports);
    b. Industry intelligence sources;
    c. Interviews and teleconferences with senior management of the firm.

3. Information from the database about each firm, its strategic role in the innovation coordination scheme of the industry, and its recent strategic repositioning in response to the industry changes, were analyzed.
4. A new model of the industrial organization of innovation was constructed for the aviation simulation and training industry.

Following the literature review, the data collection tool was defined and constructed. This consisted of a questionnaire (attached in Appendix C) to be used during interviews of senior management and innovation executives of the key influential firms and institutions in the aviation simulation and training industry. These institutions were either leading firms, regulation authorities or key customers that influence the innovation demand. The institutions chosen were:

**FIRMS**

1. CAE Inc:

CAE has been the global leader in the Full Flight Simulators market and one of the earliest entrants into it. The company offers a comprehensive suite of all flight crew training-devices and services.

2. WICAT Inc.:

WICAT is a major supplier of low cost FTDs which played, as will be demonstrated later, an important role in challenging the efficiency of the training technologies and methodologies common during *Coordination Mode I* and hence giving birth to the service-oriented industry transformation.

3. NLX Corporation:

NLX is a major supplier of low cost FTDs that later entered the FFS market and recently was purchased by an upstream aircraft components supplier, thus forming an interesting new link in the industry's value net.

4. Thales Training & Simulation Inc.:

TT&S is the second major player in the FFS market and the dominant in certain European and Middle-East markets. TT&S provides a products suite that is almost as comprehensive as that of CAE.

**REGULATION AUTHORITIES**

5. FAA:

The Federal Aviation Administration is the aviation authority of the USA and the leading aviation authority around the world. The strategic importance of the USA in the historical evolution of the aviation industry has given the FAA a leading role in defining many of the simulation and training standards and norms.

6. CMOT:

The Canadian Ministry Of Transport is the leading aviation regulation authority in Canada, where this research was based. The CMOT training and simulation standards are very similar to their neighboring FAA.

7. JAA:

The Joint Aviation Administration is the dominant aviation authority of the European Union. Based in the Netherlands, the JAA is closer to an industry forum that provides a link between the various European aviation authorities. The JAA is gradually transforming into the EASA

(European Aviation Safety Agency), which is a joint authority with an area of jurisdiction covering the member countries of the EU.

8. ICAO:

The International Civil Aviation Organization is a key industry forum that has had a significant role in the definition of the civil aviation norms and standard practices. ICAO still plays a significant role in providing information exchange and best-practices establishment for its international airline members.

**KEY CUSTOMERS**

9. Southwest Airlines:

Southwest Airlines is a key customer in the new aviation era. Founded in the late 70's with a revolutionary business model, Southwest Airlines has demonstrated a remarkable capability to remain profitable despite numerous industrial and economical adversities.

10. Air Canada Jazz:

AC Jazz is another key customer in the new era as it budded out of an international airline, only to turn to be more profitable than its parent airline and compete with it for business. Its low cost business model is one that is becoming increasingly popular in regional airlines, especially in North America.

# CHAPTER 3: THE AVIATION SIMULATION & TRAINING INDUSTRY

## 3.1 Flight Simulation & Training

A flight simulator is a replica of an airplane made for training flight crews and ground crews, engineering development of aircraft components or safety and flight standards research. Flight simulators vary in their fidelity level of replicating the aircraft cockpit look, feel and performance. Simulators vary from PC-based aircraft systems CBT to full flight simulators (FFS) that are equivalent in training value to flying the real aircraft.

Simulators added value for their customers are partly inherent in the quality of the flight training they provide but mostly acquired through the qualification of the local regulators of the equipment to provide training for a certain set of skills. The qualification guidelines, which are specific to each regulatory authority, define the simulation equipment market by prescribing certain levels of FTDs (flight training devices). The American FAA (Federal Aviation Administration) and the European JAA (Joint Aviation Administration) define the two main schools of qualification standards that are usually copied by local authorities in neighboring countries. The FAA regulations prescribe seven levels of FTDs as well as the FFS. The JAA regulations prescribe two levels of FTDs, which do not necessarily match their FAA counterparts, as well as two levels of FNPTs (Flight Navigation Procedures Trainers) as well as the FFS. Detailed descriptions of these simulators levels are not within the scope of this document and are available on the respective regulator's web site.

Simulators are used within training curriculums, approved by the regulatory authorities, for initial, transition and recurring training of aircraft crews. Initial training is required for qualifying pilots to fly certain categories of airplanes, such as twin engine or multiple-crew crafts. Transition training is required for type-rating pilots flying one type of aircraft for another. For example training Dash 8 pilots to fly CRJ-200 aircraft is considered transition training. Recurring training is the regulatory requirement of annually administering training courses to line pilots to refresh their theoretical knowledge of the aircraft and operational knowledge of the company's operational procedures and standards.

### 3.2 Definition of the Industry

To introduce the strategic development in an industry, one has to start by clearly defining the industry itself. The *Aviation Simulation & Training* industry is composed of two distinct, yet interrelated, industries, the *Flight Simulation Equipment* industry and the *Aviation Training Services* industry. A clear understanding of their boundaries and interrelationships will facilitate the understanding of the strategic innovation game shift described in this document. Consequent to their definitions below, both industries will be collectively described in this document as the *Aviation Training* industry, except where differences in their characteristics or performance are worth noting.

#### 3.2.1 The Aviation Training Equipment Industry

This industry provides simulation products and training equipment that replicate aircraft performance and behavioral characteristics for the purpose of training aviation pilots and maintenance engineers to operate, and maintain aircraft systems and controllers. Suppliers of this industry can be classified into system developers, system integrators and specialized sub-system suppliers.

**System developers** are the firms that internally develop the majority of the complex full flight simulators as well as lower end FTDs. These typically develop aircraft data-based simulation models, software libraries, motion systems, flight deck panels and sometimes the visual system as well. The number of system developers has been fairly stable throughout the history of the industry due to the high barriers of entry and exit associated to their business. These firms are mainly characterized by:

- Significant research and development expenditures;
- High technological expertise in designing simulator components and integrating them;
- High organizational learning capabilities that enable constant improvement in production quality and efficiency.;
- Presence, but not necessarily dominance, in all simulator levels markets.

**System integrators** are firms that integrate existing off-the-shelf technology with rudimentary reverse-engineered simulation models. The number of integrators have fluctuated significantly over years and with introduction of new technologies and innovations. They are mostly characterized by:

- They often rely on technological advances in their supplier industries for quality and efficiency improvements, and are therefore characterized by low R&D expenditures.

- Presence in only lower end simulation equipment and FTDs markets, although in the last decade several instances were observed when they made aggressive moves to enter the full flight simulator market using their technology integration approach. These moves were facilitated by the relative standardization of the simulator components and the increase in the number of specialized sub-system component providers.

**Sub-system suppliers** are typically smaller firms that operate either in the industry itself or in other industries upstream of the simulation equipment industry. These make components such as computing equipment, hydraulic jacks, mechanical and electrical components and visual projectors. Some of these components are built specifically to the simulation equipment industry while others are off-the-shelf technologies. These firms vary significantly in their origin industries, size and product complexity and are therefore difficult to characterize.

### 3.2.2 The Aviation Training Service Industry

This industry is the downstream user of the flight simulation equipment industry and provides the service of training pilots and maintenance technicians. Products of this industry take either one of two distribution channels: dry leasing and wet leasing. Dry leasing is the leasing of the training equipment, the facilities hosting them and the technical support required for the maintenance of the equipment. This form of entrepreneurial exploitation of the simulation equipment is the most common in the independent training centers providing simulation equipment for commercial aircraft.

Wet leasing is the second type of delivery of the training service and it consists of delivering the training personnel, curricula as well as the equipment. This form of product delivery is common in the business and executive jets training markets where the customers are often independent jet owners or private pilots whose use of the equipment does not justify their investment in the development of their own curricula or the hiring of their own instructors. Wet leasing is also becoming increasingly popular in the new millennium due to the severe financial constraints of many airlines around the world, rendering the outsourcing option to training specialists more attractive than before.

### 3.3 Industry Organization and Key Attributes

The aviation training industry is on the supplier side of the aircraft operators or airlines industry. Training and certification of air and ground crews are operational regulatory requirements for all airlines to maintain their flying permits. Figure 3.1 shows a top-level organizational structure of the aviation sector.

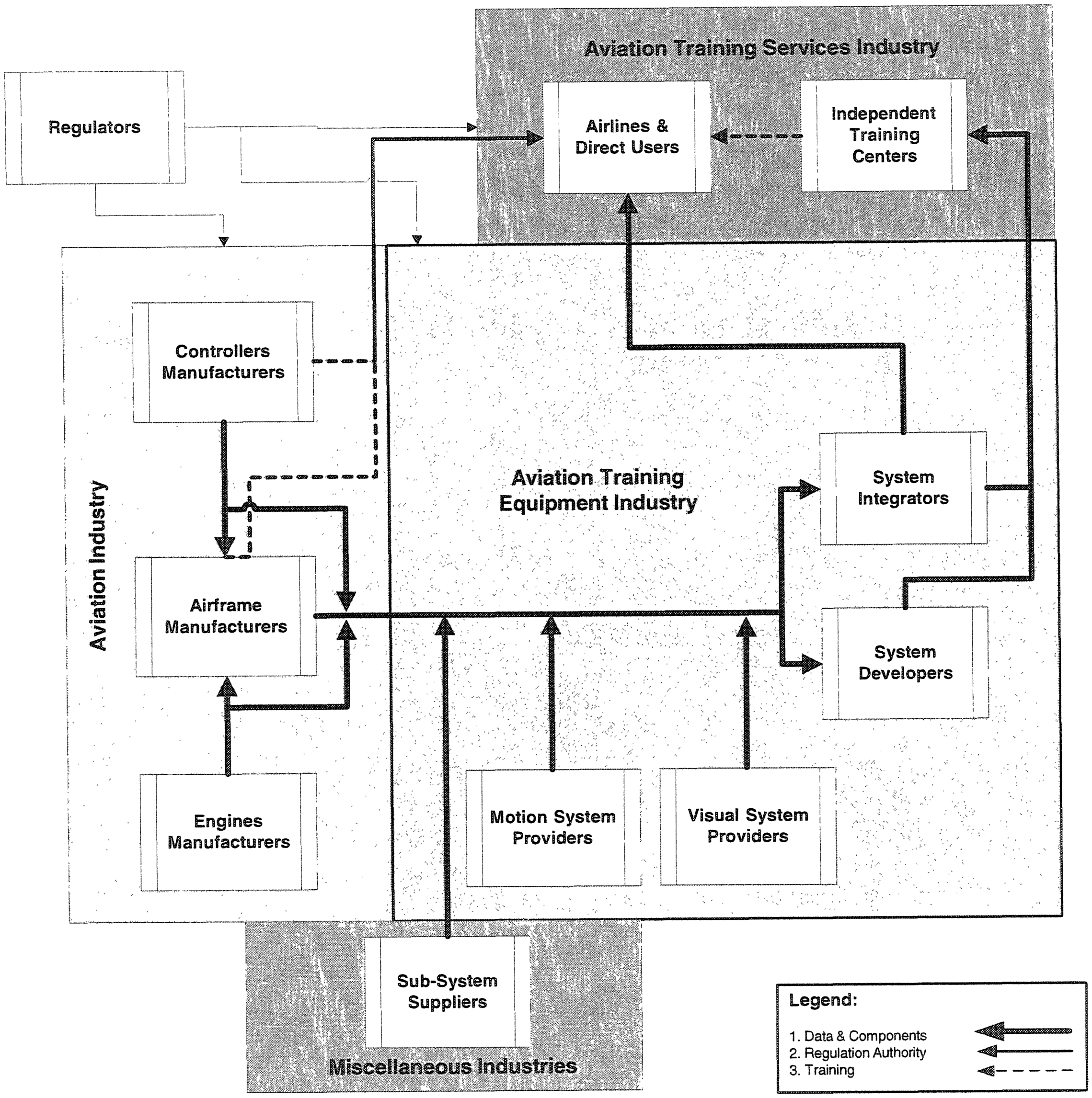


**Figure 3.1: Organizational design of the aviation sector with its various industries**

This industry has certain unique features that have to be considered when attempting to understand its organizational design:

1. Safety of aviation was the key factor that gave birth to this industry and continues to be the driving factor at the core of its existence. This puts

significant emphasis on the quality of the products of the industry and gives very little tolerance of errors or failures.

2. Customers of this industry are the well-informed and highly specialized operations and management teams of aircraft operators. This results in their direct involvement in the design of products made by their suppliers. This is also accentuated by the hefty investments customers have to make for acquiring their training products (whether these are manufactured devices or training services).

3. Training simulation devices and curricula have an intrinsic necessity of being customized as per the customer's aircraft fleet and training requirements. This radically changes the definition of a "dominant design paradigm" from Abernathy's mass-produced design model.

4. The final product of the industry is a legal requirement for the airlines to remain in business and is therefore considered an overhead cost of operation. This puts significant price reduction forces on the suppliers and therefore shifts their innovation focus to cost reduction process innovation rather than quality enhancement.

5. Due to the aforementioned high cost, safety and regulatory shifts, reputation is an indispensable asset of a supplier firm in this industry. This imposes a high barrier to entry but also generates a positive feedback loop for incumbent players as their reputations and proven-track records improve over time. Earlier studies in this industry have revealed that few entrants were able to penetrate the high entry barriers since the establishment of the industry in the 60's.

6. The products used for pilot and maintenance personnel training are quite complex technologically due to the synthetic aircraft simulations they

entail. This adds an accumulated engineering and technical know-how requirement for players to compete successfully in this industry.

7. The limited number of key players in the industry on the global level makes connections with regulators, presence in industry forums and participation in industry standards almost essential for firm survival in this industry.

8. Continued operation in the industry generates another positive feedback loop through building a library of simulation models that significantly cuts the development costs and schedules of simulation equipment for new customers. While simulation products are usually highly customized for the customer's particular aircraft configuration, the standard features across the different tails of the same aircraft constitute the majority of the simulation effort required. One key player in the industry for example, boasts that it has almost every single tail configuration of the Boeing 737-NG aircraft, an airplane that is highly customizable by its buyers.

An interesting feature of the aviation training industry is its economic performance-independence from the airlines industry despite its value chain proximity to it. Even at times when the airlines industry experienced architectural reorganizations and destructive innovation waves, the training industry seemed to adapt rapidly, showing persistent profitability and sustained innovation.

## 3.4 Historical Emergence of the Industry

### 3.4.1 Early Attempts

The history of flight simulation is almost as old as the history of flight itself. Since the Wright brothers made their historic flight in 1903 and flight started to be the promising fulfillment of every child's dream, the process of learning to fly was becoming of increasing importance. Simulation of the flight experience was always considered the optimum approach to teaching students to control their flying machines. Maximizing training time outside of an airborne plane was the aim of the rapidly emerging simulation techniques.

One of the widely used early simulation techniques was referred to as the "*Penguin System*". This learning approach used the aircraft itself as the flight simulation tool. The flight student was allowed to site behind the controls of a reduced wingspan aircraft and was towed on the ground, while moving the aerodynamic controls of the aircraft. This introduced the student to the feel of the controls and partially replicated his flight manoeuvres to be conducted in the air. This system was used in the French Ecole de Combat during the World War I.

Another similar system was the *Sanders Teacher* (Figure A.1), which consisted of a full aircraft cockpit mounted on a universal joint and placed in the direction of the prevailing wind. This allowed the flight student to move the aircraft controls and feel the resulting forces on the aircraft. Another version of the Sanders Teacher included a bar that the student had to align with the horizon and hence learned to maintain a stable aircraft attitude[2]. A picture of this trainer is provided in Appendix A, Figure 1. These early attempts were precursors to the new aviation simulation and training industry soon to emerge when Edwin Link introduces his revolutionary flight simulator.

### 3.4.2 Link's Simulator

In 1920, 16-year old Edwin Link took his first flying lesson to achieve his childhood passion, flying. Not allowed to touch the aircraft controls during his lessons, he got frustrated with the lack of hands-on training opportunities in the field and abandoned the flying lessons to work with his father in his piano factory. In 1927, a group of barnstormers taught Edwin how to fly and he got his pilot license in the same year. In the same year, he also acquired the first Cessna aircraft built and started investigating ways of making a living using his newly acquired expertise and equipment. Constantly concerned about the costs and convenience of flight training, Edwin Link started a design

[2] Aircraft attitude is a term commonly used in the aviation industry and it refers to the position, configuration and motion vector of the aircraft in question. A 'banking attitude' for example would mean that the aircraft is tilted along its longitudinal axis and is moving in that position.

project of an aircraft cockpit replica for training pilots. He later called his machine the "Pilot Maker" and launched it in 1929, out of his father's factory basement, as the first synthetic flight training device (Figure A.2).

As in the case of most new technologies, the aviation industry did not comprehend the implications of the new training tool and hence did not show any interest in acquiring it. Training for the airlines industry was, and continues to be, an overhead cost of operation and hence convincing airlines management to invest in new technologies of training is an uphill battle. Perhaps another reason for the failure to see Link's achievement was the commonality of VFR[3] flying which relies on the pilot's understanding of the flight dynamics vs. IFR[4] flying which also relies on the pilot's understanding of the aircraft navigational instruments. Flights were few and far between and risky enough that adverse weather conditions were considered a sufficient reason for flight cancellation. In the absence of any replication of the out-of-window environment in Link's technology, the added value of simulating the flight instruments was not clear to the potential end users. The commercial value of Link's new technology was not high in light of the prevailing flying techniques. Amusement Parks were the principal customers of the newly formed *Link Aeronautical Corporation*.

In an attempt to demonstrate the added value of his new invention, Link opened *Link Flying School* where the curriculum was heavily based on the new simulation technology that he developed. The market timing of the new technology-based service was not in its favor as it coincided with the great depression of 1930.

