Organizational Policies Which Promote Innovation in the Product Development Process

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Submitted to the Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of

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and

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in Conjunction with the Leaders for Manufacturing Program at the Massachusetts Institute of Technology

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ABSTRACT

Innovation is a topic which grips many companies and forms much of the basis for designing organizational processes. As companies strive to maintain a competitive advantage in the marketplace, the company that can best continue to develop innovative solutions to customer needs is at a distinct advantage. However, fostering a culture of innovation is not easy in the best of circumstances. The situation becomes even more difficult as organizational size increases, straining communication channels.

An automotive supplier was chosen as a case study to examine corporate innovation because of its unique situation. This components supplier was recently spun off from a larger automobile manufacturer. In a very short period of time this company has had to realign its business processes, improve its communication structure across the company, build a customer network, and learn how to develop and build products for the competitive market.

This thesis examines the published theories of innovation and innovation processes. It then investigates some new automotive technologies and trends which are driving change in the industry over the next decade. This is to provide guidance in some of the areas where innovation will be necessary in the future. Then, through extensive research conducted onsite, this thesis helps identify many of the key attributes a company needs if it wants to succeed as an innovative organization. These attributes are considered in combination with published literature to help examine what actions companies in similar situations can best take to ensure success in the marketplace.

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BIOGRAPHY

Most thesis do not necessarily include a biography, but since this is my chance to document to the world some of the work that I have done, I thought I would tell you something about myself. I completed my engineering undergraduate education at the University of Victoria, in Canada. There, under the mentorship of Dr. David Scott, I gained an interest in alternative energy technologies such as fuel cells and electric vehicles. I had the chance to publish and present my undergraduate research at the World Hydrogen Energy Conference in 1994. Upon graduation I began working for a start-up research and development company, BC Research. Here I performed a wide variety of engineering tasks, but the most significant was my assistance in the development of a hybrid electric vehicle, which was used as an experimental platform for testing hybrid electric control technologies. During my time at BC Research, I had the extraordinary opportunity to live in Japan on a Rotary Foundation scholarship, studying the language and culture. Some time later, after leaving BC Research, I had the chance to spend six months travelling throughout Australia and the islands of Indonesia, also meeting people and experiencing new cultures.

I returned to Canada in 1997 and began working as a research engineer for a fuel cell development company, Ballard Power Systems. After three years there I had seen many aspects of the research and product development required in the fuel cell industry. Recognizing the importance of excellence in manufacturing for the success of fuel cells, and having been recently accepted and registered as a Professional Engineer, I enrolled at MIT in the Leaders for Manufacturing program. I have found my last two years to be extraordinary fulfilling and could not have asked for a better group of colleagues and professors to share my experience. I hope to continue my work developing and commercializing new technologies, especially those that promote the betterment of the world.

ACKNOWLEDGEMENTS

I wish to acknowledge the Leaders for Manufacturing Program for its support of my work. As well, appreciation goes to my good friend, Carol Ann McDevitt, who was invaluable in helping me write a thesis, and to all of my other friends at MIT who made my LFM experience so memorable. Sean Hilbert and Mike Kimber will always be appreciated for their efforts to make my internship a successful one. I learned a great deal from their different styles and I can only hope to present the same hospitality to others in the future.
# TABLE OF CONTENTS

1.0 Introduction ................................................................................................................................. 7
1.1 Background .................................................................................................................................. 7
1.2 Recent History ............................................................................................................................... 9
1.3 Objectives .................................................................................................................................... 9

2.0 Current Literature Regarding Innovation and Product Development ........................................ 11
   2.1 Types of Innovation and Definitions .......................................................................................... 11
      2.1.1 Creativity, Invention, Exploitation and Innovation ............................................................... 12
      2.1.2 Incremental and Breakthrough Innovation ......................................................................... 13
      2.1.3 Architectural and Modular Innovation ............................................................................... 15
      2.1.4 Autonomous and Systemic Innovation ................................................................................ 16
      2.1.5 Sustaining and Disruptive Innovation .............................................................................. 17
   2.2 Why Innovation is Important .................................................................................................... 19
   2.3 The Innovation and Product Development Process ................................................................. 20
      2.3.1 Cooper ................................................................................................................................. 21
      2.3.2 Ulrich and Eppinger ........................................................................................................... 22
   2.4 How Innovation Should Be Encouraged in Organizations ..................................................... 25