In 1934, the US Air Force was mandated to deliver the mail by Air around the US. The military pilots were not trained to fly in the dark and in adverse weather conditions. Unlike the commercial flights, still considered as a luxury at that time, mail delivery was a more pressing need that reshaped the demand on the flying industry. New techniques had to be devised to minimize the risk of night and adverse-weather flying, especially

[3] VFR = Visual Flight Rules: flying using the pilot's visual cues to locate his aircraft in space and identify his aircraft's attitude and relative positions from nearby terrain.
[4] IFR = Instrument Flight Rules: flying using the aircraft navigational instruments and displays for identifying the aircraft location in space and its proximity to nearby terrain.

after 5 pilots and their planes were lost in the first few days of the new mail-delivery service. Openness to the new notion of instrument-dependent flying was increasing and hence Link's invented technology was now seen as a value-adding tool. Link was invited by the Air Force to Newark airport to demonstrate his new technology. Flying in, Link's approach of instrument flying proved its success by his own safe and smooth flight despite the stormy weather. This started the demonstration on the right foot and Link received an order of six pilot trainers for the US Air Force.

The launch order of Link's training devices was timely with the increasing importance of the flying industry and the increasing dependence on its timely and consistent performance. This opened new markets for his new concept of instrument flying and new instrument flight training equipment to the extent that throughout the following five years, *Link Aviation Devices Inc.* sells flight simulators to more than 35 countries around the world.

The Second World War was a major reason of booming the simulation equipment aviation training industries, as it was for many other industries. Link Aviation grew significantly to employ 1500 people, producing more than 80 simulators per year.

The period between 1934 and 1945 was the time of technology transfer from the applied research stage of Edwin Link (Rodgers 1996) to a commercially profitable product. Using Abernathy's transilience map (Abernathy and Clark 1985), Link's innovation resulted in an architectural innovation as his product gave birth to a new industry that soon developed a stable architecture and grew to be an $800 Million industry over the following 5 decades.

### 3.5 Technological Innovation Milestones of the Industry

Cutting-edge technological innovation continued to shape the future of the flight simulation equipment industry. Regularly sustained research and development efforts in the industry continued to improve the modeling techniques and simulation fidelity on various levels and hence increasing the training value derived from the simulators. Some of these innovations can be considered revolutionary, though, in the sense that they provided radically different solutions to certain limitations and hence replaced the old approaches along with their technologies and core competencies.

### 3.5.1 The Image Generator

Link's pilot trainer focused on the instrument portion of airmanship training leaving a huge room for improvement in the replication of the other cockpit environment parameters. With a flight deck suite of navigation and avionic systems similar to the aircraft, pilots can reproduce a significant portion of their flight procedures, systems familiarity training and aircraft maneuvering techniques. The pedagogic value of the skills learnt in the simulator would be quite limited though because in the students' minds, these skills would be associated with the simulator and not with the aircraft. The transfer of the learnt skills to the aircraft environment would not be easy given the drastic differences between the aircraft cockpit environment and that of the simulator. This is particularly true in skills pertaining to emergency response mechanisms where the pilot is expected to perform a sequence of steps without much thinking or rationalization but rather in a rather mechanical way. The above shows how the evolution of the need for more high fidelity replication of the cockpit ambient environment and not just the systems physical performance characteristics.

Given that approximately 85% of the data that the brain analyses is visual, one of the most important of these ambient environment cues is the "out-of-window" environment or what the pilots see through their cockpit windshield. This created the need for a system that visually replicates the terrain, surrounding weather conditions and common obstructions like buildings or other aircraft.

The first dominant design of flight simulator visual systems appeared in the 1950s and used an ingenious idea of running a video camera over a 3-D scale model of a generic airport terminal, runways, taxiways and common terrains that the aircraft flies over. The video camera was mounted on a moving arm that received its motion signals from a computer that interpreted the cockpit controls. The image was transmitted via a closed-circuit television system to monochrome screens in the simulator. The coordination between the pilots movements inside the cockpit and the resulting changes in the broadcasted scenes increased the pilots' learning value from the simulator and deepened their understanding of the aircraft response to their cockpit actions. The first color visual system was produced by Redifon (a subsidiary of Rediffusion, a flight simulation company in the UK) in 1962.

With the digital computer revolution, the technology of dynamic image generators started to appear with 2-D terrain images only. The technology is based on transforming images of aerodromes into databases of polygons, each stored with its color and shade attributes. The image generator is a computer that loads the appropriate polygons to represent the scene that corresponds to the rate and attitude of movement of the simulated aircraft. General Electric developed the first of these image generator computers for the space technology and soon afterwards they extended to flight simulators as well. McDonnell-Douglas Electronics Corporation made yet another leap in 1971 with their Vital II which introduced the calligraphic display technique permitting the depiction of night scenes.

Companies like Evans & Sutherland and CAE contributed to the continuous innovation in the digital image generators technology. Currently, visual systems provide nearly photographic quality of images with resolutions of up to 3 million pixels and fields of vision of up to 180° horizontally and 60° vertically. Typically 3 to 5 projected images (referred to as 'channels') are seamlessly projected side-by-side to form that image which is manipulated in real time and updated at 30 to 70 Hz. A typical scene from a modern visual system is shown in Appendix A, Figure 3.

Regular innovation continues to push the envelope of resolution, calligraphy and image quality. A recent innovation in the visual systems technology, potentially a niche innovation, is the creation of PC based image generator cards. These PC cards that fit in a typical home PC motherboard, have the memory capability to store multiple airport databases and the computing power to load them in real time. These image generators have the potential to create interesting airport familiarity and procedures trainers for pilots and airport ground vehicle operators. They may open several niche market opportunities for the company that will pioneer their integration and commercialization to the aviation market. One such modern system is the CAE Tropos™ system, launched in 2002 (Figure A.3).

For the sake of comprehensively covering the innovation history of visual systems, it is worthy to note that rotor-wing aircraft (helicopters) simulators visual systems have far more room for improvement that fixed-wing aircraft. The out-of-window scenes to be simulated in rotor-wing aircraft are usually of a much wider FOV making the mere spatial design of the visual projectors an engineering challenge. One system developed by CAE for the UK Navy simulating the Merlin helicopter used a spherical visual projection screen with more than 9 projectors to simulate the surround windows environment of a helicopter.

### 3.5.2 The Motion System

The motion system was perhaps the earliest identified environment replication cue to be needed in a flight simulator. Starting with the universal joint in Sanders Teacher and ropes hanging an airplane mockup in the wind, the creation of motion responses to pilot inputs was recognized as quite essential since the onset of the industry.

With the introduction of digital computers in the simulators, computer controlled hydraulic actuators were used as the main motion force. Six Degrees-Of-Freedom (DOF) hydraulic motion systems soon became the norm and innovation was limited to improving the maximum travel permitted by the hydraulic pistons. The travel of the pistons is directly correlated with the movement sensation inside the simulator cabin. Standard systems now offer a travel of up to 60 inches, which provides sufficient maneuverability for wide-body carrier aircraft and nearly realistic motion for smaller jets. A picture of a modern simulator motion system is shown in Figure A.4.

Motion systems continue to lack the capability to deliver continuous g acceleration to the cabin due to their limited travel, regardless of how long it is. This is compensated by rapid return of the hydraulic piston to its neutral or idle position to be able to continue delivering acceleration when needed. This hydraulic return happens at a slower rate than the human body can sense and hence the feeling of a continuous motion is conserved.

For rotor-wing aircraft, simulator motion systems are often coupled with vibration platforms to replicate the movements inside the cockpit resulting from the aerodynamic maneuvering as well as the wing piston vibrations. These vibration platforms are placed between the standard motion system and the aircraft cabin to deliver the vibration sensation at all aircraft attitudes and movements.

### 3.6 Organizational Milestones of the Industry

One can easily observe several innovation coordination strategy eras when scrutinizing the historical evolution of the aviation training industry. These innovations range in their effect from incremental innovations to Schumpeterian destructive creativity (Schumpeter 1934). Combined with generic economic changes and inherent instabilities in the neighboring airlines industry, this produced an environment of constant change for this industry. Despite these turbulent conditions though, several firms in the industry have been able to survive, grow organically and forward-integrate along their value chains. These firms that had the most influential endogenous effect on reshaping the coordination of innovation in the industry and leading its evolution.

In the following, we explore, in chronological order, the phased progression of the games of innovation coordination in the aviation training industry.

#### 3.6.1 Demand-Driven Innovation

Following the architectural innovation (Abernathy and Clark 1985) of Edwin Link in 1928, and the emergence of the aviation simulation industry architecture, the innovation coordination mode was initially driven by market demand. As in most other emerging industries, the market dynamics were being developed between the suppliers and potential buyers, and demand for particular product features was the main engine driving the investment into developing technological solutions for these features.

Immediately following the commercialization of Link's "Pilot Maker", the aviation industry did not comprehend the implications of the new training tool and hence did not show much interest in investing in it. One of the reasons for the failure to see the added value of Link's invention was commonality of VFR[5] flying which was seen to rely more on the pilot's understanding of the flight dynamics than on his understanding of the aircraft navigational instruments (Rolfe and Staples 1986). Amusement Parks were the principal customers of the newly formed *Link Aeronautical Corporation*.

Edwin Link later formed his own Link aviation training school where he applied his new instrument-based training philosophy, and trained pilots using his innovative technology and techniques. His proof of concept went unnoticed until 1934, when the US Air Force was mandated to deliver the mail by Air around the US. The military pilots were not trained to fly in the dark and in adverse weather conditions. Reliance on the instrument-dependent IFR flying was increasing, and in doing so creating a new industry around Link's analytical motion and instruments simulation technology. Unlike the chronological order implied by Abernathy's definition of architectural innovation (Abernathy and Clark 1985), Link's architectural innovation provided a technological solution for a problem that was soon to emerge.

For the following few years, innovation in the new industry was driven by the need to improve the fidelity of the aircraft simulation and enhance the pilots' training experience. Major technological milestones, in this customer-driven innovation arena, were mostly in the fields of motion and visual simulations. Until the advent of microelectronics technology, closed circuit television systems depicting imagery from huge 3-D scale terrain models were quite popular as what is known today as the visual system (Rolfe and Staples 1986). Simulation of the out-of-window visual scene was perhaps the biggest challenge that many inventions tried unsuccessfully to address. These rapidly emerging innovations gave rise to numerous firms in this industry, most of which could not survive the fast-paced radical innovations which rendered their technological core competencies obsolete.

[5] VFR = Visual Flight Rules: a flying philosophy that relies on the pilot's view of the out-of-window scene and his assessment of the aircraft attitude accordingly.

In 1939, the training industry was considered sufficiently crucial as a part of the aviation industry that President Roosevelt signed the Civilian Pilot Training Act, which prescribed regulations for individuals to obtain their private pilot licensing (FAA 2004). It was not before February 2nd 1970, though, that simulation technology reached a sufficient fidelity level for the FAA to approve expanded use of qualified flight simulators for training. These events paved the way into the second phase of innovation coordination games in the industry, namely the regulation phase.

### 3.6.2 Regulation-Driven Innovation

Consequent to the formation and stabilization of the architecture of the flight simulation equipment industry, its necessity to the safety of flying was recognized by the transportation authorities around the world. Measures were taken by various authorities to ensure the maximum utilization of these training tools for maximizing the security of flight and the effectiveness of pilot training. These measures had to be enforced by law especially that pilot training is an overhead cost for airlines and hence cost-cutting measures were likely to hit training first during hard financial times. Two of the most proactive and influential aerial transportation authorities around the world have been the FAA in the USA and the JAA in Europe. These pioneered the enforcement of minimum annual simulator training requirements for airline pilots to maintain their flying licenses. These required "training credits" evolved in number and distribution over time with the emergence of new learning aids and simulation tools.

The regulatory authorities have identified various fidelity levels of flight training products for the various stages of the pilot training cycle. Adherence to the minimum requirements of each of these training devices is what gave any training device its commercial training usability and hence its commercial value. The FAA or JAA certification level achievable by any aircraft simulation device is what determines the training credits that can be obtained on it and hence the return on the investment made into that simulator. The authorities qualification decisions also take into consideration the end user's perception of the product quality and the planned utilization of the device in the user's training program. This is an important feature of the flight simulation equipment industry since innovation is not solely dependent on the technology transfer capabilities of the innovative firm but also on its acceptance by the various other stakeholders involved (Miller and Olleros 1993). Unfortunately, this potential flexibility element of the guidelines did not encourage innovation in the training methodology or simulation philosophy. This was because training in the airlines industry is an overhead requirement, one that has to be fulfilled at the least possible costs and risks. This resulted in risk minimization attempts, by the equipment producers and customers alike, through strict adherence to tested and proven technologies.

The aviation authorities have a crucial role in the commercialization of innovation in the flight simulator industry. Traditional Porter analysis of the industry usually ignores this role though as they do not fit into any of the 5 forces affecting the firm. In fact their interaction with the firm is far more complex than the bi-directional arrow linking each of the entities interacting in Porter's 5-force industrial model (Porter 1980).

Due to the high safety implications involved, the regulation guidelines were slow to evolve in reaction to technological evolution. Few and far between revisions of the guidelines were made, and these were mostly related to training methodologies more than technologies. In other words, these changes reflected the evolution of the aviation industry rather than that of the aviation training industry. The only changes made to simulators' qualification guidelines were reactive to accidents revealing their deficiencies.

The strict product-oriented regulatory guidelines created a product-centered equipment industry that competed for satisfying the regulatory requirements at the optimum quality-price ratio. The grouping, utilization and placement of the training products into a training curriculum were solely the end-user's concern. This resulted in a schism between the two halves of the product lifecycle:

1. Producers innovated and produced to satisfy the regulation guidelines of the individual product, often irrespective of its utilization. For example, a contractual agreement would be awarded to build an FAA Level 4 FTD. Details of the training intended to be conducted on that device were not

necessarily pertinent except for limited customizations of a few training aids (e.g. animated schematics and simulated malfunctions);

2. Customers used the "off-the-shelf" products to tailor-made a training curriculum for their needs.

The second phase often involved the users acquiring various training components from different producers and then designing courses around them to:

- Utilize the training products for learning specific skills;
- Overcome the discrepant fidelity levels between the various tools by creating *Difference Courses* for the pilots to "unlearn" a skill acquired on a machine before learning the more aircraft-like skill on the higher fidelity machine;
- Customize certain aspects of the standard design of the training devices to match their own training needs;
- Build training manuals and books for the students to understand the limitation of every training tool, the specific skills they are expected to acquire by using it and those that they should *not* acquire using this particular device.

A graphical depiction of the industry organization, and consequently the innovation organization, is shown in Figure 3.2.

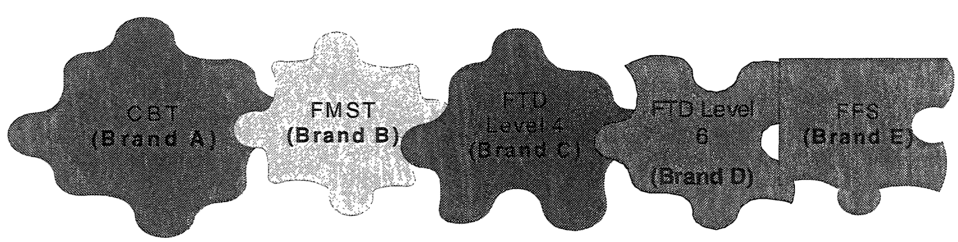


**Figure 3.2: A graphical depiction of a regulation-driven training curriculum**

Incremental innovation was allowed to take place in the industry through a joint coordination scheme, lead at the core by the regulators and their prescribed equipment qualification guidelines. Value creation and capturing were therefore determined by the innovation's compliance with the regulatory frameworks. Since profits are earned from value creation, (Brandenburger and Nalebuff 1995), the regulatory frameworks acted as guidelines for innovation too. Value capturing only occurred at the product level and it was geared towards a higher product quality to price ratio. Since the only value of a training simulator was acquired once the authorities qualified it, the innovation was very conservative when it affected the user interface and was mostly focused on embedded technologies. This meso-system of ex-ante selection of innovations based on the regulations resulted in an efficient allocation of research and development efforts (Miller and Olleros 1993).

This framework for innovation put the regulatory authorities at the heart of the innovation generation process in the aviation training industry. The regulators were the principal interface between the two distinct phases of the product lifecycle: the equipment production and the training utilization. Not only did suppliers adhere to the regulation guidelines for giving their products the acquired value from qualification, customers also did not create demand different from what the authorities dictated. These rules defined the structure of negotiations between buyers and sellers (Brandenburger and Nalebuff 1995).

This mode of innovation was established during the mid 1980's and through the 1990's. During this period, the airlines industry was dominated by huge international carriers, which were getting larger and bulkier by the mergers and strategic alliances that characterized that period. Low-cost and "no-frills" airlines were starting to emerge and gradually gain visibility in the aviation arena by the mid 1990's. These emerging airlines were at the phase of establishing their training establishments, infrastructure and curricula. They created a demand for reduced-cost training equipment to suit their business models but this demand was not satisfied by the existing equipment suppliers who were geared towards the higher-cost training devices popular among the bigger airlines. A few companies were created to fill that demand gap by providing lower-costs

FTDs. The technological complexity, legal liability and strict regulations restricted the entrants role to the FTDs segment of the equipment market.

The regulation-centered game of innovation in the aviation training industry persisted throughout the 90's partly because the industry leaders succumbed to one of the most popular and valuable management dogmas, namely staying close to their customers (Bower and Christensen 1995). This, coupled with the customers' regulation-based value-capturing criteria, closed the positive feedback loop strengthening the regulation mode of innovation coordination in the industry.

Due to the high safety implications involved, the regulation guidelines were slow to evolve in reaction to technological evolution. Few and far between revisions of the guidelines were made, and these were mostly related to training methodologies more than technologies. In other words, these regulation changes reflected the evolution of the airlines industry more than that of the aviation training industry. The only changes made to the simulators qualification guidelines were reactive to accidents revealing deficiencies in their minimal requirements.

The regulation-based coordination of innovation in the aviation simulation and training industry helped define the required core competencies of its key players. Being a highly regulated non-utility-product industry, the most crucial core competencies were the industry's perception of the firm's closeness to major customers, its understanding of the regulatory requirements of simulation equipment and its close relationships with the regulation authorities (Miller and Olleros 1993). These competencies strengthened the positions and market shares of a few key players. This eventually resulted in the development of a highly stable oligopoly. In fact more than half of the currently existing system integrators were there, under different ownerships, during the emergence of the industry (Miller and Olleros 1993).

In recent years, a few of the leading firms in the aviation simulation equipment industry made strategic repositioning moves. These transformation steps initiated the evolution of the industry's game of innovation. Before describing the new transit mode of coordination or the predicted final mode, the forces that helped shape the transformation are presented.

The regulatory innovation game in the aviation training industry helped define the required core competencies of its key players. Being a highly regulated non-utility-product industry, the most crucial core competencies were the industry's perception of the firm's closeness to major customers, its understanding of the regulatory requirements of simulation equipment and its close relationships with the regulation authorities. These competencies strengthened the positions and market shares of a few key players. This eventually resulted in the development of a highly stable oligopoly. In fact, more than half of the currently existing system integrators were there during the emergence of the industry, under one ownership or another (Leroux-Demers 1993).

# CHAPTER 4: THE SHIFT OF INNOVATION COORDINATION IN THE INDUSTRY

## 4.1 The Forces of Change

Despite the apparent dichotomy between the two extremist strategic management schools, namely the *Rationalist* and the *Incrementalist* schools, most real-life strategies emerge as combinations of the two disciplines. This was also the case for the evolution of the aviation training industry from being a technology-intensive regulation-centered manufacturing industry into a pedagogy-centered training services industry. A series of factors and forces shaped this transformation and these will be explored here in the chronological order in which they emerged. Figure 4.1 graphically depicts these factors and forces.

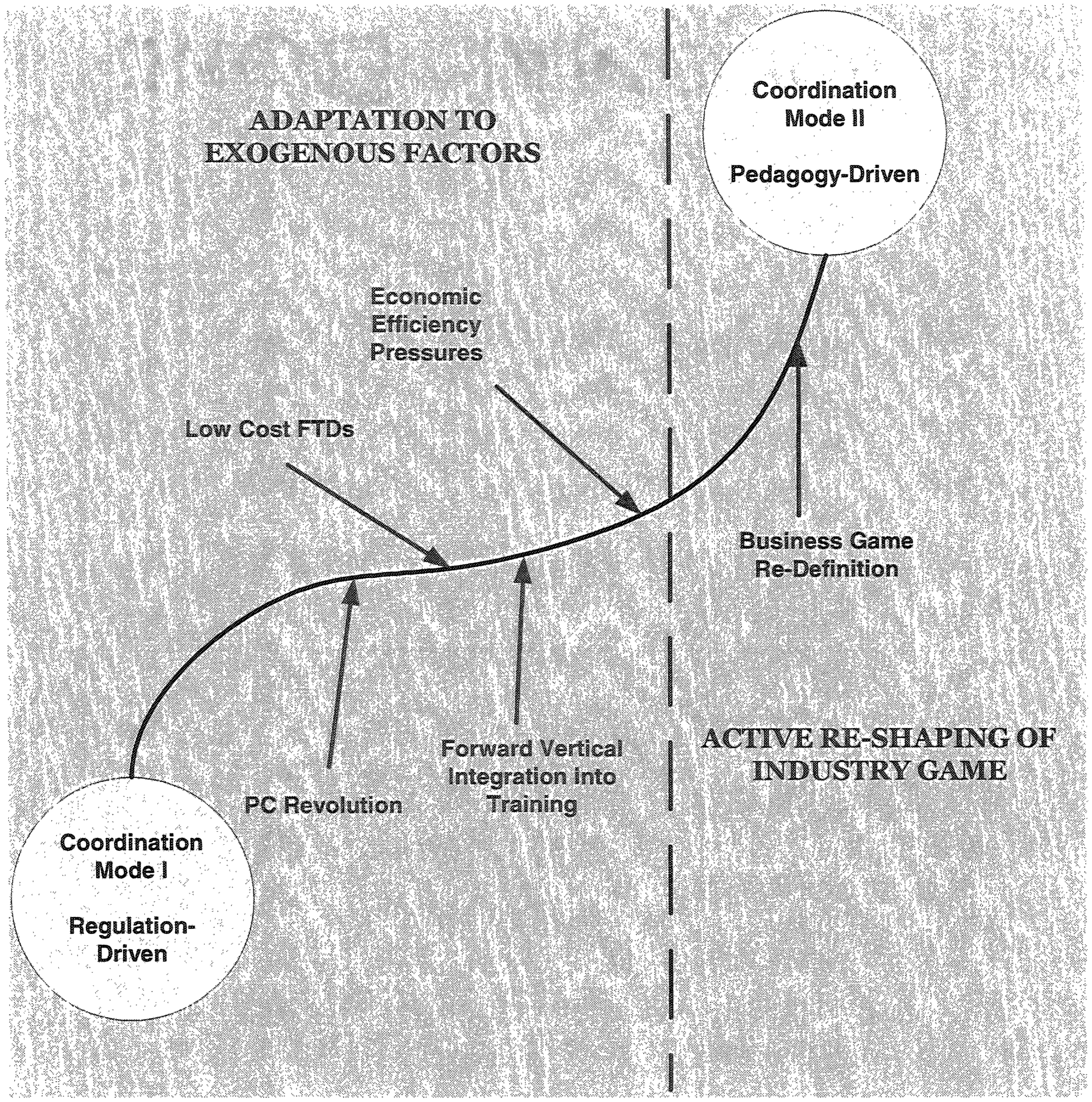


**Figure 4.1: Industrial Transformation of Innovation Coordination**

### 4.1.1 The PC Revolution

Despite the use of analog computers in the earlier designs of flight simulators, it was not long before digital computing was the core technology in flight simulators. Image Generators, motion systems, and aerodynamic simulation algorithms all heavily depend on the underlying computing speed and processor execution rate. This dependence on computing technology resulted in the chronological dependence of simulation innovation on computing innovation.

The digital computing world has introduced numerous technological revolutions ranging from the transistor technology in the early 1960s to the World Wide Web (www) in the 1990s. Each one of these evolutionary stages in the computing technology has opened the way for a subsequent innovation in the aviation training industry. Personal Computing, or PC, technology was the most recent of these computing innovations.

The first PCs started to emerge in the late 1970s. It was not before the mid 80s that Personal Computers showed signs of commercial success in the North American market. Linked to the transistor and electronic Large Scale Integration (LSI) innovations, PCs capitalized on technology mostly used for scientific research purposes for creating a new household commodity market. The following decades saw a steep increase in the volume of the PC industry and soon PCs became a nearly indispensable part of the North American household consumer. This rapid development in the computing hardware complexity and capabilities was paralleled with an equally rapid advancement in the computer software products. Software packages, aided by the rapid increase in computing hardware power, were rapidly introducing new ways of doing things and replacing the conventional manual ways. One of these areas where computers became an increasingly popular tool was education and training, and specifically flight training.

CBT (Computer-Based Training) systems started emerging in the mid 1990s aimed at familiarizing pilots with aircraft systems and flying procedure checklists. These courses added the new dimension of home-based training with its associated cost savings. For most major airlines where pilots had to be flown in from around the globe for training twice a year, this new feature off-loaded a significant portion of their travel and living bills.

One of the major drawbacks of traditional CBT systems though was their limited pedagogical capability in teaching the operational aspects of the aircraft systems. The static sequences of slides, animations and narrations were not able to replace the interactive classroom learning experience. The limited information presented on these slides was also insufficient to replace an experienced instructor's knowledge of the aircraft systems performance. They were therefore used as supplementary training aids that prepared the pilots for the ground school portion of their training.

One way to overcome this limitation would have been to run fully interactive aerodynamic and systems simulation behind these CBT courses. This would have allowed the pilot interaction with dynamic models of the aircraft and hence provide a significant portion of the learning experience acquired on the FFS. This was a technological challenge though due to the speed limitations of the PC processors compared to the mini-computers and mainframes typically used to host the simulation on a FFS (Rolfe and Staples 1986). This technological barrier was gradually diminishing though with the leaps made in PC technology that rendered COTS PCs capable of handling the computing burden of the aerodynamic and systems simulation models. This increase was matched with an increase in complexity of the simulation models offered on CBT packages. The emerging technology was threatening of a wave of creative destruction converting the key suppliers core competencies into core rigidities and driving them out of the new industry (Leonard-Barton 1992).

In 1997 CAE, one of the key suppliers of the FFS market with an average 75% market share, decided to catch on to the new wave of technological innovation and invest in the developing PC-based training devices market. The company capitalized on its vast simulation experience and embarked on entering the CBT market through what was called a DTSim (Desk Top Simulator) product representing an MD11 aircraft. The product was sold to FedEx Corporation as a part of a multi-FFS purchase deal as a troubleshooting and engineering testing tool. The product was developed using the existing full-flight simulation models for ease of development and improved fidelity.

The product consisted of dynamic graphical representations of the various cockpit panels integrated with simulation software taken off the FFS. Other learning tools such as animated aircraft system schematics were added to enhance the learning value of the product. The product was a successful endeavor that a small engineering group was formed to specialize in developing similar products for other aircraft types.

The role of the newly formed nucleus group and its new PC-based product could have stagnated had other factors not interfered and contributed to the transformation process.

### 4.1.2 Low Cost FTDs

The growth in number and size of the low-cost and no-frills carriers, prompted numerous small suppliers to seek new market opportunities by developing low cost FTDs that are better suited for the budgeting needs of these airlines. They built devices designed to barely meet the requirements of regulatory qualifications. The bottom-up design approach resulted in significant cost savings over the traditional FTDs in the industry. For customers with established training centers, the cost savings that the new equipment would provide did not outweigh the risks and operating costs of acquiring them. For the key suppliers in the high-end equipment oligopoly, this resulted in ignoring the innovative trend and the emerging low-end equipment market.

The customer base of these low cost producers started to grow beyond the low-budget airlines due to the sharp slow-down in the global economy. Major carriers and established training providers started to consider the lower quality, lower-price alternative devices when planning their training equipment acquisitions. The increased attention to the low-cost producers disrupted their judo economics advantage [3] acquired in their niche markets. While their products were not technologically more complex than the higher-end ones, their destructive creativity threat [25] came from their capability to find low cost alternatives to expensive components and package them into products that still satisfied the regulatory frameworks.

The new low-cost market strategy was difficult for large suppliers to imitate because:

- Their organizational designs did not support low cost production models;
- Their industry image of being high quality (and price) equipment producers did not match the low cost products offered;
- They continued to sell the high price, high margin products to existing customers and therefore were unable to provide similar products at significantly lower prices;
- Their production methods and expertise did not enable low cost production;
- Their late entry into this market and hence their lost early movers advantages.

In the late 1990s, met with a drastic decrease in market share of FTDs to the new low-end industry entrants, CAE Inc., one of the leading firms in the simulation equipment industry, studied in this research, decided to enter the low-end FTD market. Multi-disciplinary teams from sales, engineering and product design were formed to define a new product capable of launching the company in the new market and recuperating its market share leadership. CAE was an example of the larger suppliers that were eager to enter the newly emerging market and redefine their products to compete with the lower cost FTDs that were gradually gaining market acceptance.

In 2001, CAE launched a new product line, CAE Simfinity™, with the mandate of capitalizing on its extensive libraries of simulation models and expertise for producing low-cost training tools. FTD designs were generated from the bottom up, diverging from the CAE classical designs, with cost savings and basic minimal compliance with regulator guidelines, as the main imperatives. The new product line provided a suite of PC-based products positioned to compete in the lower-end of the simulation equipment, with the difference of using FFS-fidelity simulations instead of the competition's reverse-engineered technology. The cost savings were achievable due to the amortization of the simulation development costs over the FFS and the lower-end devices proportionately.

### 4.1.3 Forward Vertical Integration into Training

Simultaneously to the above-described movement of the key suppliers of higher-end simulation and training equipment to cover the lower end of the product spectrum as well, a forward vertical integration movement was pursued by a few of them. In 2000, Thales Training & Simulation (TT&S) formed a 50-50 joint training venture with Crossair, a European regional airline marking its forward integration move into the training industry consequent to the company's repositioning in 1998 and 1999 (TT&S 2000). In the same year, CAE's new appointed CEO announced the company's "major, but disciplined" move into the pilot training market (CAE 2000).

The move was initiated and supported by several factors. One of these is the relative size of the training industry versus that of the training equipment industry. The latter is of the magnitude of $8 Billion compared with $800 Million for the equipment industry. The 1000% discrepancy between the industry sizes is quite lucrative, especially in an industry where revenues are generated from continued operations, based on long term, often 10 year, contracts and training agreements. The training equipment industry, on the other hand, is based on discrete projects that last between 6 months and 2 years on average. Unlike the simulation equipment industry, the training services industry is also periodic following the regulatory semi-annual training requirements of incumbent pilots and the hiring cycles of new ones. With an average of one FFS for every 10 airplanes, the market growth is likely to experience saturation plateaus linked to saturation of sales of new aircraft. The technological and financial risks in the training services industry are also significantly less than the Engineer-To-Order R&D-intensive industry of simulation equipment. All these factors converge to the potential advantages that simulation equipment providers can reap from this forward integration move, especially in light of their ability to compete efficiently in the services market due to their lower costs than their equipment sales customers, who are also their training competitors.

By the year 2002, both of the major suppliers in the commercial simulation industry, namely CAE and TT&S, were well established in their newly ventured training markets. Once they acquired the necessary expertise in the training market, through acquisitions or partnerships, their lower-cost advantage proved to be of high competitive value for them. In fact, the unfavorable economic conditions in the industry helped highlight this competitive advantage and rapidly give them a strong foothold in the training market. CAE pursued this forward integration strategy more aggressively than TT&S. In one fiscal year, the company purchased two leading training firms in Europe and North America and inaugurated a series of training centers around the globe. From a new entrant, the company became the world's second largest training provider in one year.

### 4.1.4 Economic Pressures

In the midst of all the market pressures resulting from the emerging low-cost FTDs and consequent to the repositioning of the key industry suppliers to adapt to these markets, a few global events lead to an economic downturn. This has lead to the tightening of the budgets of key customers and hence increasing the low-cost pressures on the suppliers.

The first of these events was the infamous terrorism events of September $11^{th}$ 2001. These hit the aviation industry worst and immediately major airlines and flag-carriers around the world started declaring bankruptcy. The training budgets became increasingly heavy in the eyes of aviation corporate executives and new low cost solutions that barely "do the job" were increasingly popular.

This downturn in the economy was made even worse by the consequent wars in Afghanistan and later the Persian Gulf, the outbreak of SARS in the Far East and the constant threat of terrorist activities around the world.

While revolutionary ways of conducting aviation training may have been hovering in the minds of a few visionaries in the industry, the need for them became evident in light of the struggle for survival that the whole industry experienced consequent to these difficulties. The need for new ways of conducting the increasingly stringent training in more effective and efficient ways was repeated relentlessly in several of the industry trade shows and forums. The legitimate leadership of the transformation was questioned at the beginning until an implicit agreement was reached that it would be best done by innovative suppliers who have commercial interest in pursuing such training solutions. The ideal leaders were the ones equally experienced with simulation technology as with training methodology. The door was implicitly opened to such suppliers to research new methodologies and technological means.

### 4.1.5 Business Game Shaping

The dominant business game in the classical aviation simulation and training industry consisted of two components:

- On the equipment side: competing for offering to the market the highest quality to price ratio of simulation equipment, defined by the regulatory standards;
- On the training side: competing for maximizing the training quality to cost ratio by designing curriculums that optimize the utilization of the training equipment available in the market.

Recapping the effects of the above-mentioned forces of change, we see that:

- The PC technology that was needed for developing innovative low cost training equipment was sufficiently mature and commonplace;
- The low cost FTDs market has emphasized the importance of low cost training tools and introduced some of the key suppliers to the low cost end of the market;
- Several simulation equipment providers have already entered the downstream pilot training market and have started to accumulate knowledge about the service industry
- The economic circumstances are constantly pressuring for better and less expensive ways of conducting training.

The firm best suited for introducing a new training platform to satisfy the changing market conditions is therefore one that:

- Has entered the PC-based training equipment market and can therefore capitalize on its cost-cutting benefits for operators;
- Has already entered the lower-end FTDs market and built the necessary knowledge for producing low-cost training devices;
- Has embarked on providing training services and therefore has enough knowledge to lead a new training platform.
- Has the capability to respond to the turn-key outsourcing needs of some operators.

CAE, one of the key suppliers in the simulation products industry and a recent entrant in the training services industry started engineering a repositioning strategy to assume the leadership position of the new training platform awaited. The company introduced a new curriculum, termed the "Advanced Curriculum". The new curriculum was designed to increase the efficiency of training through its elimination of the use of the various levels of FTDs that filled the gap between the classroom initial training and the costly FFS sessions. Rather than moving the student up through increasing levels of cockpit realism in the various FTDs, the Advanced Curriculum attempted to train the student on the various pre-FFS skills, using the same fidelity and realism levels throughout the whole training cycle. This training is provided using dedicated training devices that do not necessarily fit within any of the standard equipment templates prescribed by the authorities. The added value from these new training tools is not derived from their compliance to the regulatory frameworks but by their overall pedagogical value within the training curriculum. CAE chose to change the industry game rather than playing it as it is (Brandenburger and Nalebuff 1995).