3.0 Future Trends In Automotive Power Trains .............................................................................. 29
   3.1 Industry Forces ......................................................................................................................... 29
   3.2 Advanced Internal Combustion Engines .................................................................................. 30
      3.2.1 Cylinder Deactivation .......................................................................................................... 31
      3.2.2 Camless Engines ................................................................................................................ 32
      3.2.3 42V Systems ....................................................................................................................... 33
   3.3 Hybrid Electric Vehicles ........................................................................................................... 35
      3.3.1 How Hybrid Electric Vehicles Work .................................................................................. 35
   3.4 Fuel Cell Vehicles ..................................................................................................................... 37
      3.4.1 Thermodynamics ................................................................................................................ 38
      3.4.2 Operation ........................................................................................................................... 39
      3.4.3 Electrochemistry ............................................................................................................... 41
      3.4.4 Hardware .......................................................................................................................... 41
      3.4.5 System Requirements ....................................................................................................... 44
      3.4.6 Safety ................................................................................................................................. 45
      3.4.7 Barriers to Commercialization ......................................................................................... 48
   3.5 Adoption Rates Witnessed in the Auto Industry ....................................................................... 49

4.0 Research Methodology ............................................................................................................... 57
   4.1 Research Goal ......................................................................................................................... 57
   4.2 Data Selection ......................................................................................................................... 59
   4.3 Interview .................................................................................................................................. 60
   4.4 Survey ...................................................................................................................................... 62

5.0 Results ......................................................................................................................................... 65
   5.1 Business Planning Time Horizon .......................................................................................... 66
      5.1.1 High Priority of Near Term Business Pressures ................................................................. 66
   5.2 Strategic Focus ....................................................................................................................... 68
   5.3 Clear Go/No Go Decision Gateway ....................................................................................... 69
5.3.1 Financial Tracking System ................................................................. 70
5.3.2 Sense of Urgency and Tolerance for Risk ........................................ 71
5.4 Organizational Understanding .............................................................. 72
5.4.1 Understanding of the role of Marketing ............................................ 72
5.4.2 Clarity Over Who Approves Innovation ............................................ 75
5.4.3 Effective Communication and Information Dissemination .................. 76
5.5 Incentives for Cross Divisional Collaboration ........................................ 80
5.6 Personnel Skill Set and Motivation ........................................................ 83
6.0 Discussion and Recommendations .......................................................... 85
7.0 Conclusions ............................................................................................ 95
8.0 References .............................................................................................. 97
Appendix A - Interview Script ..................................................................... 99
Appendix B - Survey Questionnaire ............................................................. 101

LIST OF FIGURES

Figure 1 - The Improvement Process and Innovation .................................... 14
Figure 2 - Architectural/Modular Innovation Matrix ...................................... 15
Figure 3 - Stage Gate Innovation Process ................................................... 21
Figure 4 - Ulrich & Eppinger's Product Development Diagram ....................... 23
Figure 5 - Series Hybrid Vehicle Configuration .......................................... 36
Figure 6 - Parallel Hybrid Vehicle Configuration ......................................... 37
Figure 7 - Membrane Electrode Assembly .................................................. 43
Figure 8 - Four Cell Stack (side view) ........................................................... 44
Figure 9 - Fuel combustion: Time = 3 seconds .............................................. 47
Figure 10 - Fuel combustion: Time = 1 minute ............................................. 47
Figure 11 - Adoption Curves of Select Technologies ..................................... 50
Figure 12 - Predator/Prey Behaviour in Transmissions (Ward's Automotive Yearbook) ................................................................. 52
Figure 13 - Adoption Curves for ABS, Driven by Market Forces .................... 53
Figure 14 - Adoption Curves for Airbag Systems, Driven by Regulation ........ 54
Figure 15 - Proposed Communication Mechanism Between Functional Groups ................................................................. 61
Figure 16 - Distribution of Employees Interviewed ....................................... 62
Figure 17 - Percentage of Survey Responses Returned .................................. 64
Figure 18 - Issues most relevant to the company's ability to promote innovation and new products ......................................................................................... 65
Figure 19 - “I feel comfortable that the connection I have with the Marketing organization is sufficient.” ....................................................................................................................... 73
Figure 20 - “More connection with more people in Marketing would be relevant or useful to my group.” ........................................................................................................... 74
Figure 21 - “I know what is expected of me at work” – Decreasing agreement at lower organizational levels ............................................................................................................ 74
Figure 22 - “The mission of my company makes me feel my job is important” – Decreasing agreement at lower organizational levels ......................................................................................... 78
1.0 INTRODUCTION

1.1 Background

This thesis was written to complement the research performed on a Leaders for Manufacturing (LFM) internship with an automotive supplier. This company is a partner in the LFM program, a dual degree program at the Massachusetts Institute of Technology. The program aims to produce leaders who have a solid understanding of manufacturing and industry, through training in management and engineering. Part of the degree program involves an extensive on-site internship where the student is exposed to the issues which arise while leading a manufacturing organization. This thesis is based on the results and insights gained from that internship.

The name of the company examined has been concealed, however all references in this thesis to “the company” refer to this automotive components supplier. It was recently created, having been spun-off from a larger automotive manufacturer and is in a unique and challenging position. Previously a captive supplier, the various divisions had long had as their primary responsibility the sole mission of meeting the needs of the parent company. They were not required, nor necessarily encouraged, to engage in product innovation independently. Their goal, as part of their parent organization, was to provide the necessary parts for the assembly of vehicles, and to act as a negotiation lever against its other component suppliers.