In an attempt to secure its new strategic position, CAE designed the various tools used for the Advanced Curriculum to be at the same fidelity level as its Full Flight Simulators. This sheltered the new platform from competitors that are not FFS producers and left a few potential rivals capable of introducing a comparable competing platform. The new curriculum advantages are:

- It is approximately 30% shorter than the classical training programs;
- It is less capital intensive due to the significantly reduced use of flight training devices;
- It is more effective as it avoids the learning-unlearning cycles of older programs of progressively increasing fidelity.

## 4.2 Pedagogy-Driven Innovation

The new pedagogy-driven training curriculum utilizes the classical FFS combined with a matrix of closely intertwined training devices for achieving its educational objective. The FFS remains as an immoveable part of the training cycle. Attempts to substitute its full aircraft realism are likely to prove unsuccessful, at least in the short term. Replacing the former classroom "chalk-and-talk" training, classroom-lead virtual simulators were introduced. These ran the full simulation fidelity of the FFS on classroom PCs, thus introducing the students to the aircraft systems as early as day 1 in their initial training curriculums. A fully interactive equivalent of CBT would constitute the next step where the student independently practices the learned systems knowledge, with the aid of a virtual instructor. Procedures training requiring spatial orientation, formerly done on the FTD, is then conducted on an IPT (Integrated Procedures Trainer). This device resembles a classical FTD in its cockpit enclosure resemblance, except that it does not have many of the hardware controls and inceptors present on a classical FTD. Touch-screens mounted on a cockpit-like structure provide the graphical replicas of the aircraft panels and indications with full behavioral fidelity. The cost savings achieved by this significant reduction of tactile panels outweigh by far any resulting degradation of training quality.

While the individual training devices may not be built to comply with specific regulatory guidelines, some operators have qualified overall training programs describing different utilization patterns and magnitudes of these devices. Figure 4.2 depicts a graphical representation of the new pedagogy-driven training philosophy.

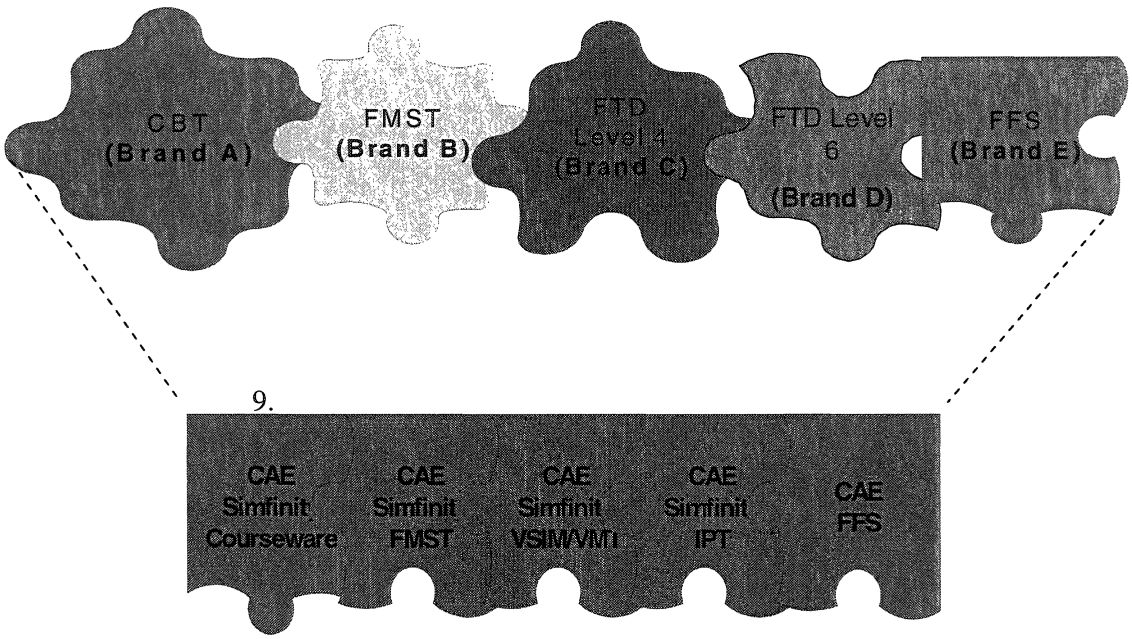


**Figure 4.2: The new pedagogy-driven training platform**

The newly introduced training platform started and continues to be gaining wide acceptance around the world. Airlines that are not burdened by heavy sunken costs in classical FTDs, were the first to respond to the methodological innovation. Some no-frills and regional airlines adopted the idea and partnered with CAE in developing it further. The increased training effectiveness and efficiency are luring many others into acquiring parts of the new training solution to replace their outdated equipment. Others are choosing to outsource their training completely to CAE to be conducted at one of its global network of training centers. CAE is selling either the full turnkey training service using the Advanced Curriculum, dry leasing its training equipment or selling specific training equipment from the new training footprint.

CAE is engineering the new training philosophy using one of main strategic features of complex industries: coordination. The company is leading initiatives with airlines, airframe manufacturers as well as regulators to prove the viability of the new curriculum and work on improving its pedagogic value. Industry forums, trade associations and customer conferences are also other arenas where the company is promoting its innovative platform and soliciting participation in its evolution from potential partners. The company's main aim is to shift the customer's focus away from the defined equipment to the effective training solutions framework.

The emerging pedagogy-based innovation resulted in a similar transformation in the modes of coordination of innovation. The ex-ante system of innovation coordination guided and constrained by the regulation frameworks was being gradually replaced by a pedagogy-centered innovation system that is heavily reliant on supplier-customer coordination. The regulators' role moved downstream from dictating the content and format of the supplier products to approving the supplier-customer defined pedagogy-based training solutions.

The new training platform currently utilizes training equipment that are mostly based on former training tools and devices. The main modifications to the old tools consisted of:

- Incorporating the same level of fidelity of simulation as the FFS on all the training tools
- Re-designing these tools to make them geared towards training on specific tasks and skills;
- Re-designing these tools for making them more efficient by reducing their unnecessary over-design caused by the former top-down approach starting from the FFS.

For example, the new simulation-based courseware is a more complex and innovative derivative of the already-existing CBT. The IPT is also a watered-down version of the former FTD product. The training products and tools that are currently used, at the onset of the new training philosophy, are not radically innovative, in and of themselves, compared to the former ones. However, their innovative pedagogy-geared curriculum opens the door for more radical equipment innovations in the future. While the tools used in the transition phase closely resembles those formerly used, their new platform opens the door for novel products and methodologies that may enhance the platform's pedagogic value.

The new pedagogy-based platform is gradually dividing up new categories of suppliers. The market is becoming divided into solution-providers and individual equipment providers. It is too early in this innovation's life to observe or even predict if the industry will be entirely transformed away from the individual regulator-prescribed training equipment towards the pedagogy-driven equipment-containing solutions. If this change is to occur, the solution-providers will assume a platform leadership role prescribing the rules of production and innovation for equipment-only producers (Gawer and Cusumano 2002). The game of innovation would then evolve to be a hybrid between a High-Tech Craft game and a Battles of Architecture game (Miller and Floricel 2004). Unless competition fails to introduce an equivalent training platform, an oligopoly of a few solution-providers will be likely to be formed again similar to that previously established during the regulation-driven innovation era (Miller and Olleros 1993).

# CHAPTER 5: DISCUSSION

The study leading to this thesis focused on a single regulated high-technology industry, namely the aviation training industry. Findings therefore cannot be blindly generalized to all similar industries. Most of the conclusions drawn from the strategic transformation of the innovation coordination though are general enough that they are likely to apply in most regulated high-technology industries.

## 5.1 Is Creative Destruction Necessary?

In light of the findings of this research, one would question Schumpeter's creative destruction innovation model that is held by many to be the dominant model of innovation in capitalist economies. An interesting point to note in the case of the aviation industry transformation is the type of innovation that lead it and its apparent contradiction with the leading firm's strategic position in the industry. Contrary to the conventional wisdom that technological revolutions often come from new entrants in the industry, the leader of the transformation in this industry was the established leader reaping the rewards of the dominant design phase described by Abernathy & Utterback's model of technological change (Abernathy and Clark 1978). The creative destruction attempts of the incumbent firm's core competencies by new entrants were outweighed by its strategic shift and capitalization on its other sources of competitive advantage. In fact, this is in line with what Tushman & Anderson (1991) argued consequent to studying the industries of minicomputers, cement and glass manufacturing in the US. They attribute this to the observation "*that veterans still are able to exploit strengths upstream and downstream in the value chain following a process discontinuity; only their core technical know-how is overturned*" (Anderson *et al* 1991).

This was precisely the case in the aviation training industry as CAE exploited the strength of its technological expertise and comprehensive product suite to capitalize on the innovations made in PC-based training equipment and low-cost FTDs to competitively provide efficient training equipment.

## 5.2 From Survival to Leadership

While several exogenous factors prepared the stage for the industry coordination scheme to evolve, an endogenous force was required to harness these factors and change the industry game. Coping with the exogenous forces, CAE has demonstrated a significant flexibility on its technological front, by its rapid adaptation to the PC technology, as well as on its strategic front, by its timely adaptation to provide low-cost FTDs. Both adaptations involved the foregoing of technical and commercial know-how for catching on to a novelty that has not yet proven successful. However, the timing of the strategic investment in the new trends is perhaps the most critical factor that determined its success.

Flexibility alone though would have guaranteed the company survival in turbulent times. The industry game manipulation move though was what was needed to convert the mere survival into an active leadership role of a new platform industry. Brandenburger & Nalebuff elaborate on this point of actively shaping the industry game the firm is presented with rather than playing the game that has been defined and seeking a competitive position in it (Brandenburger and Nalebuff 1995). Firms seek to manipulate the game for their advantage by reinforcing the core competencies that they master by leveraging their skills into a technological, methodological or procedural standard that they present to the industry. This standard, if well presented to the industry, may gradually restructure the industry and change the roles of some of its key players.

## 5.3 Traits of the Leader

One of the practical applications of the observations in this study would be the sketching of the necessary profile of the firm that can capitalize on exogenous changes in its innovation environment for initiating a transformation move and eventually leading the transformed industry. This profile will have to describe the strategic position and core competencies of the firm before, during and after the transformation.

Before the transformation, CAE had the biggest market share in the FFS product line [4]. Being the cornerstone product for flight training, the FFS market dominance enhanced the company's credibility for providing lower-end products despite its obvious scale disadvantage against the smaller competing firms. This helped it to adapt commercially to the destructive innovation waves described with success. CAE's learning culture and engineering-geared organization must have helped it achieve the technical flexibility required to cope with the radical innovations despite its size, product complexity and organizational design.

For shaping the industry game, CAE possessed most of the key success factors required for its industry. Reviewing the key attributes of the industry present in the literature [17] it is found that CAE has accumulated the necessary knowledge for mastering them. The company has therefore established a strong image that gave the industry the sufficient confidence in its capability to lead an innovative training platform. The mastering of these key attributes and the resulting firm image presented very high barriers of entry to the industry.

1. *Safety*: CAE's simulation expertise was characterized by high fidelity replication of aircraft and system performance, based on OEM and vendors' design documentation. Unlike reverse-engineered simulations, which may be sufficient for certain flight skill training, data-based simulations are sufficient for eliminating the need for real aircraft flying within the training curriculum. CAE's simulation approach, therefore, gave it the safety understanding necessary to assume leadership in a safety-driven industry.

2. *Customer role*: due to CAE's historical positioning as an ETO firm producing technically complex products, it possessed a good understanding of the roles customers prefer to play in the product design process. This mastering of the listening and interaction dynamics with the customers reduced the industry fears from an equipment provider assuming the leadership of a new pedagogical training standard.

3. *Customization*: this point is directly related to the above customer focus attribute. CAE's product customization approach essentially consisted of a matrix of technological options that could be offered on any aircraft or device type. This customer-driven product design persisted even when CAE defined "standard products" which were normalized medians of an

aircraft suite of possible permutations. These defined standards only offered lower cost standardized products without removing their customization potential or design involvement. This attribute helped CAE establish its credibility as capable of creating a standard pedagogical platform that is still flexible enough to be tailored to the airlines' individual training needs.

4. *Efficiency*: due to the above-mentioned positive feedback mechanism in the industry strengthening market share with every sale, efficiency also increases due to economies of scale. The low volume of units sold and the high construction costs of each unit render process innovations unattainable except for the few firms at the top of the market share list.

5. *Reputation:* CAE was one of the first firms to invest into the emerging flight simulation industry in the 1960's. Back then an electronic technology provider, CAE had an industrially diversified portfolio that extended into any new areas identified as high-technology niche markets that required sufficient economies of scale to heighten its barriers of entry and prevent fierce competition (CAE 1969).

6. *Technological Capability:* In an industry where accumulation of dynamic capabilities is crucial for survival (Miller and Olleros 1993), CAE has acquired an organizational learning culture that fostered knowledge accumulation. This technological capability enabled the firm to assume the role of a transformation agent as it is technologically competitive in the various parts of the training equipment supporting the pedagogic platform.

7. *Marked Presence:* Despite its large volume, the aviation industry is considered a small tightly-knit community for its players. This is because of its necessarily global scale and travel requirements. In such an industry, a marked presence can be quite crucial for competitiveness.

CAE's early comprehension of this aspect of the nature of the industry played for its advantage in its assumption of the platform leader role. The company's tight relationships with major airlines around the world, various regulatory authorities and most of the industry's forums have established its reputation as a global leader at all fronts. The firm's perceived commitment and excellence in aviation training has lead various industry leaders to agree to its new role as a platform leader.

8. *Libraries Accumulation:* Despite CAE's high level of product customization to suit its customers needs, its self-reinforcing history of simulating various aircraft types and configurations provides assurance of its understanding of the wide-scope of aircraft types in the industry, and hence its capability to lead it.

### 5.4 Evolution within the Game of Innovation:

It is remarkable to note that the evolution of the coordination mode of the industry was still within the same game of innovation exhibited by the industry, namely the customized high-tech craft game. Despite the external and internal forces behind the change, the changes were mere re-organizations of the various players and their relocation on the industry value chain, within the confines of the existing game. Consequently, the core competencies and the best practices in the industry were conserved.

This may seem to be an obvious observation based on innovation games' theory. However, in light of Schumpeterian innovation, destructive creativity is assumed to cause the devaluation of the current industry core competencies and the architectural formation of new ones in the transformed industry. This was not what was observed in this industry and therefore at first glance, both theories may seem contradictory. A detailed look reveals that Schumpeterian innovation theory is a simplified version of the innovation games' theory.

Destructive innovation is, undoubtedly, one way that radical innovation may take place in certain industries. In complex industries though, technological competencies are not the only critical skills, and are therefore not detrimental for the firm when changed by destructively creative innovations. Understanding of the innovation game the firm plays in and the mastering of the unique competencies required for that game are the crucial performance differentiators (Miller and Floricel 2004). These skills are not affected nor devalued by *technological* destructive creativity and therefore complex industries do not undergo major reorganizations or changes when faced with this type of destructive creativity.

Introducing new core competencies in complex industries to the extent of causing an architectural innovation essentially requires changing the game of innovation of that industry. This change is not easy to come about as the game of innovation is a function of the industry's product, its complexity, its nature and its effect on the society and public, as well as the historical emergence of the industry and the various roles of its players. Radical changes affecting these traits may result in changes in the industry's game of innovation and hence may cause the Schumpeterian destructive creativity effect, on a strategic rather than a technological level, on the incumbent players.

# CHAPTER 6: CONCLUSION

## 6.1 Theoretical Implications

This research focused on the evolution and transformation of games of innovation in the regulated high-technology industry of aviation training. While attempts were made to preserve the generic nature of the conclusions, they need to be validated against other industries before they can be applied to other regulated high-technology industries. Industries, such as telecommunications and aero-engines (Tidd and Hull 2003), exhibit forms of ex-ante definition of innovation by industry regulators, similar to the pre-transformation aviation simulation and training industry, and may therefore be interesting candidates for validating the conclusions below.

- Complex industries need innovation strategic management theories that take into account cooperation between players to analyze them. Theories like Porter's competitive approach or Schumpeter's technological destructive innovation implicitly assume the independence of a firm and its innovation strategies. These assumptions are not realistic and render the analysis frameworks insufficient for understanding the industries.

- A stable equilibrium mode of coordination in an industry may be reconfigured due to exogenous and endogenous forces. The resulting configuration though is expected to be within the same game of innovation as the original one. Exceptions to this may arise if the industry's unique core competencies, found by Miller *et al* to be the main performance differentiators, are changed.

- The aviation simulation and training industry exhibited a change in its coordination mode from regulation-based ex-ante innovation to pedagogy-based ex-post innovation. This change was brought about by a variety of economic, industrial and strategic changes that gradually challenged the old equilibrium and thus giving rise to the opportunity for firms to propose and lead more efficient configurations in light of the changes in the industry.

- Exogenous creative destruction is not likely to drive out the leaders of complex industries if their strategic positions are not sustained through technological leadership alone but also on the understanding of their industry's game of innovation and the mastering of their core competencies. Technological leadership shifts may shake the industries but they are likely to adapt to the new technologies.

- Active shaping of the industry game is what can make the difference between survival and leadership following creative destruction waves in complex product industries. The persistence of non-technological core competencies and flexibility to adopt new technologies and methodologies can ensure survival of the firm facing technological threats from outside of the industry. Active leadership though may necessitate the re-shaping of the industry by leveraging a firm's core capabilities and offering an innovative product platform.

## 6.2 Further Research

There are two possible dimensions for expanding the research described above. These are summarized below:

1. In the vertical dimension, more research could be done on similar complex industries for confirming the validity of the observations made in the aviation simulation and training industry. Scrutinizing other similar regulated complex industries may result in finding similar transformations of the coordination modes of the industry. This can help further validate the conclusion that active reshaping of the industry is necessary to transform mere adaptation to threatening exogenous changes into active leadership. This research avenue may shed some light on other factors that did not surface in the case of the aviation training industry.

2. In the horizontal dimension, more research could be conducted within the aviation simulation and training industry to include more firms and regulatory authorities. For the purpose of this research, mostly larger firms and key industry players were interviewed and studied. Studying smaller firms, for example, could reveal equally interesting findings about the effects of the transformation of the mode of innovation coordination at their level. This will help to complement the findings above, with the reactions of the industry competitors, regulators and suppliers to the transformation.

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# APPENDIX A: PHOTOGRAPHS AND ILLUSTRATIONS

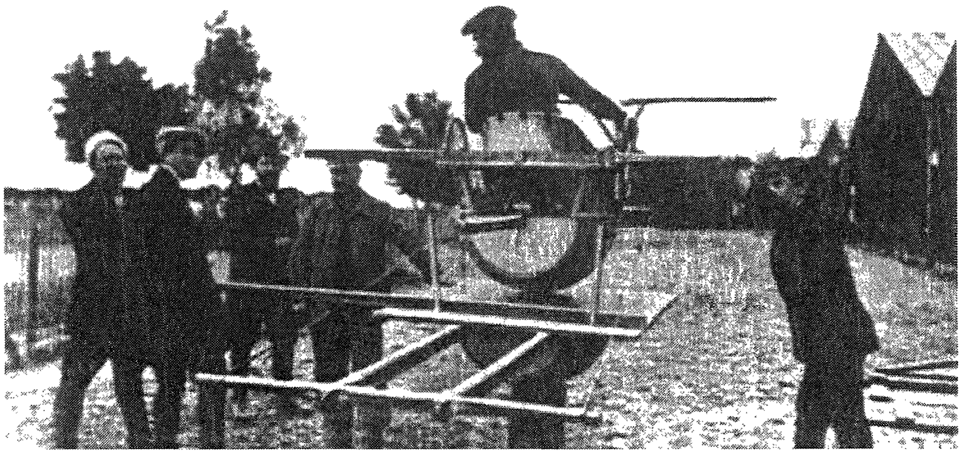

**Figure A.1: A modified version of the Sanders Teacher**

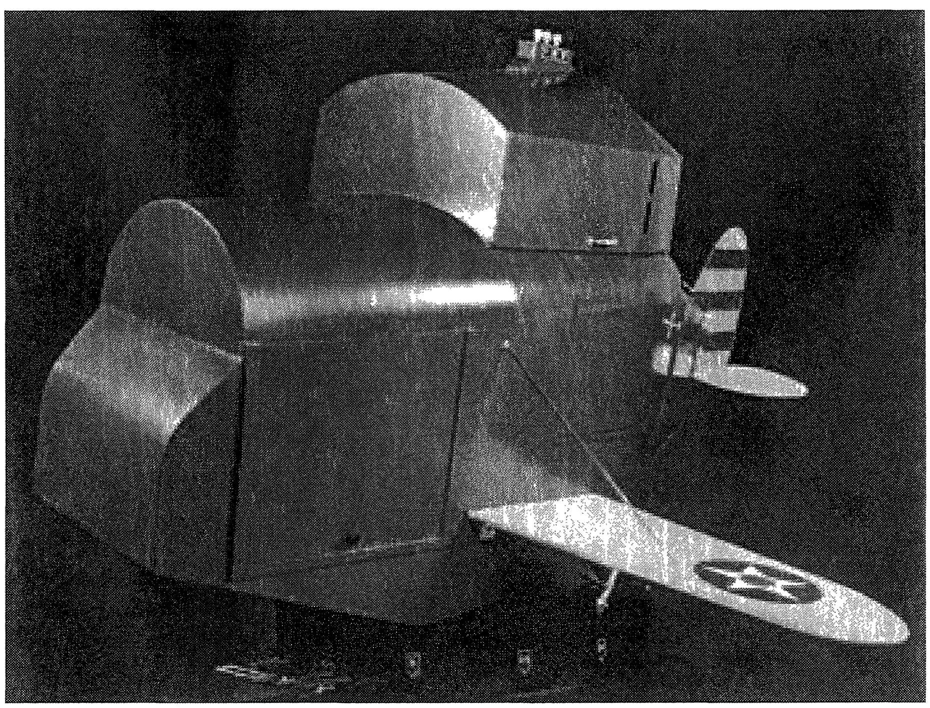

**Figure A.2: Edwin Link's Pilot Maker**

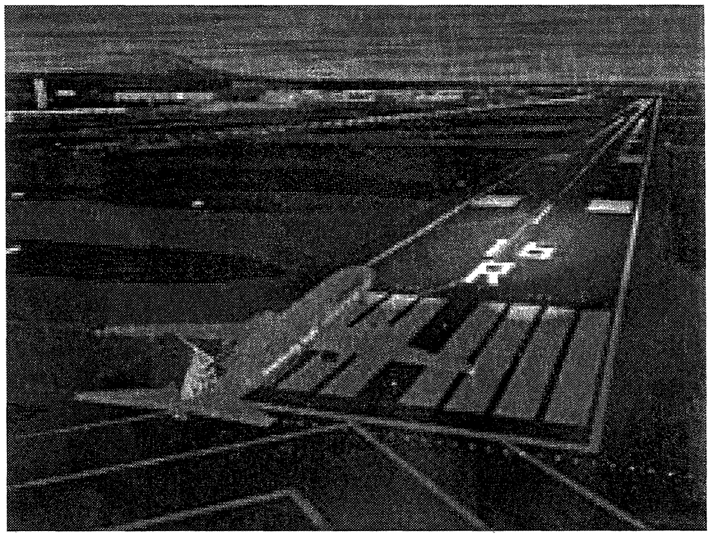


**Figure A.3: A Calligraphic Night Scene in the PC-Based CAE Tropos™**

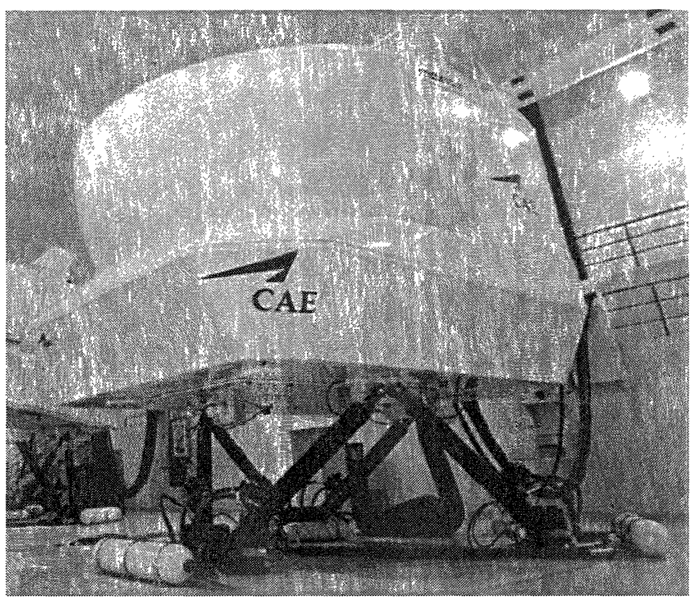


**Figure A.4: A modern Full Flight Simulator on a 6-DOF Motion System**

# APPENDIX B: PERFORMANCE CHARTS OF THE INDUSTRY

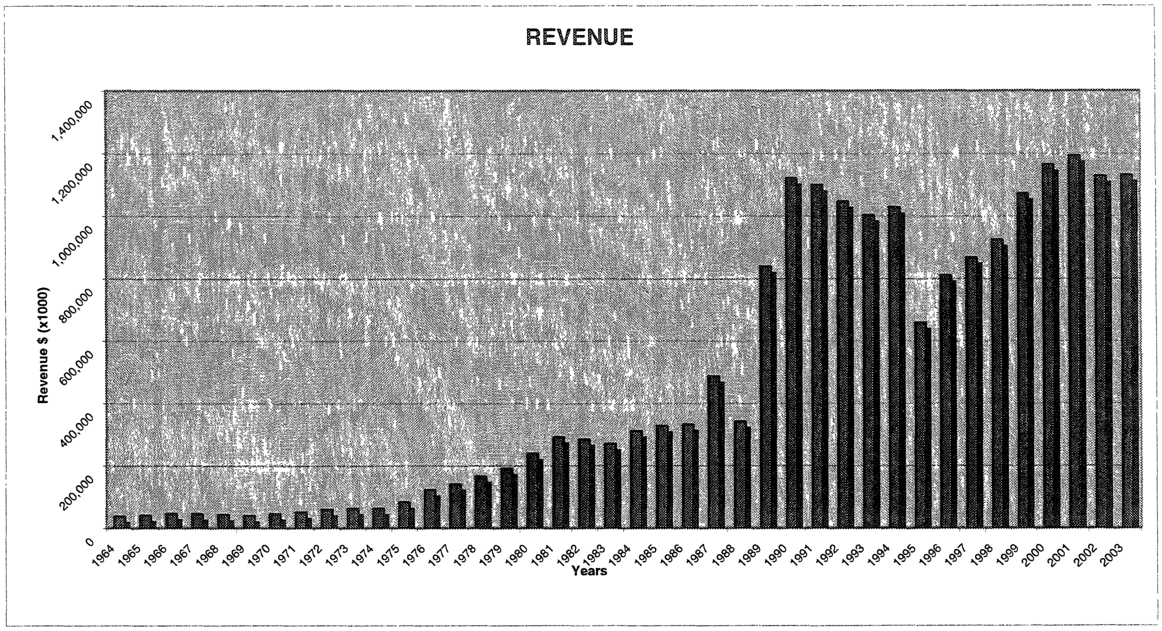


**Figure B.1: Revenue of CAE over the years**

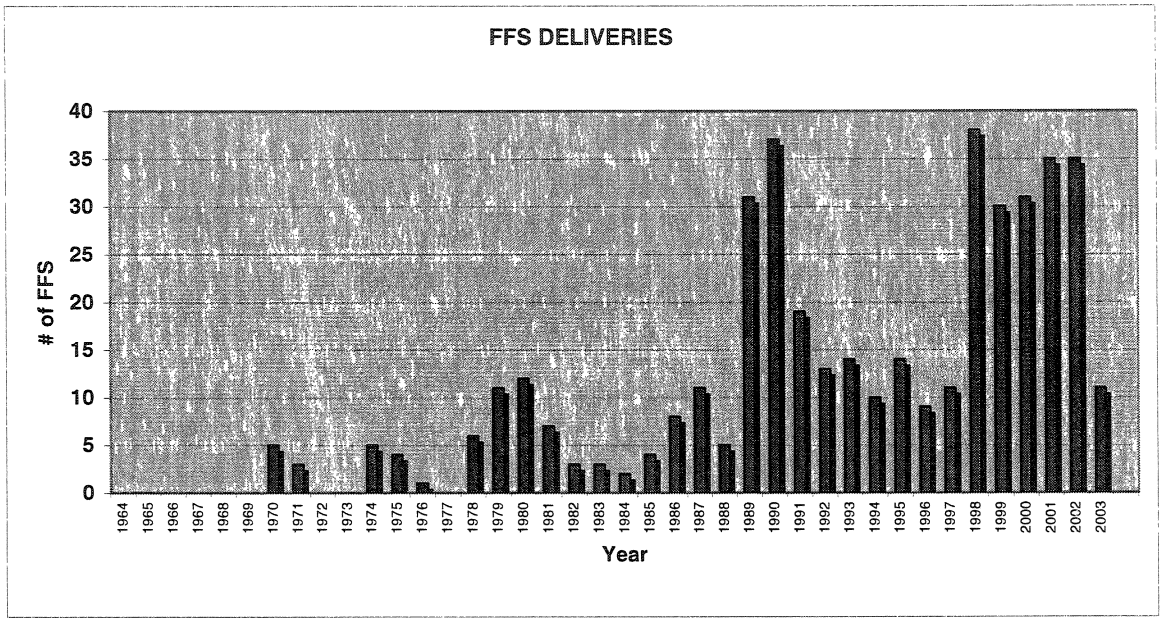


**Figure B.2: Full Flight Simulator Deliveries of CAE over the years**

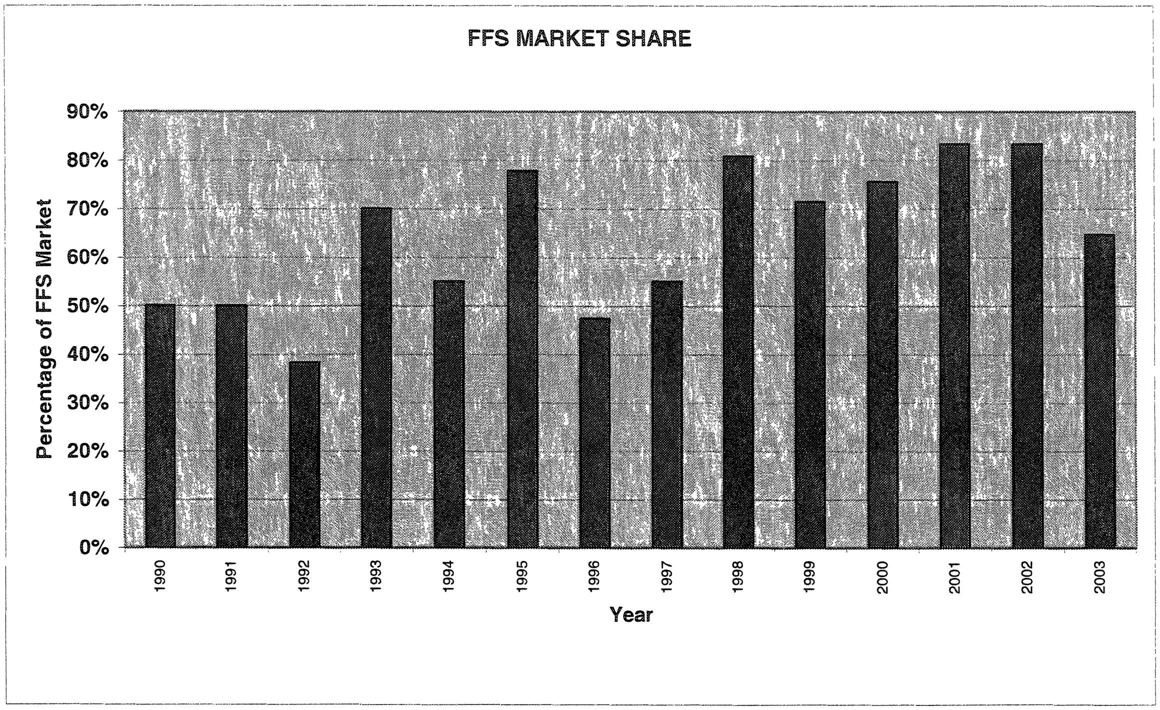


**Figure B.3: Full Flight Simulators Market Share of CAE over the years**

# APPENDIX C: DATA COLLECTION TOOL

MINE PROJECT

MANAGING INNOVATION IN THE NEW ECONOMY

# Corporate Case Studies

**SECTION 1: ISSUES FOR DISCUSSION- SENIOR MANAGERS (TECHNICAL AND NON-TECHNICAL)**

## A. VALUE CREATION ISSUES AND STRATEGY

### A.1 VALUE CREATION

1. How does **your firm create value for customers** through innovation activities? By what particular ways?

2. By what criteria do your **customers assess value** created for them by your firm through its products/services?

3. What are the key dimensions of **customer value** in your sector of activity? Which of them are currently emphasized. What are the main ways by which innovation creates value for the customer (i.e. most valuable kinds of innovation among developing new technologies, adding new features, cost reduction, customization etc.). How is all this changing?

### A.2 CORPORATE AND BUSINESS STRATEGY

4. Please describe the **business** you are in. What are your main products, services? What is your firm's position in the value chain?

5. Please characterize your **business environment**. What major external shifts have impacted your business over the last decade or so?

6. How do you **identify and prioritize the strategic directions** you will pursue or develop through innovation (new markets, technologies, capabilities, product lines)?

7. What are the major thrusts (vectors) of your **corporate strategy**? How do innovation investment rank among them? How the importance of investment in innovation evolved in the last 10 years?

8. What are the major **strategic transformations** that your firm has experienced recently or intends to undertake?

- Investment in innovation
- Investment in corporate level activities
- Investment to penetrate new markets, etc.

**B. INNOVATION AND NETWORK FOR CREATION OF VALUE**

*(ideally draw a map of network)*

9. Please describe the **network of innovative activities** that create value in your industry.
   - Draw a map of value creation activities and identify specific firms or types of firms associated with these activities.
   - Which activities in this network your firm performs itself?

- For which ones do you rely totally or partially on other entities? Which ones do you covet? Why?

10. Who are the main **stakeholders** that influence innovative activities in your firm and your industry? (financial stakeholders, scientific community, special interests, regulators, partners, clients, suppliers, competitors). How do you interact with them?

**11.** What are the **other players** (competitors, complementors, innovation support) and what **roles do they play**? What is the **role of your firm** in these innovation activities?

12. As industry evolves many roles appear or disappear. What **roles in your opinion have changed over recent past and what do you see for the future?**
    - Venture capital
    - Chip design
    - Regulators
    - Sponsors etc.

**13.** Which factors control the **pacing (frequency) of innovation** in this industry? What are the main obstacles in your sector?

**14.** Who **drives innovation** in your sector?

## C. ORGANIZATIONAL ISSUES

### ***<u>C.1 ORGANIZATIONAL STRUCTURE AND COMPETENCIES</u>***

15. What are the distinctive features of the way **innovation is organized** in your firm?

    - Organization structure and its impact on innovation (responsibilities and subordination of units and managers, configuration and sites of units and labs, decision committees etc.)