However, that paradigm has changed dramatically. In the last couple of years around 80,000 employees in various divisions were bundled up and partitioned off as an independent company, to compete in the open marketplace. There were high hopes within both companies for the success of the spin-off. Independent, they would have access to even greater markets, by
being able to sell products to other automotive OEMs and the original automotive manufacturer would reap the cost savings and efficiencies obtained from the supplier’s efforts in market competition. At its most positive incarnation, the spin-off would provide greater opportunity and cost savings for both companies.

While it is not clear that the spin-off has been less than successful, it has certainly become clear that the magnitude of the task, in terms of organizational challenges has been extraordinary. The newly independent company’s goal is to use their complete vehicle knowledge to offer products to automotive OEMs that other, more narrowly focused, suppliers cannot. However, due to the fact that the divisions were assembled in a somewhat disparate fashion, combined with the fact that they are just learning how to assess the needs of their customers and develop new products, the company is continuing to work to bring all departments under one working umbrella and move forward in a unified fashion.

The goal of the LFM internship was to examine future technology paths for the company, as well as to determine what policies help promote innovative behaviour in the company for new product development. In order to effectively compete in the new marketplace, they recognize that they need to determine for themselves which direction they feel the technology is heading, and what they need to do to ensure they are a viable competitor in the future. This thesis examines technology trends in the auto industry, particularly in the area of vehicle power trains, as well as examines what organizations need to be aware of to ensure that they promote innovation and new product development within their companies.
1.2 Recent History

The company recognized that now that it was competing on the open market that its old business processes which were geared towards only one customer, would not serve the company well. Therefore, in late 2000 they began the process of reorganizing themselves from a Strategic Business Unit (SBU) structure to a Customer Business Group (CBG) structure. The SBU structure was one where the different organizational units within the company, such as Chassis, or Climate Control, were responsible for the operation, including profit and loss, of their own businesses. The CBG structure is one where the organizational units are defined by the customer. By orienting the company away from a product focus towards a customer focus two goals were hoped to be achieved. The first was that some of the communication barriers between product groups would be dismantled. The second was that increased customer service would be possible as now there would only be one point of contact for a customer to interface with, rather than having to deal with each of the company’s departments separately. This organizational shift was one of the biggest steps they made in transitioning into their new role and acted as a catalyst for many of the discoveries relating to innovation, organizational effectiveness, and product development that were made during the internship.

1.3 Objectives

The assertion in this thesis, based on primary research and subsequent reading, is that correct organizational structure and policies are required to foster an innovative culture within a company. Details outlining specific policies which benefit this culture are described later. In addition, there are three other objectives for this thesis. The first is to provide an understanding of what the current literature reveals about innovation and product development – why it is
important, how innovation differs depending on product life cycle, and how innovation can be promoted within a company. This will be examined in Chapter 2. The second is to examine some of the future trends in the auto industry, particularly related to vehicle power trains, to provide examples of why innovation and new product development is necessary for this particular industry. This will be examined in Chapter 3. The third objective, discussed in the remainder of the chapters, is to present the results of research performed onsite at the automotive supplier. The company was used as a learning laboratory to examine, for them, what the major barriers are for developing new products. In a broader context, the information discovered is applicable to many companies and can further understanding of effective product development management practices.
2.0 CURRENT LITERATURE REGARDING INNOVATION AND PRODUCT DEVELOPMENT

Innovation and product development processes are very hot topics in business research. Dubbed as critical for the success of companies in rapidly changing industries, many researchers have examined what it takes for a company to continue to compete effectively in times of rapid change. Innovation is seen as key for this success. However, even with all of this attention there remains much confusion as to what innovation means, how it affects companies, why it is important, and what companies can do to foster innovation in their organizations. The goal of this chapter is to examine some of the literature published to help answer some of these questions. In doing so, it is hoped that the reader will better understand the foundations of strategy formulation regarding technological change.

2.1 Types of Innovation and Definitions

R&D means transforming money into good ideas.
Innovation means transforming good ideas into money.¹

Innovation is a popular word in the business press. A search through ABI/INFORM, a database of 1,400 business and management journals, revealed that 9,139 articles were published between 1999 and 2002 relating to “innovation”. Its frequent use implies a universal understanding of the definition of the word when, in fact, the opposite is the case. There are many definitions and connotations of the word “innovation” and it is important to understand what different authors mean.
2.1.1 Creativity, Invention, Exploitation and Innovation

The Random House College Dictionary defines innovation as “something new or different introduced; introduction of new things or methods”. However, others provide a more precise definition. Specifically, innovation is the combination of creativity, invention, and exploitation.

![Innovation = Creativity + Invention + Exploitation](image)

Creativity refers to the generation of novel ideas. It is the starting point for innovation. This can be a solitary process, wherein someone has an idea and, over time, through thought and experimentation develops and improves an idea. Or, this process can be done in a group, such as an excited brainstorming session wherein many ideas are created to address a problem. However, this ideation process is only the front end to innovation. As 3M states, “Creativity is thinking up new things. Innovation is doing new things. The relationship between the two is clear: Innovation is the practical application of creativity. Both are necessary for 3M to succeed and grow.”

Invention applies to the process of transforming the novel idea into reality. This process involves the effort of many people, beyond the initial creative process, to happen successfully. Invention involves more than just prototype building. Invention refers to the engineering studies, analysis, product testing, simulations, and all of the other steps required to move from a simple idea to production. Invention is the solution to a problem, often a technical one, whereas innovation is the commercially successful use of the solution.

However, the third aspect, exploitation, is probably the most important. Exploitation refers to the profitability of the innovation. An idea, or even a prototype, which has no economic viability is not a successful innovation. It is important for innovations to add value to a
company, and simply being creative and developing lots of products with no economic viability is not innovation, it is a waste of resources. The challenge facing companies is not the creation of novel ideas, it is success in all three of these areas. Creating a novel idea, bringing it to production, and having a successful economic return are all required for successful innovation.

2.1.2 Incremental and Breakthrough Innovation

The basic definition given above captures the understanding of the creation of new ideas, new products, or new methods. It does not give any indication of what extent of change will take place with the new thing or method; i.e., incremental innovation and breakthrough innovation are both types of innovation.

There is a difference in the two. Breakthrough innovations are infrequent and result in dramatic cost or performance improvements. An example of a breakthrough innovation would be the transistor over the vacuum tube, allowing for tremendous reductions in size and cost and dramatic increases in speed for computing devices. As well, the jet engine over the piston driven propeller engine for airplanes allowed much greater speed and range, substantially changing the possibilities of the industry.

Incremental innovation is arguably one of the tenets of Total Quality Management (TQM) – continuous improvement. Incremental innovation is the numerous, smaller innovative changes that allow for the improved performance or decreased cost of a product. While the piston driven, internal combustion engine for automobiles has been mass produced since the turn of the century, countless improvements have been made, both in product design and production process, to provide ever increasing power and reliability, with ever decreasing costs. The microprocessor itself was a breakthrough innovation, however the continued improvements in speed and transistor density within a microprocessor are due to numerous incremental
innovations. While incremental innovation can lack the history making attraction of breakthrough innovation, it occurs much more frequently and is just as valuable as breakthrough innovation in terms of its cumulative effect on cost and performance.

Figure 1 - The Improvement Process and Innovation"
2.1.3 Architectural and Modular Innovation

Henderson and Clark further develop the distinction between incremental and radical (breakthrough) innovation. By examining a matrix, where the two axes are core concepts, and linkages between core concepts and components, they identify four categories. There are the two discussed above, incremental and radical (breakthrough) innovation, and two additional categories of innovation: modular and architectural.

![Core Concepts Matrix]

Figure 2 - Architectural/Modular Innovation Matrix

Returning to incremental innovation, if the example were an analog telephone, and a company had developed a better means of filtering noise, for example, this would both reinforce the core concepts of analog circuit design, and reinforce the linkage between the core concept (analog circuit design) and the components (resistors, capacitors, etc.). This would be considered an incremental innovation. However, if the same company were to replace analog telephones with digital telephones, the core concept of analog circuit design is overturned. The scientific and engineering knowledge in the company used to make analog circuits is not transferable to digital circuits. However, the product architecture of the telephone and how the
components fit together remains relatively unchanged – the digital signal processing replaces the analog circuitry, but still fits within the overall product architecture for a telephone. This would be an example of a **modular** innovation.

Turning to the remaining two boxes of the array, Henderson and Clark use the example of a ceiling fan. For a company that designs and produces ceiling fans, the switch to centralized air conditioning would be a radical innovation. Central air conditioning both changes the core concepts and their linkages to components with respect to climate control. However, the switch from a ceiling fan to a portable fan would be an **architectural** innovation. While the company may possess scientific and engineering knowledge to design each of the fan’s components, the blade, the motor, the shaft and housing, the company may have no experience with the fundamentally different product architecture. Examples are given of Xerox and RCA, both leaders in their industry (one, copiers and the other, radios), struggling to compete with competitors who had introduced smaller, cheaper products that used a different product architecture containing fundamentally the same components. While Xerox and RCA both had skill with the specific components of their respective products, they were ill equipped to react to a change in product architecture using those components which stressed a different performance metric (either size or cost) than the company had historically used.