16. What are the key **organizational policies** you have developed to stimulate innovation

    - Management structure, formal and informal processes
    - Corporate policies
    - Incentives and reward systems
    - Funding

17. How do you **allocate resources** to innovation activities?

    - Level of investment
        - Innovation related expenditures (R&D, New product, etc.)
        - Partnerships with complementary players
    - Allocation between different directions and activities
        - Choice between investment in current business vs. new businesses
        - How much to invest? In what areas ?
        - Choice between internal R&D, partnership, acquisitions, etc.
        - How are these investment made: small incremental, large bets...
        - Approaches to control and evaluation

18. What are the **key capabilities** needed for innovating in your business?

    - What capabilities are needed for your current business
    - What capabilities are needed due to changes in competition

19. How do you stimulate the **organizational change** required for implementing strategic directions you will develop through innovation?

    - How do you steer the external network in favor of these changes?

20. How do you **develop new technological capabilities** (proprietary technologies, platforms, core competencies) in your firm?

    - By what processes the priority directions (the technology strategy) are defined?
    - What are the preferred ways for developing new capabilities?
    - How do you renew the capabilities (ensure that old ones do not get in the way)?

***C.2 KNOWLEDGE***

21. Who produces the **relevant knowledge necessary** for innovation in your business (e.g. product ideas, scientific principles, technologies, operation-related knowledge)?

    - Give specific names of clients, universities, research centers, suppliers, other firms, etc. from which the main new ideas came from over the past three years.
    - Predict the next breakthroughs or innovative steps. Where are these likely to come from?

22. What key practices do you use to **obtain knowledge**, get it integrated and circulated in your organization?

    - How do you ensure that your firm is abreast of new ideas, opportunities and technologies developing outside your firm that could be relevant to your activities?

23. What techniques do you use to **stimulate the generation of ideas** for new products and technologies in your firm?

    - How do you ensure that good ideas are not suppressed? Is this a problem in your organization? What techniques do you use to protect new ideas?

## D. KEY SUCCESS FACTORS

9.

24. In your view, what are the **success factors** for innovation in your industry? Give an example of a firm that you feel has been particularly successful? Why do you say this

25. What are the factors that have **facilitated or hindered** your firm to bring innovative efforts to fruition? Please give examples (e.g. relationships with stakeholders, internal capabilities, internal misfits, blockages, other)

26. Anything to add about the **dynamics of innovation** in your industry?

- What makes for success/ failure?
- How is this changing?

**SECTION 2: ISSUES FOR DISCUSSION- PROJECT MANAGEMENT (SUCH AS PROJECT MANAGER, MARKETING MANAGER, KEY TECHNICAL EXPERT)**

## E. PROJECT MANAGEMENT

### *E.1 PROJECT CHARACTERISTICS*

1. Please briefly describe the **essence** of the project (the product it intended to develop).

2. What was the **origin** of the project? How was the idea defined, evaluated and promoted?

3. Please characterize the key elements of the **external context** when the project was initiated. (market, scientific and technological, regulatory, legal, social, political etc.)

4. Please describe the **sequence** of key decisions, activities and milestones of this project (with an emphasis on knowledge production and problem solving, e.g. prototypes). Concrete dates?

5. What major **unexpected developments and difficulties** affected the project? How did you deal with these issues? What were the factors that favored/precluded an effective response?

### *E.2 PROJECT AND BUSINESS STRATEGY*

6. Please describe the **business strategy** (model) for the project/product (value emphasis, firm's role, revenue sources, partners etc.). How it was established and it how evolved?

7. Please characterize the **organizational context** surrounding the project.
   - Position in the strategy and organization of you firm? Links with other projects?
   - What obstacles did you encounter inside your firm? What was particularly helpful?

7. What **issues, challenges and risks** were anticipated initially? How did you tackle them?

8. What where the key **unknowns** in this project? What approach did you use to obtain or produce the required knowledge?

9. What key **external parties** contributed to the project. What was their role? How were they co-opted and tied to the project (contract, j.-v.)? How relations evolved during the project?

*E.3 PROJECT AND ORGANIZATIONAL ISSUES*

10. How did you obtain **resources** for the project? How were resources renewed, allocated and controlled over the lifecycle of the project?

11. What key measures you took to **organize** for this project? How did the project organization evolve? (charter, product development process, activity and resource planning and control, type and composition of project team, internal structure, technical/scientific board, etc.)

12. How do you **structure your portfolio of innovation** projects? (project types, sizes, stages; technology demonstration vs. product development; internal R&D vs. external ventures etc.)
    - What objectives do you pursue in managing your portfolio?
    - How do you evaluate, balance and integrate your portfolio as a whole?
    - How do you decide to start a new project? How do you make go/no go decisions?
    - What are the strengths and weaknesses in the current structure? Why have they occurred?

13. How do you **manage innovation projects** in your firm?
    - Standard product development processes. If possible, please draw or provide chart.
    - Resource allocation and planning practices.
    - Integration of user-related knowledge regarding operation and functionality.
    - Coordination among different functions and firms involved in the project.
    - Important definition, evaluation, development, monitoring and testing practices.

***E..4 PROJECT AND KNOWLEDGE***

14. How did you **integrate** the knowledge and contributions of different internal and external participants to this project? How successful were your efforts to draw on their knowledge?

15. How do you ensure **cross-pollination** among different innovation projects?
    - How important is to share knowledge across projects? Why?
    - How do you foster sharing over time? What techniques of have you tried? How do they work? What effect has the formal structure and incentives on sharing?

16. How did you **transfer** the innovation to production, business units, or external partners for manufacturing and commercialization?

***E.5 PROJECT PERFORMANCE***

17. What are the achievements of the project (ex. schedule and budget compliance, patents, costs, sales, agreements, technical achievements, licenses sold, IPO etc.)? How do you see the perspectives for success (market, financial, strategic etc.) of the product?

18. How do you ensure that innovations realize their potential and do not get bogged by internal and external obstacles? Give a few examples of obstacles and solutions (champions, internal venturing, corporate teams, coalition building, lobbying, educating, IP management).

19. How satisfied are you with the current **innovative performance** of your firm?
    - Innovativeness relative to other firms in the same sector.
    - Contribution of innovation to firm's growth and profitability and to shareholder value.
    - Key positive or negative factors that affect your ability to innovate successfully.

20. Changes in the way you manage innovation that would improve innovative performance

**SECTION 3: ISSUES FOR DISCUSSION- FOCUS ON MARKETING MIDDLE MANAGER (PROJECT)**

1. What was the **market context** when the project was initiated? How familiar was your firm with this market? How uncertain and unpredictable was the market? Why?

2. What was the **place of this project** in the overall market strategy of your firm? How was it related to and integrated with other innovation projects, including those of your partners?

3. What steps did you take to understand and characterize **customer needs** with respect to the product? How did you incorporate this knowledge into the development, design process?

4. How did you assess the **sales potential** for the product?

5. What key **issues, risks and uncertainties** did you anticipate for the successful development and commercialization of this product? What did you do about them?

6. What was the **marketing strategy** for this product (key customer value dimensions, positioning, product concept, pricing, promotion, distribution etc.)? How did you define it?

7. How did you work with other **internal participants** (R&D, finance, manufacturing etc.). What impact had the organizational and project structure on your collaboration?

8. What **entities outside** your company played a key role in the development and launch processes? How did you work with them? What obstacles did you encounter?

9. How did customer **needs evolve** during the project? What led to these changes? How did you learn about these evolutions? How did you react to them?

10. What other **unexpected market developments** occurred (new competitors, products, substitutes, applications)? How did you react? What precluded an effective response?

11. What additional **strategies** were used to assess **market acceptance** as the team developed functional prototypes? What did you learn? What remained unclear? How did you react?

12. How did you **organize for commercialization** (transfer product to internal business units or partners outside your company, roll out the product to customers, stimulate its diffusion)?

13. What **difficulties** did you encounter during the initial stages of commercialization? How did you deal with these difficulties? What favored/precluded an effective response?

14. How would you characterize the current and potential market **performance** of this product? How reliable were your early assumptions about the market?

15. How **effective** were market research, product development and commercialization processes? How do they compare with those in other projects or firms you have known? How have such processes evolved over the past few years? What would you do differently in the future?

**SECTION 4: ISSUES FOR DISCUSSION- FOCUS ON KEY TECHNICAL EXPERT (PROJECT)**

1. What are the **key features of the technology** used in your sector. How does technology evolve? Who are the key actors that drive this evolution?

2. What was the **degree of technical novelty** of this project compared to existing products, to other projects in your company? What was its role in the technological strategy of your firm?

3. What role did you (R&D) play in **understanding the application domain** and the concrete user needs (requirements). What role did you play in defining the business case?

4. How the **technical objectives** (specifications) of the project have been established? How did you assess the feasibility and the technical risks involved in achieving these objectives?

5. Please describe the main **stages and activities** of technical development. What were the major issues that you anticipated for this process? How did you deal with them?

6. How did you approach the **key technical problems** and challenges of this project? How did you obtain or produce the knowledge required for solving them?

7. How did you develop the **technical concept** and architecture of the product? Which factors influenced your decisions? How did you demonstrate the viability of the concept?

8. What **external entities** played a key role in the technical development? How did you work with them? How successful were your efforts to integrate their knowledge?

9. How technical **objectives evolved** over time? Why? Who approved changes? How did you adjust to the changes? How progress was monitored? When the product was deemed ready?

10. What **unexpected difficulties** and external changes affected technical development? How did you react to these events? What factors favored or precluded an effective response?

11. Please characterize the **relations** between the technical experts and the other participants (e.g. marketing). How technical results impacted the business aspects of the project?

12. How was the **transition** to production and commercialization organized? What was your role in educating business units on the functionality of the product and in its external promotion?

13. What difficulties surfaced during **final testing and early commercial** exploitation of the product? How did you deal with them? What favored/precluded an effective response?

14. How would you characterize the **technical achievements** of this project?

15. How **effective** were the **processes** and approaches you used? How do they compare with those in other projects or firms you have known? How have such processes evolved over the past few years? What would you do differently in the future?

# APPENDIX D: MINE RESEARCH PROGRAM PROPOSAL

ÉCOLE POLYTECHNIQUE MONTRÉAL

MINE PROJECT
MANAGING INNOVATION IN THE NEW ECONOMY

## RESEARCH PROPOSAL

**GENERAL SUMMARY.** The management of innovation is important to Canada's competitiveness in the global economy. Competitiveness results from the interplay between institutional conditions and human resources on the one hand, and the strategies developed by firms, on the other. This project is about the effective ways by which firms create and capture value through strategies and capabilities for innovation. The program is multidisciplinary and covers a wide range of industrial sectors from several perspectives. It is particularly oriented toward Canadian needs but is international in scope. It details, documents, and amplifies the Letter of Intent submitted to the INE program on Nov. 9, 2001.

**(A) The New Economy.** The last 20 years have seen a dramatic shift from capital- and energy-intensive large-scale production, standardized products, structured competition and large hierarchies with integrated labour movement[1] to the emergence of a New Economy[2] based extensively on new knowledge and information. This new era was ushered by unprecedented numbers of industrial innovations,[3] intensive entrepreneurship in both high- and low-tech sectors,[4] infusions of venture capital and market deregulation,[5] such factors contributing to the emergence of large numbers of new firms. Governments, for their part, have been shifting from a Keynesian approach to the building of climates conducive to private-sector initiatives, as well as national and regional systems of innovation.[6-9]

**(B) The Origin of this Research.** This proposal builds upon an initiative led by Prof. Miller in 2000, jointly with the Innovation Management Association of Canada (IMAC) and the Industrial Research Institute (IRI) in the United States, to conduct an exploratory study of the impact of the New Economy on the management of industrial innovation. The study revealed that managing innovation is a matter not only of adopting best practices, but also of mastering value-creation games and selecting a strategic position based on the capabilities of the firm. The study was well received by industrial leaders but the sample of firms was too small and too limited in time; hence, the present project.

**(C) Research Objectives.** The main objective is to develop a grounded multi-level theory of industrial innovation linking games, strategies of firms and dynamic competencies. Supported by empirical evidence, this theory will offer practical recommendations to executives and government officials. To achieve this, the factors that promote or deter the dynamic efficiency of innovation processes must be fully understood. The challenge is to get knowledge and resources flows to bear quickly on products and services that meet the needs of customers and society, and to design incentives for risk taking. We also want to identify the approaches by which firms can achieve higher levels of innovative and economic performance in their specific domain.

**(C) Research Team.** A team of 22 research scholars from Canada and abroad has been assembled by Prof. Miller to carry out this project, which is strongly supported by Canadian industry, both leading firms and industrial associations. It will be managed from the Ecole Polytechnique and involves researchers from 5 Canadian universities, together with MIT, University of North Carolina, University of Sussex (UK), and the University of Torino (Italy). A number of disciplines are involved: engineering, management, economics, and social sciences. All parties will be linked by a Web-based intranet.

**(D) Research Program.** Starting from the MINE research model, a set of at least 30 hypotheses will be tested empirically. The field data will be from two sources: (i) a cross-sectional on-line questionnaire survey of 1,500 firms from Canada and abroad, and (ii) 100 case studies of the evolution of strategies and practices in 10–12 games of innovation.

**(E) Training.** This program will have a strong impact on creating a new generation of research scholars in innovation policies, strategies and practices, primarily in Canada. More than 40 MSc, PhD and postdoctoral students will be trained. Research findings will serve as a basis for training university students and executives in innovation management. Seminars, conferences and publications will ensure wide dissemination of results. On-line hot-topics sessions and forums will also assist.

**(F) Budget.** Our detailed budget calls for a contribution of $750,000 a year from SSHRC for 4 years and an equivalent sum from Canadian industry to help us carry the program to successful completion and ensure the widest dissemination of our research results, including training of executives. The major conditions for success, we believe, have been assembled.

## 1. OBJECTIVES

The main objective of this research is to develop a grounded multi-level theory of industrial innovation linking innovation games, strategies and dynamic competencies of firms. This theory will suggest practical recommendations to executives and government officials. To build an empirically tested theory, we need to understand the interplay between:

(i) the factors that promote or deter the dynamic efficiency of innovation processes in the environment of firms, The overriding issue is to discover efficient ways of organizing value-creation flows that absorb scientific and technological knowledge and bring them to bear quickly and efficiently on products and services that meet the needs of customers and society. Thus, we want to identify the structures that offer adequate rewards for the risks involved in innovation in order to attract investments, avoid excessive institutional barriers, minimize unneeded efforts such as prolonged wars on standards, and facilitate the diffusion and adoption of new products.

(ii) the strategies and capabilities of the firms. For this, we must identify the effective strategies, capabilities and practices that enable firms to position themselves within these flows of value creation and capture and improve internal innovative processes. The intent is to identify the approaches by which firms can achieve higher level of innovative and economic performance in their specific domain.

Our basic premise is that not all domains of innovation are similar. Some are characterized by high scientific and technological fertility, while others are not; some operate within regimes of heavy regulation, while others do not; some sell to individual consumers, while others sell to expert buyers; and so on. Our central thesis is that these exogenous conditions lead to distinct patterns of inter-organizational cooperation and competition.

In developing this new approach, we will train a team of promising young scholars who will gain a realistic understanding of innovation and develop solid theoretical frameworks. These scholars will participate in the research design, selection of firms, data gathering, data analysis, theory building, and wide dissemination of the research results and their incorporation in advanced training programs.

## 2. THE GROUNDED ORIGIN OF THIS RESEARCH

The impetus for this research came from the concerns raised by chief technology officers and R&D executives of the IRI regarding the context created by the New Economy. Our research journey began by clarifying with them the problems they faced. Next, we undertook qualitative grounded theorizing[10] because the literature offered only partial answers. We did 75 face-to-face interviews with executives from a variety of firms and industries in North America and Europe. We then elaborated a theoretical framework and a structured questionnaire with 156 items. Then, we undertook exploratory quantitative research in 2001 by gathering data in face-to-face meetings with executives and noting their comments. The resulting 73 questionnaires were analyzed using statistical procedures such as principal components and correlation analysis. Two conclusions emerged: (i) several different patterns of innovation appear across industries, and (ii) the strategies, capabilities and practices of firms are constrained by the game in which they play. Even though our exploratory results opened up new pathways for understanding innovation in the New Economy, our sample was too small to validate our conclusions. We need to expand our field data and build a theory from field observations and discussions. The present proposal outlines a set of testable hypotheses and a research strategy that builds on our exploratory work.

## 3. THEORETICAL FRAMEWORK

As shown in Figure 1, the theoretical framework comprises: (i) a "supra-organizational" level referred to as "games of innovation," which involves many players linked by knowledge and resource flows, and by patterns of competition, cooperation and mutual coordination; (ii) an organizational level, which refers to strategic positions and capabilities of game participants; (iii) a sub-organizational level which consists of practices that firms put in place in order to achieve the desired capabilities. This model includes the fit between real games and the "ideal" type corresponding to theory.