### 2.1.4 Autonomous and Systemic Innovation

When examining organizational structure, Chesbrough and Teece talk about **autonomous** and **systemic** innovation\(^9\). Autonomous innovation is that which can be done independently, without the coordination of others. Hard disk development and manufacturing can be done with minimal coordination with the developers of laptop computers. Standardization of components and modular product architecture allows individual companies to innovate and optimize
components independently, free from the difficulties of coordination across larger company or intra-company collaborations. However, a modular product architecture may result in local optimization, sacrificing a global optimum which may have been achieved with an integrated product architecture.

Systemic innovation, by contrast, requires input and coordination across multiple components. The example given is the Polaroid camera. While Polaroid had developed a new film technology, in order to produce a product they needed to also develop new camera, lens and film loading technology. This required a vertically integrated structure at Polaroid to effectively develop a product that had an integrated architecture. The critical difference with this type of innovation is that it affects outsourcing and partnership decisions. Companies with vertical integration and integrated product architectures are better able to develop systemic innovations. A company without this structure will be required to develop partnership arrangements with other companies to best profit from this type of innovation, or to ensure it is developed at all.

2.1.5 Sustaining and Disruptive Innovation

A few other notions of innovation are worth mentioning. One exciting area of study deals more with technological change than innovation type, but bears mentioning. This is the work that Clay Christensen did comparing disruptive vs. sustaining technologies. Sustaining technologies foster improved product performance. That is, sustaining innovation can be either breakthrough or incremental in nature, as described above, but the key aspect is that sustaining innovation improves the performance of established products, along the dimensions of performance that mainstream customers have historically valued. A disruptive innovation, by contrast, is a technology or innovation which may result in lower product performance along the typically desired product performance metrics, at least, in the short term. However, a disruptive
innovation allows a product to compete along different performance metrics that the mainstream market historically has not valued. Disruptive technologies have the potential to thrive in their newly created market, improving until such time that they are able to compete along the traditional market metrics, when they can supplant established technologies. It is this ability for a disruptive technology to slowly improve, unnoticed by mainstream technologies, and then rapidly displace mainstream technologies that warrants their title of disruptive. An example of a sustaining technology might be continued improvements to an automobile engine. Mainstream customers desire an engine that is powerful, inexpensive, and fuel efficient. Incremental improvements to the engine, or even breakthrough improvements (such as discovering a new engine material which reduces weight and cost by half) would both be sustaining innovations, insofar as the improvement achieved is measured using the traditional market metrics (performance, cost, efficiency). However, a disruptive technology, Christian describes, could be a low powered, electric vehicle suitable for use in local neighbourhoods. The performance and cost of the vehicle could be woeful when compared to traditional engines. However, if the electric vehicle allowed for silent operation, which for some reason was greatly cherished by community dwellers, then there would be the potential for the vehicle to gain an introductory market while the technology matures. Eventually the disruptive technology may be improved enough to compete against the mainstream technology, or eventually the mainstream market will come to value the benefits of the disruptive technology (in this example, the silent engine noise), and when that occurs, the disruptive technology can cause a sudden and dramatic shift in competition, such that the companies unprepared for the shift can be caught unawares and fail.


2.2 Why Innovation is Important

Many articles discuss the importance of innovation. Without further explanation it is common for statements to be made about the obvious importance for companies to continue to be innovative or face extinction. However, this statement, while generally correct, is a misinterpretation of the real mantra for strategy: companies need to maintain a sustainable competitive advantage for long term profitability. Sustainable competitive advantage means that a company is able to do something better than its competitors and it can keep this advantage over a long period of time. In its most basic form this means having a premium product, or a low cost advantage that a company’s competitors cannot match. There are a few examples when innovation is not required. Coca Cola was punished viciously in the market when it tried to come up with “new” Coke, even though they came up with the idea in the first place from their research with focus groups and blind taste tests\textsuperscript{11}. Tide detergent, although forever plastered with a “New and Improved!” banner, is effectively the same stuff that has been sold for decades. These products have established a competitive barrier through their powerful brand image that functions as their long term competitive advantage. However, very few companies are this lucky. Most advantage gained is not protected by barriers to entry and is only temporary at best. Therefore the only sustainable competitive advantage in an environment of temporary advantage is continued development and continued improvement. This is the environment in which most companies find themselves, especially technology companies, and therefore, with this consideration, it is true that it is necessary to “innovate or perish”.

With this in mind, companies should not forget that the third tenet of innovation is commercial success. It is not acceptable to simply develop ideas for ideation’s sake. As Hattori and Wycoff state, nothing is more risky than not innovating, with the possible exception of
confusing innovation with something that fails to add value. A firm that expends time and energy promoting ideas that are not strategic to the direction of the company is worse off than before, having wasted precious resources. It is for this reason, that innovation, like product development can benefit from a guided process.

2.3 The Innovation and Product Development Process

The means of developing products through a methodical, stage-gate process has been used for some time. However, when people hear of an “Innovation Process” it seems, to them, to be an oxymoron. How can something as unstructured as innovation be subjected to a rigorous process? When it is understood, however, that innovation is the development of a commercially viable invention discovered through creativity, and more than just the creative process itself, then the structure begins to apply. Below, different innovation and product development process plans from different sources are examined and discussed.
2.3.1 Cooper

Cooper\textsuperscript{13} identified a stage-gate system for project management which ensured measuring progress against a predetermined series of milestones. Sage identifies this approach as a means of capturing the innovation process which starts with a bright idea and ends with a commercial product or process. The process has six steps:

\begin{itemize}
  \item \textbf{Idea Generation} \quad \textit{"I have an idea!"} \\
  \item \textbf{Recognition and Qualitative Evaluation} \quad \textit{"Who are the customers?"} \\
  \item \textbf{Business Evaluation} \quad \textit{"Is this economically attractive?"} \\
  \item \textbf{Prototyping} \quad \textit{"Let's build it"} \\
  \item \textbf{Testing and Validation} \quad \textit{"Let's ensure it performs"} \\
  \item \textbf{Production Ramp Up and Marketing} \quad \textit{"Let's make lots of them"}
\end{itemize}

\textbf{Figure 3 - Stage Gate Innovation Process}

The first two stages of this process involve creative tools such as brainstorming. The goal is to generate ideas and evaluate their fit with the marketplace. There is an implied “push” approach to this kind of innovation process. Ideas are generated and then evaluated against a set criteria – sort of a “let’s think up a bunch of really neat things, and then go see if they are of use to anyone” method. However, this is not the exclusive intent. While some successful innovations are created with no customer in mind (3M’s Post-It notes being a good example), most successful innovations begin with a brainstorming exercise to solve a known customer problem. In fact, writing out an effective problem statement that removes hidden bias and allows for creative solutions is typically the most important first step.
2.3.2 Ulrich and Eppinger

Ulrich and Eppinger\textsuperscript{14} also identify a six step process. However, from their point of view, they focus much more closely on the development steps of the product itself. By following a structured process, even as simple as the generic process they propose, they foresee at least five benefits.

**Quality Assurance** – With checkpoints throughout the development process errors in design, or even just improvements in design, can be caught and corrected earlier in the process. With an ordered approach, and various levels of detailed design involving different groups in the company, it is possible for input to be better integrated into the design, solving problems that might otherwise have occurred downstream.

**Coordination** – With a well defined process, everyone involved in the project can see the “master plan” and react accordingly. This better allows groups who are working in parallel to coordinate efforts and ensure that they are both contributing to the same goal, with the same schedule.

**Planning** – By writing out a schedule, this allows the goals and milestones of the project to be anchored in place, keeping the project from drifting in its final delivery date.

**Management** – By preparing a plan in advance it is possible to assess the progress of the project continuously by comparing the performance against the initial plan. This way, additional resources may be brought in, or resources may be allocated in different ways than initially thought, to keep the project on schedule.

**Improvement** – With careful documentation of the project’s progress it is possible to learn from the development of one product and integrate improvements into the next project.
Without a good understanding of the development issues that transpired, it is difficult to best exploit the experience gained for other projects.

Their generic six step process is shown below. A major difference between this approach and the one described by Cooper is the focus of the customer information. Ulrich and Eppinger stress obtaining customer needs up front and then going through several stages of refinement to meet that need, as opposed to developing an idea and then seeing if or where it fits in the marketplace.

![Ulrich & Eppinger's Product Development Diagram](image)

The six stages can be described as follows.

**Planning** – This stage involves the cooperation of Marketing, Design, Manufacturing, and other functions to assess the market opportunity and the customer need, consider effective product architecture, assess production constraints, and determine other relevant issues up front. Obtaining successful integration of all design functions and avoiding a “throw it over the wall” serial design mentality is of great importance for this process. Concurrent engineering, as it is called, allows for the product and the process to be developed simultaneously, allowing problems to be discovered sooner, and allowing collaborative efforts to yield a better design. In fact, Fine argues that a three dimensional concurrent engineering approach of product, process, and supply chain are necessary. Fine cites IBM’s loss of its dominant position in the PC market to Microsoft and Intel as a classic case of reasons for having a critical understanding of the
dynamics of the value chain. The key factor with the Planning stage is to understand and assess opportunities up front, and to do so with the participation across all relevant functional groups.

**Concept Development** – This stage is similar to the brainstorming, creative approach most affiliated with innovation. It is at this stage that market needs are examined and solutions considered. Quick prototypes may be developed. Rough sketches may be used. Manufacturing prepares estimates for manufacturing costs of the ideas. Everything is done in such a way to promote quick evaluation of ideas and creation of new ones to help determine the future direction for the product.

**System-Level Design** – At this stage the product architecture is set and the major systems and sub-systems are identified. Marketing develops a plan for how derivative products can be marketed and how a product portfolio addressing different price points could be created. Supplier discussions begin and financial analyses, such as make-buy decisions, are performed.