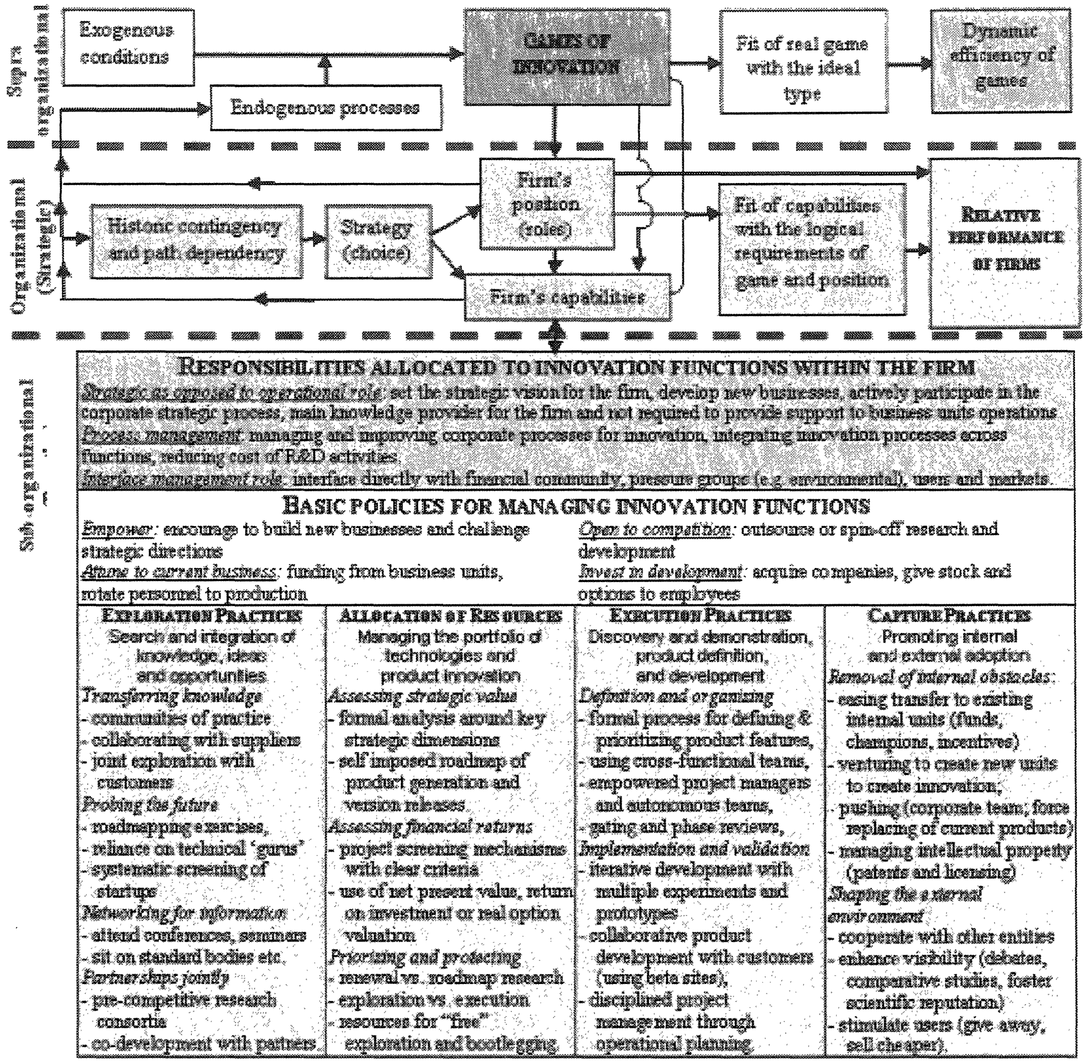


**Figure 1- Multi-level model of innovative capabilities for playing games of innovation.**

**3.1 Games of innovation.** This concept refers to the relevant task environment[11,12] of innovating firms and other players such as universities, venture-capital groups, public regulators, and stakeholders. The term "game" is used as a metaphor to stress the fact that firms find themselves in structured contexts that constrain their approaches to innovation although, within the given rules, they have ample strategic freedom. The game influences the strategies and capabilities of firms somewhat as an ecosystem influences the characteristics of species. The boundaries of a game are more comprehensive than industry structures[13,14] which focus on competitors, but narrower than a national or regional system of innovation,[15,16] because games are limited to a specific domain of value creation.

On the other hand, the networks within a game often spread globally. We define a game of innovation as an inter-organizational system characterized by:

- • A dominant logic of collective value creation and capture
- • A configuration of participants (size, type), value-creation roles, propensities for competition and cooperation, and 'scenarios' for negotiating and jointly implementing innovation
- • A particular network of information and knowledge flows between the participants
- • A governance structure—i.e. an arrangement for coordinating and influencing the efforts of the participants, with specific degrees and loci of deliberate network control, directions of resource flows (e.g. people, purchase orders, capital), and risk-sharing arrangements
- • Particular dynamics of innovative activities, with intensities of entry and exit, sustainability of incumbent positions, overall path and speed of change and turbulence, and types and amounts of innovative production
- • A reward structure characterized by an overall potential profitability, risks and growth horizons, and a differentiated ability to capture value among participants

The "*dominant logic of collective value creation*" is a construct based on the observation that participants in a game converge on coherent objectives and emphasize specific innovative activities. Preliminary statistical analyses of our data indicate that four vectors explaining 65% of the variance characterize these value-creation activities:

**1. Productizing knowledge**: transforming academic research and intellectual property into new products and accelerating regulatory approval (as opposed to cost reduction and quality enhancement for existing products). Productizing creates value by using different knowledge principles to produce new products or enhance the performance of existing ones.

**2. Matching users' needs** by generating a variety of products and features and customized solutions for complex and unique applications, in response to anticipated needs of clients. This logic creates value by more closely matching products' features and performance to evolving user requirements.[17]

**3. Stabilizing architectures** of interconnected products by maneuvering them to become *de facto* standards, or aligning products on dominant architectures (as opposed to focusing on products seen as stand-alone). This logic creates value by reducing customers' uncertainty with respect to the sustained relevance and interoperability of the products.

**4. Engineering reliability and safety** into complex products, by relying on systems engineering and other techniques (as opposed to designing simple non-critical products). This logic creates value by reducing users' and regulators' uncertainty with respect to product functionality, risk of failure, accidents or side effects.

<table>
<tr><th colspan="5">LOW DEGREE OF INFORMATION AND EXPERTISE OF CUSTOMERS</th></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Scientific and technological potential in the areas that provide knowledge to the game</td></tr>
<tr><td>High<br>(exogenous advances)</td><td>Average<br>(endogenous advances)</td><td>Low<br>(marginal advances)</td></tr>
<tr><td rowspan="3">Structuring potential</td><td>High<br>(exogenous structuring)</td><td rowspan="2">Structured races<br>Biotechechnologies,<br>Fuel cells,<br>Nanotechnologies</td><td>Safety journeys<br>Agri-business,<br>Food products;<br>Chemical drugs,<br>Medical equipment,<br>Aerospace)</td><td rowspan="2">Asset-based problem solving<br>Mining, Oil and Gas;<br>Forestry, Pulp, Paper<br>Wood Products;<br>Public utilities<br>(water, power<br>regulated telecom,<br>gas)<br>"Learning and marketing"<br><br>Automotive and<br>Transportation<br>Equipment</td></tr>
<tr><td>Average<br>(endogenous structuring)</td><td>Battles for architectures<br>(Mass software,<br>Computers,<br>Office equipment,<br>Networking equipment,<br>Internet and telecom services;<br>Microelectronics &<br>Optoelectronics)</td></tr>
<tr><td>Low<br>(weak mechanisms)</td><td colspan="2">"Gadgets"<br>E-contents providers (AOL-Time Warner, etc.)<br>Medical and Health Services</td><td>"Novelties"<br>Financial services,<br>Mass consumer products</td></tr>
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<table>
<tr><th colspan="5">HIGH DEGREE OF INFORMATION AND EXPERTISE OF CUSTOMERS</th></tr>
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<tr><td rowspan="3">Structuring potential</td><td>High (exogenous structuring)</td><td rowspan="3">Research and Development Services<br>Scientific instruments, Tools for design (drugs, electronic chips, CAD/CAM) Analytical services, etc.</td><td colspan="2"></td></tr>
<tr><td>Average (endogenous structuring)</td><td colspan="2">DELIVERING INNOVATIVE SOLUTIONS IN PACKS<br>Chemicals, Cement, Building Products;<br>Metallurgical (aluminium, steel, etc.)</td></tr>
<tr><td>Low (weak mechanisms)</td><td>System design and consulting services<br>Systems Engineering (MIS, knowledge management etc.)</td><td>High tech craft<br>Computerized manufacturing, Robotics, Simulators, Aircraft and Aerospace</td></tr>
</table>

Participants in each game face a value-creation logic shaped by one or several of the above vectors, leading to distinct game configurations. Each logic is caused by a combination of exogenous contextual factors that game participants cannot influence in the short or medium term.

Proposition 1. **Distinct configurations of contextual elements lead to distinct dominant logics of value creation and capture.** The literature review and our field research led us to the identification of a series of contextual (exogenous) factors that were converted into questionnaire items. Statistical analysis of data from our exploratory survey led us to the identification of three exogenous factors explaining 57% of the observed variance. Further grounded theorizing led us to the following three key dimensions:

(i) The production of scientific and technological knowledge that can potentially be applied to new products and processes. We divided this dimension into three levels of intensity: (1) high: continuous flow of "exogenous" knowledge production, representing fundamental advances often originating with universities, public laboratories or independent inventors and yielding radically new approaches (e.g., genetics); (2) average: "endogenously" produced knowledge, often achieved by incumbent firms and representing significant extensions of the basic principles (e.g., semiconductors); and (3) low: only marginal exogenous or endogenous advances (e.g., mining).

*(ii) The potential for game structuring* refers to the likelihood of emergence of institutionalized mechanisms, such as markets, collective strategies, standard designs, and regulatory frameworks, that create barriers, lock in or lock out technologies and players, protect intellectual property, and so on. This allows protection of the investments made in innovation. We divided this dimension into three levels: *high* - likelihood of "exogenous" structuring, such as effective IP protection, structured scientific communities; *average:* likely "endogenous" structuring potential, resulting from dominant designs, interface standards, technical and knowledge architectures. and important network, scale, and learning economies; *low:* only "weaker" mechanisms, which result in fads, fashions, and so on.[18-20]

*(iii) The degree of information and expertise of buyers* influence games by creating additional challenges and providing additional "know what."[21] Buyers of consumer electronics, cars and even drugs are *moderately informed* whereas buyers of

optoelectronic parts, semiconductor equipment, or packaging solutions are *highly qualified* and influential in design.

Using these three factors, we produced a typology of 18 possible games, but only 11 are expected (see figure 2) as several will merge. Figure 2 presents the mapping of the 8 games identified in our exploratory research (in boldface), to which we added 3 that games we think are missing because of the small size of our original sample. Our project may uncover other empirical configurations.

**Figure 2. Typology of games as a function of innovation environment factors.**

Before presenting specific research hypotheses, we illustrate here two of the many games in the New Economy: *Battles for architectures* and the *Structured races to the patent and regulatory offices*. The first is characterized by an average pace of technological change, average structuring potential (low regulation, weak patent protection but endogenous structuring potential) and relatively unsophisticated clients, whereas the second features high knowledge production, high structuring potential (regulatory safety approval, intellectual property protection, structured scientific community), and relatively unsophisticated customers.

Value creation and capture also differ. In *Battles for architectures*, participants compete for market domination by identifying architectures and promoting them through partnerships, alliances, and coalition building, e.g., mass software, networking equipment, and telecommunications and Internet services. In *Structured races*, the protection afforded by regulations enables value creation to focus on productizing university research, screening and testing products, and managing the regulatory processes. Akin to a relay race, the resulting intellectual property can be sold to other players.

In formulating hypotheses, our approach is based on the configuration of exogenous and endogenous factors (see Figure 2). We argue that for a given combination of contextual factors, there is a corresponding value creation and capture configuration.

Many specific hypotheses could be developed for each combination of contextual factors, but we present here only three examples:

**H1.1** In games with high science-and-technology potential and high to average structuring potential (exogenous, i.e. regulation, IP protection, safety approval), the dominant value-creation logic focuses on the productizing of newly produced knowledge.

**H1.2** In games with average to high science-and-technology potential and average structuring potential (endogenous), the dominant logic of value creation focuses on stabilizing architectures.

**H1.3** In games in which customers are not expert, the logic of value creation will emphasize product novelty, while in games where clients are expert the logic of value creation will emphasize user needs.

These hypotheses are premised on the interplay between the range of opportunities stemming from the potential of science and technology and the market development and the investment protection afforded by the structuring potential within a game. In the first hypothesis, value creation takes the form of continuous productizing by entrepreneurial firms while in the second one, as the potential for structuring is low, firms focus on endogenous dynamics—i.e., stabilizing architectures. In the third hypothesis, the role played by strong buyers is dominant.

**Proposition 2. Contextual elements and the emphasis in value creation produce games of innovation with distinct structure and dynamics.** Games evolve as the roles, linkages, governance, and dynamics change. In order to present hypotheses, we need to define these elements:

***Configuration of roles.*** Scholars tend to focus on "first-order" value-creation chains such as component supply, manufacturing, assembly, distribution, logistics, marketing, and sales.[22] However, innovation is often structured around "second-order" value-creation activities, such as idea generation, problem solving, trials and selection, coordination and vision making, legitimating, risk bearing, standardization, and knowledge brokering. Second-order activities renew methods, accelerate pace, and enhance the performance or the productivity of "first-order" value-creation activities. For instance, rational drug-design methodologies and software tools lead to cheaper and more targeted drugs. In many cases, innovation roles are defined around the architecture of technical modules and system integration. Hence, we distinguish three networks of roles oriented towards (i) second-order value creation, (ii) technical architectures, and (iii) first-order value-creation chains.

***Structure of network linkages.*** The emerging theoretical consensus is that weak ties (temporary, reversible, opportunity-based collaborations) enable extensive information search, while strong ties (long-term partnerships and alliances) enable joint learning and adaptation. Some authors add that each domain develops a topography of strong and weak ties fitting their needs for information and knowledge flows.[23-24]

Linkages will generally follow the configuration of roles with a dominance of (1) *weak* linkages, which enable fast movement of ideas and easy reconfiguration of coalitions, or (2) *strong* linkages, which enable rich knowledge transfer between participants but are less flexible and mobile.

***Nature of the governance.*** Governance refers to coordination mechanisms often beyond market transactions, necessary to achieve common goals (such as increasing knowledge and legitimating products through regulation) and avoid waste.[25] We observed a range of mechanisms from quasi-hierarchical coordination (a leader imposes conduct on others), to emergent coordination through spontaneous alignment. Achieving a coordinated result may take longer, with less predictable results.

***The dynamics of games***. We distinguish three levels: (i) high and steady flows of innovation and entries of competitors, (ii) sequences of stable lock-ins punctuated by innovative sweeps, and (iii) flows of marginal innovation in stable networks. Below we present two illustrative hypotheses on the relations between the logic of value creation and the game structure and dynamics:

**H2.1** <u>In games where the focus is on *productizing* scientific and technological knowledge</u>:

- - *The configuration of roles will tend to be structured around second-order value-creation activities* because rapidly growing knowledge stocks require specialization and the institutional structure that has been built enables participants to obtain rewards matching assumed risk.

- - *Links across the second-order value chain will be weak* because participants continually pursue new opportunities and re-build temporary coalitions to marshal resources and manage risk.
- - *Quasi-hierarchical governance will be exerted by non-incumbents* (scientific community, regulators, financial institutions), because of their advantage in knowledge, resources, or formal authority .
- - *The dynamics will take the form of high and steady flows of innovation* because competitive positions are contestable based on new knowledge (many entries with clearly superior concepts), and institutional protection of property rights provides entrants with a fair chance of earning returns.

**H2.2** In games where the focus of value creation is on *stabilizing* architectures:

- - *Networks will tend to be structured around competing technical architectures* (in unique or competing alliances) because promoting each of these architectures requires fast parallel development of complementary products around a core platform.
- - *Linkages will be predominantly weak* because firms shift opportunistically between alliances in order to be on the winning side and the gains from joint learning are limited by the relatively high speed with which concepts are produced.
- - *Quasi-hierarchical governance will be exerted* by the owners of closed-source architectures or the sponsors of open-source architectures that control a key knowledge resource (otherwise we will observe emergent coordination).
- - *The dynamics will take the form of repeated lock-ins on architectures* because non-linear effects make dominant positions difficult to contest and new entrants tend to align with the dominant architecture. Dominance will be challenged only when radically superior architectures are proposed; in these cases, rigid large firms and alliances built around old architectures are swept away.[26.27]

**Proposition 3. Games of innovation will differ in their dynamic efficiency as a function of the adequacy of their structure to the logics of value creation to which they are subjected.** Given the imperatives that exogenous contextual variables and value-creation logics impose, each game has an ideal structure resulting in maximal efficacy of innovation processes. However, due to historical evolution, local conditions, dysfunctional endogenous processes, and institutional pressures,[28] some games may adopt structures that waste the resources of firms and society and do not match the required logic of value creation. We call the distance between the ideal type and the observed reality *the dynamic efficacy of the game*.

**H 3.1** The dynamic efficacy of a game will be inversely related to the distance from the logical configuration (ideal type) that corresponds to the conditions in which the game takes place:

To avoid circular reasoning,[29] the construction of the ideal type[30-31] for each game will be based on logical arguments from our theory as well as insights from case studies, as opposed to empirical measures. Ideal types will reflect our interdisciplinary perspectives—institutions, strategy, technology policy—and will be validated through independent evaluation by industry and government experts, as well as modeling and simulation. The distance between ideal profiles and reality, as well as game performance, will be measured using survey and secondary data.

**3.2 Strategic roles and capabilities within games.** Firms position themselves within the relevant game by playing one or several roles and fostering capabilities that fit the role and the dynamics of the game. For example, in "structured races," firms conceive their business model in terms of second-order value creation. They see themselves as creators of tools and services that enhance research productivity. Others see themselves as developers of new products up to phase II clinical trials. Still others will assume risks by providing funds. Finally, some firms will assume most of these roles.