**Detail Design** – Marketing begins developing the marketing plan for the product. The materials, tolerances, and part geometry are finalized. Manufacturing will begin to design tooling and prepare production process plans.

**Testing and Refinement** – At this stage reliability testing is established. Regulatory approvals are obtained. Marketing will begin developing the promotional materials and Manufacturing will begin training the workforce and finalizing production-assembly plans.

**Production Ramp-Up** – Once production begins, the early production output needs to be evaluated to monitor product quality. Manufacturing begins operation of entire production system. Early sales begin to go out to lead customers.
2.4 How Innovation Should Be Encouraged in Organizations

Implementing an innovation process is an effective means of managing new projects. However, of equal, or greater, importance is instilling a culture within a company that supports innovation in the first place. Thinking of creative ideas, spending resources developing prototypes for uncertain concepts, and performing exploratory research are all necessary to develop innovative customer solutions; however, each of these actions may yield no positive gain and hence there is an inherent risk to such actions. While it may be easier, and often true, to say that it is more risky not to innovate, that still does not take away from the fact that immediate term resources are being spent for a long term, uncertain payoff. It is this trade-off which many managers find difficult.

Tucker describes four essential principles that he says firms must embrace to promote innovation:

1. A company’s approach to innovation must be consistent – By this he states that while many innovative outcomes appear to come from coincidental or serendipitous occurrences, it is important to approach the development of innovative concepts with a consistent, thorough fashion. Many companies have an innovation process which is piecemeal and haphazard, promoted only when the tides of popular thought turn in that direction. He goes on to state that the practice of innovation in many companies is similar to the approach to quality in the 1980s. At that time, Quality was a department and products were inspected before they shipped. Now, quality is the responsibility of everyone in the company and is infused across all actions of the company. This is what should be the case with innovation. However, today innovation is still primarily confined to a handful of departments such as R&D or advanced programs. The rest of the company then acts as if innovation is not relevant to them because they are not in one of
those departments. New ideas tend to come from the top down, rather than from the customers up; however, Tucker argues that we are entering an era where innovation, like quality, needs to be everyone’s responsibility.

2. Innovation must include an organized, systematic, and continual search for new opportunities – With the changing pace of technology and consumer demands it is not enough to make upgrades or improvements to existing product lines, nor to hope to stumble across breakthrough new business. Tucker argues that it is important to set up teams within a company that actively scout for future technology trends and be able to act accordingly. While questions about the future of the company would traditionally be the realm of senior management, Tucker’s point is that a cross-functional team allows people from various areas of the company, who know better the details of their expertise, to collaborate and better spot future opportunities.

3. Organization must involve everyone in the innovation process – Tucker’s concern is that many companies structure job descriptions to minimize the amount of decision making and creative thinking employees are expected to do. For an organization to be effective at fostering innovative behaviour, at all levels, it must tap its employees dormant creativity. Teaching people how to champion their ideas and implement solutions should be the real work of training managers. Disney’s successful retail format was proposed by an employee at their thrice-yearly “Gong Show” for pitching new concepts. Dana Corporation receives an average of four ideas per month, per employee, with a 75% implementation rate. Sony corporation demands that all of its employees contribute with their hands and their minds. While not all ideas are useful, it is Tucker’s argument that not having an effective means of soliciting and implementing ideas is a sure way to quash innovation.
4. A company must work constantly on improving its climate for innovation – The previous three points have basically said that innovation must involve everyone in the company, must be consistent throughout company processes, and must be continually emphasized to search out new opportunities. However, all of this is done under the environment of the company culture and it is this culture which will promote or diminish the previous three points. Many people understand that a company culture is used to describe its values, traditions and priorities. To assess a company’s culture and how well it promotes innovation, it is useful to examine past cases. What happens to creative, out-of-the-box mavericks in the company? What happens when someone fails? How many people say to employees, “We want you to take risks, and we want innovative ideas bubbling forth.” while really stressing that what’s most important is that a department makes its numbers and has no embarrassing failures? There are three ways to deal with failure: 1) cover the failure up and not acknowledge it, 2) acknowledge the failure and assign blame, or 3) acknowledge the failure and try to learn everything possible from it. The climate is the “feeling in the air” about how the company responds to certain events. If people see that there is an understanding amongst all members of the company of what is required for innovation and that failure is involved, then the employees will be more comfortable engaging in innovative behaviour. If people feel that innovation is desired, but no allowance is made for risky investment, then no one will risk anything that does not have a confident outcome, which is typically the least innovative path of all.
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3.0 FUTURE TRENDS IN AUTOMOTIVE POWER TRAINS

Given an understanding of the fundamentals of innovation we now turn to specific technological examples affecting the automotive industry. Innovation and product development deal with continuous improvement and the development of new things, be it products or processes. Continuous innovation allows a company to maintain or improve its advantage over its competitors who are less able to bring about new improvements. A major factor determining a company’s success, therefore, is its ability to understand its competitive environment and react to the future trends in the industry. While there are many markets for competition as a component supplier, enormous potential changes could come with future power train technologies – advanced internal combustion (IC) engines, hybrid electric vehicles, and fuel cells. The goal of this chapter is to examine these new technologies and understand some the issues are regarding their introduction and the introduction of other new technologies.