**<u>PROPOSITION 4</u>. ROLES WITHIN GAMES WILL DIFFER IN THEIR INHERENT PROFITABILITY POTENTIAL AND HENCE THE PROFITABILITY OF FIRMS WILL DEPEND ON THEIR RELATIVE POSITION WITHIN THE GAME.** FIRMS ORIENT THEMSELVES ACCORDING TO THE RELEVANT VALUE NETWORK (FIRST ORDER, SECOND ORDER, OR ARCHITECTURE-BASED). WITH A CONFIGURATIONAL APPROACH, SPECIFIC HYPOTHESES CAN BE DEVELOPED FOR EACH GAME. WE PRESENT BELOW HYPOTHESES FOR TWO DIMENSIONS ONLY:

- *The coverage of the network of value creation* is important because it opens opportunities to create value, either through specialization or integration, and it impacts the competitive agility (*via* the size and complexity of the required organizational system). We propose three degrees of coverage: (i) *highly integrated players* cover most of the stages in the value chain; (ii) *sponsors of innovation* assume the risk of innovation projects and integrate the contributions of other firms but do no cover most of the activities; and (iii) *dedicated firms* specialize in one or very few stages of the value chain, often in less risky contractor roles.

- *The position within innovation flows* refers primarily to the distinction between *pioneers* or inventors and *imitators* (early or late). This dimension is important because it involves the ability of firms to retain the benefits of innovative activities. A number of theorists have dealt with the issue of whether it pays to be a pioneer,[32-35] but the question still evades an answer. We argue that an answer is possible only by taking into consideration the heterogeneity of innovation domains.

**H4.1** <u>In games in which the focus is on</u> <u>productizing knowledge</u>:

- *Sponsors will be most profitable* because they develop the knowledge that creates most of the value and will own the corresponding intellectual property; the integrated firms are burdened with irrelevant knowledge while dedicated contractors are not able to capture a large share of value.[36]

- *Pioneers will be most profitable* because exogenous structuring helps retain the created value, via intellectual property protection and regulation that keep copycat products at bay.

**H4.2** <u>In games where the focus of value creation is on</u> <u>stabilizing product architectures</u>:

- *The sponsors of innovation will be more profitable* because they control the architectural design that creates most value, while being faster and more flexible than integrated firms by relying on external suppliers to rapidly develop the complementary modules.

- *The followers will be more profitable*; because they will have the possibility to observe the institutionalization processes and jump on the bandwagon with a superior product; the fluid period[37] before an architecture emerges precludes the accumulation of learning by early movers.[38]

The firms participating in a game will also have to develop organization-level innovative capabilities that will be adapted to the game as well as the role that they choose to play. Even firms that have chosen a less potentially profitable role in a game could attain a good level of performance by fostering appropriate capabilities. They may in fact be more profitable than a firm that selected the right role but did not develop the right capabilities to support that role.

**Proposition 5. The relative profitability of a firm depends on the fit between the capabilities that it develops and the logical requirements of the game and the position that it occupies.** We argue that firms combine a limited number of game-specific capabilities that enable them to compete and innovate in a given game.

Lampel[39] identified four capabilities required for competing in the project-based engineering and construction industry: entrepreneurial capability, technical capability, evaluative capability, and relational capability. Kusunoki[40] argues that process capabilities, emerging from dynamic interaction of modular and architectural knowledge, play a key role games with an engineering value-creation logic. In sum, generic capabilities are not sufficiently adapted and specific capabilities will need to be developed. Moreover, firms will have to develop them internally rather than acquire them. Therefore, historical accidents and path-dependent processes will lead to distinctive capabilities for each firm.[41] The development of a full typology of capabilities is thus one of the key objectives of this research project. Below we present a few examples of capabilities that we observed in various firms:

*Dynamic capability* refers to the ability for fast absorption and integration of information and knowledge, the fast redefinition of goals and configuration of resources.[42] This capability has been presented as a generic panacea[43] but we see it as one among many others, particularly useful in some games, but clearly not the most important source of competitive advantage in others.[44]

**H5.1** Dynamic capabilities are important in games that focus on stabilizing architectures because of the need to overcome sudden sweeps in product architectures and markets.

*Steering capability* includes the ability to marshal coalitions of autonomous participants to supply resources for innovation projects, coordinate contributions from numerous partners and contractors; foster political alliances to influence the adoption of rules and regulations that would legitimate or protect the domain, orchestrate alliances of firms to stimulate adoption of architectures, standards and practices and so on.[37]

**H5.2** Steering capacities are important in roles that involve the sponsoring of innovation projects, which occur in games focusing on productizing and stabilizing architectures.

- *Energizing capability*: R&D personnel often complain that secondary activities (e.g., supporting operations or "putting out fires") dominate, as opposed to activities that open strategic avenues for innovation. A key capability is, then, the creation of conditions and incentives for individuals and teams to perform, provide inputs, and demonstrate the potential of innovation. Moreover, removal of the obstacles to implementation and value capture is required.

**H5.3** Energizing capability is important in domains that focus on engineering and cost reduction because an apparent lack of opportunities tends to distract from innovation.

**3.3 Practices within organizations.**

**Proposition 6. Few practices are significantly related to performance across games, but within games there are many significant relationships between practices and performance.** Organization-level capabilities result from a system of concrete practices used in different areas of the organization. Each practice that a firm adopts must enhance systemic capability. Hence, contrary to Eisenhardt and Martin[29] who maintain that there is a significant area of universal "best practice", we argue that attempting to apply a generic set of practices is often inadequate and even counter-productive in some games.

Figure 2 presents the results of our preliminary research with respect to the structures and practices favored in different games.

**Proposition 7. Within games, the relative performance of firms is related to the fit between their structures and practices and the requirements of needed capability.** Our exploratory study of innovative practices and their role in developing organizational capabilities led us to the six categories shown in Figure 1. Their underlying dimensions are illustrated by specific practices. We present below the hypotheses related to achieving *dynamic capabilities*:

**H7.1** Firms with high capabilities assign a strategic role to innovation activities, while firms with low capabilities give innovation activities a subordinate or minor role. (Strong inputs of innovative functions in the definition of strategy are needed o detect early signals on new trends).

**H7.2** Firms with high capabilities will more directly couple their innovation activities to their external stakeholders (universities, public markets, venture capital), while firms with low capabilities will more directly couple innovation activities to their internal business units. (Direct coupling will increase their ability to detect new trends and answer better the concerns of their stakeholders.)

**H7.3** Firms with high capabilities will allocate more resources to exploration practices for identifying new opportunities and ideas, while firms with low capabilities will allocate more resources to exploitation practices for taking advantage of existing knowledge and markets. (Extensive exploration will enable firms to map the spectrum of opportunities and probe new developments early.)

**H7.4** Firms with capabilities will emphasize strategic-fit criteria, while firms with low capabilities will emphasize financial criteria in managing their portfolio of innovation projects. (Financial criteria are difficult to apply in market turbulence. The best option is to judge whether the innovation projects can pave the way to new technologies and lead to promising application markets.)

**H7.5** Firms with low capabilities will put more emphasis on structured development practices, while firms with high capabilities will de-emphasize such practices. (Structured product development builds on gradual accumulation of knowledge, whereas the continuous embodiment of features into products requires flexible project management.)

**H7.6** Firms with high dynamic capabilities will put more emphasis on removing organizational obstacles to innovation and on cooperation practices to stimulate external adoption of new products, while firms with low dynamic capabilities will emphasize intellectual-property management to capture value. (Venturing will short-circuit organizational obstacles while cooperation will accelerate adoption.)

**3.4 Game evolution.** We argue that the basic structure of games of innovation remains stable in spite of the shifting technology and market dynamics that affect them. Major reconfigurations of games, such as the transition of pharmaceuticals from chemistry and large-firm leadership (*safe journey* game configuration) to biotechnology and small firm leadership (*structured race* game configuration), are rather rare (25 years and more).[45] Moreover, similar game structures can be found across historical periods. Our study of the early railroad and power industries reveals interesting parallels with the emergence of the Internet. For instance, the emergence of the railroad industry was characterized by battles between incompatible architectures and incompatible standards, innovative financial and business models, and "irrational" investment bubbles followed by crashes.[46]

Therefore, we expect to see and study two types of dynamics

***(1) Gradual co-evolution of game structures, strategies and capabilities, and practices.*** As shown in figure 3, we expect that game structures will evolve while they reproduce the same basic pattern as a result of actions, learning, and adjustment to socio-political pressures. Yet, firms will learn to play new roles, alter their capabilities, and develop new practices.

***(2) Radical transitions between types of games.*** Although much rarer than implied by some scholars and the media, radical transitions nevertheless take place. Therefore, we need to understand how structures are destabilized by radical discontinuities—how participants absorb radical changes, migrate across games, and are able to grow over long periods of time or, alternatively, fall victim to discontinuities because rigidities delay adaptation to change.

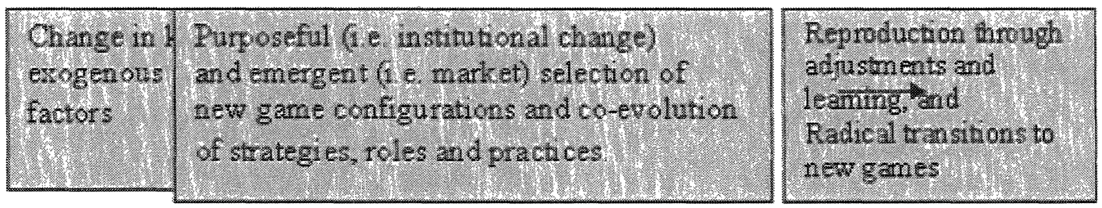


**Figure 3.– MINE model of the evolution of games of innovation.**

## 4. RESEARCH STRATEGY AND METHODS

Validating the MINE theoretical framework requires both cross-sectional comparisons between games, strategies, and capabilities of firms and practices in order to test hypotheses on the factors leading to higher performance, and longitudinal studies to understand the conditions and processes associated with the co-evolution of games, strategies and practices. Prior to undertaking field-research activities, we must arrive at a common understanding and sharing of methods.

**4.1 Sharing a common methodological perspective.** Our experience with large research projects is that the quality of outputs depends on careful front-end planning and development of the research strategy. The anticipated scope of the work supposes that a number of semi-autonomous teams will gather and analyze the data. To enable cross-team comparisons, ensure coherence in thinking and achieve comprehensiveness in data gathering, we need to jointly develop and convey to each team a research plan, standardized methods, expected outputs and quality standards. Prior to data gathering, four methodology teams will be formed to finalize and share a standardized approach:

**(1) Quantitative cross-sectional survey instrument** (team: Miller, Floricel, Michela). The survey will be the main source of data for cross-sectional comparison. We already have an instrument, but our exploratory research has revealed a need to eliminate a number of measurement items and add about 15% new items to better cover issues such as roles, strategies, capabilities and performance. We are planning for an on-line instrument that could be answered in 45 minutes. The team will also develop a strategy of sampling and hypothesis testing.

**(2) Case studies** (team: Langley, Floricel) will be the main approach for studying dynamic processes in games, strategies, and firms. We have to ensure that all data-gathering teams share the same definitions of terms, have a common understanding of the research themes and cover the entire scope of desired data. Case studies must cover the main events, players, perceptions, strategies, relations, and structures. Data analysis must identify evolutionary sequences. Hence, the team will propose unified themes, codes, constructs, analysis templates (e.g., required figures and tables) and report formats.

**(3) Quantitative secondary data and time series** (team: Pavitt, Nightingale, Beaudry) will survey methods and the qualitative process research with "objective" indicators such as patent and citation counts, industry entry levels and concentration, R&D expenditures, new product introductions, sales levels and growth, number of regulatory decisions), costs, product prices, and so on. The team will identify reliable sources and set criteria for data gathering.

**(4) Qualitative historical methods** (team: Bean, Olleros, Fleck) will establish the rules for validating historical sources and data, as well as approaches for studying processes over long historical periods

The preliminary methodological effort will conclude with a two-day seminar in which each team will present and discuss the studied methods and educate the researchers who will perform the data gathering and analysis activities. By the end of the seminar, we will have an approved, standardized, and appropriate methodological approach.

**4.2 DATA GATHERING AND PRELIMINARY ANALYSIS.**

**4.2.1 The survey** will be performed using a secure Web site, which respondents will access using a password to enter their data on-line. The survey will target 1,500 firms (of various size) across 20 industrial sectors, with some 1,000 firms representing the New Economy and 500 the Old Economy in Canada, the United States, Europe, Asia) and Latin America The selected sectors are: (1) agri-business and food products; (2) aircraft and aerospace; (3) automotive and transportation equipment; (4) biotechnology and pharmaceuticals; (5) financial services; (6) chemicals, cement and building products; (7) computers and office equipment; (8) consulting (MIS, knowledge management etc.); (9) E-content providers; (10) medical and health services; (11) computerized manufacturing and robotics; (12) mass consumer products; (13) mining, oil and gas; (14) metallurgical (aluminium, steel, etc.); (15) microelectronics & optoelectronics; (16) forestry, pulp & paper and wood products; (17) software (specialized & mass); (18) scientific and measurement instruments, (19) networking equipment, (20) water and power utilities.

A dedicated group led by a full-time survey professional will perform the following activities: design and maintain the Web site and the afferent databases, identify potential firms from publicly available directories (*listed in stock exchanges or funded by venture capital*) and contact them to solicit participation, assist contact persons in filling the questionnaire, gather secondary data on firms, and ensure data quality. The group will also do descriptive data analysis, provide information to senior researchers and send standardized feedback reports to participating firms.

**4.2.2 Case studies** will be performed at three levels (the evolution of the game, of firms' positions and capabilities, and of practices). We will study 11 or 12 games, and within each one we will cover 2 industrial sectors and 10 firms. We will have 6 teams, each composed of 2 faculty, 2 doctoral students, 1 postdoctoral fellow or industry participant, and MSc-level research assistants. Each case study team will study 2 games (2 industries and 20 firms). Team leaders will be (1) Miller and Bourgault, (2) Floricel and Olleros, (3) Pavitt and Nightingale, (4) Paradi and Smith, (5) Hafsi and Langley, (6) Miller and Beaudry. Other teams might be formed if the need arises.

Team members will travel to partner organizations and will conduct individual face-to-face interviews, lasting 1 to 2 hours, with 3 to 5 executives per firm, as well as with about 10 experts for each game, such as venture capitalists, regulatory agency officers, consultants, and industry association executives. All interviews will be recorded, transcribed, and entered into the MINE Structured Knowledge Base. The groups will also gather historical and secondary data on the games assigned to them. In the end, they will produce a report on each game and a case study for each firm.

### 4.3 Data Analysis and Theorizing

***(1) Exploratory survey data analyses.*** The survey results will be analyzed using statistical packages to probe dimensionality and clustering in our data and compare them with the *a priori* dimensions of our typology of games. This stage will yield a rich taxonomy, a full description of games and many useful statistical relationships.

***(2) Analysis of case studies.*** Innovation game reports and other longitudinal and historical data will be analyzed using *within-case analysis*, *nested-case analysis* (games and participating firms), and *comparative analysis* (across games and historical periods). This will enable us to uncover co-evolutionary and transformation sequences and to make predictions about the necessary conditions for dynamic efficiency of games. Software such as NVivo will be used for content analysis.

***(3) Modeling and simulation.*** Using system dynamics, organization modeling, and specific programming (leader: Beaudry), we will validate the process models developed with case studies and survey data.

***(4) Hypotheses testing.*** The testing of our hypotheses will require building ideal types of games, positioning of firms, and organizational capabilities. As indicated above, we will measure the distance between logical configurations and observed reality. We will also use the survey and secondary data to test the relations set forth by our framework and hypotheses.

***5) Integrative theorizing.*** A special group of co-applicants (Miller, Bean Floricel, Langley, Lessard, Pavitt) will act as a sounding board for building an integrative theory of industrial innovation and positioning this theory vis-à-vis other theoretical approaches. This group will also identify the constructs, dimensions and relationships to be emphasized.

***6) Specialized theorizing.*** The breadth of our framework will enable us to develop prescriptions relative to several important issues in the New Economy. We will form a number of working groups to assemble theory, survey data and case studies. This will enable us to develop clear points of view on issues of direct relevance to our stakeholders. The purpose is to build knowledge on issues that cut across various games of innovation, such as intellectual property protection, strategic planning and technology, risk taking and financing policies, incentives for internal entrepreneurship, technology and product portfolio management, methodologies for exploration of science and markets, organizational transformations, strategic thrusts and competitive dynamics, and capabilities for effective innovation.

***4.4 Innovativeness of our Approach.*** *To our knowledge, this is the first framework that spans three levels of reality—supra-organizational, organizational, and sub-organizational (see Figure 1) —and links them in coherent but pluralistic configurations. The multilevel nature and configuration of the framework results in what Langley[47] and Ofori-Dankwa and Julian[48] call a "complex theory."*

This framework shows that highly innovative performance requires building capabilities at several levels, in ways that are sometimes counter-intuitive because of the systemic effects and often contrary to what "best practice" seems to suggest. Some levers are well under the control of managers, while for others they must cooperate with other players. Finally, in many cases all they can do is understand the flow of knowledge and resources and find suitable positioning within a game.

The inclusion of the supra-organizational level takes in to account that innovation is a collective problem-solving activity shared between co-specialized organizations, each competent in solving parts of the problem[49-50] and sharing risks and rewards.[51] Hence, focussing on the inside of one organization is not sufficient. Relevant actors must learn how to steer the efforts of other participants.

Our framework also accounts for the specificities of different contexts. This means that there is no one best practice, but each contexts calls for a distinct yet coherent set of strategies, capabilities, and practices.[52-54] With such an approach, even in the starkest contexts, some innovative firms manage to develop capabilities and strategies that lead to superior results. Innovation is considered to be a phenomenon occurring over time. Games of innovation, roles played by firms, and their capabilities and practices evolve and change over time. In general, these changes occur within the same basic structure; only rarely are there dramatic transitions from game to game. Only by understanding the different dynamics of games and their underlying structures, as opposed to postulating complete turbulence and chaos, will we be able to produce innovation in efficient manner.