3.1 Industry Forces

There are a number of pressures that are driving forward new power train technologies. Some of these forces are aligned in purpose, whereas others are unrelated. Primarily they are demand for greater fuel economy, cleaner emissions, and more electrical power available on board the vehicle.

Interest in improved engine technology is not new. In the 1970s the oil shocks inflicted by the OPEC cartel caused gasoline prices to rise suddenly. This prompted a large amount of research into technologies which would improve the fuel economy of vehicles. The driving force at that time was improving the economy and reducing foreign dependence on oil.
Government regulations, and market competition from smaller vehicles began pushing automakers for improvements.

During the mid-80s, oil prices stabilized and the price of oil remained flat. With minimal taxation on gasoline in North America (as compared to European countries, or Japan) interest began to wane, in North America at least, on extremely fuel-efficient cars. A resurgence in concern for the environment in the 1990s rekindled interest in alternative fuels. This time concerns over fuel economy were rooted in concerns over air pollution and the release of greenhouse gases. However, the discussion on fuel economy was not focused on simply examining ways for cars to burn less fuel, but was more broadly considered to include the possibilities of different fuels as well. California introduced air quality standards that promoted zero emission vehicles by 2010. As well, several “green” states followed suit by implementing similar policies.

A third market driver, less related to the previous two, is increased demand for electrical power on board the vehicle. With the proliferation of power locks, power windows, power mirrors, power seats, and other loads, electrical systems on vehicles are nearing saturation. Customer demand is pushing for products with even greater electrical requirements, such as on-board navigation systems, wireless internet connectivity, active suspension systems and drive by wire technology such that vehicle manufacturers are examining better means of providing adequate on-board electrical power to meet the growing demand.

3.2 Advanced Internal Combustion Engines

The nearer term innovations of power train technologies will be improvements to the internal combustion engine (ICE). The ICE has been the dominant design for one hundred years
and has been enormously refined since its first inception. However, improvements in electronics
and control systems will pave the way for other changes which can help improve engine
performance and efficiency.

There are a number of advancements being made to improve the internal combustion
engine. Most of these are being made to improve fuel economy. A government regulation,
Corporate Average Fuel Economy (CAFE), dictates the average fuel economy of the sales of an
auto manufacturer. Failure to meet CAFE standards can result in fines and this provides an
incentive for an automaker to comply with the regulations. There are a number of new
technologies which can improve engine efficiency, a few of which are discussed below.

3.2.1 Cylinder Deactivation

The idea behind cylinder deactivation is simple. For engines with a higher number of
cylinders (six or eight cylinders or more) it can be more efficient to simply close off some of the
cylinder valves when the vehicle is not under load and operate as a four cylinder engine. This
would provide the power and performance of a large displacement engine when required, yet be
far more fuel efficient. Fuel economy at low vehicle load conditions, such as cruising, is
enhanced because fuel and spark is only delivered to half of the cylinders, causing these
cylinders to operate at a higher load and efficiency levels. For higher load conditions, such as
passing or towing, all cylinders can be active. Delphi Automotive Systems claims that such a
system can improve fuel economy by 8 or 9 percent\textsuperscript{17}. Cylinder deactivation was tried many
years ago; however, the computer control systems necessary to ensure a smooth transition were
not sophisticated enough to prevent extreme noise and vibration from occurring. With the
improvement of computer technology, this problem has been solved and automakers are
advertising the commercial application of this technology. Enhancements to computing power
and control system technology have allowed other engine technologies to be enabled, specifically the ability to have a camless engine.

### 3.2.2 Camless Engines

The valve timing of an engine is set by the contour of the cam profile. As the camshaft in an engine rotates around, it dictates the opening and closing times of the valves in the engine. The cam shaft is an elegant solution to the need to be able to open and close the valves in a combustion chamber extremely rapidly, and with extremely precise timing. By physically coupling the drive shaft to the cam shaft with a timing belt, and then coupling the valves to the cam profile, the valves position can be exactly determined for any angle of the drive shaft.

However, the optimal valve timing for any engine is a function of the engine speed\(^{18}\). At low speeds it is desirable to have the intake and exhaust valves closed for the complete combustion process to maximize the power obtained. At high engine speeds, however, the momentum of the rushing air/fuel mixture is such that it is desirable to open the intake valve before the exhaust cycle is complete and to keep it open a little longer into the compression stroke. The faster the engine goes, the faster the air/fuel moves, and the longer the intake valve should stay open. Since a cam profile is fixed, an awkward compromise is made and the cam profile is designed to provide the best average overall performance over the range of the vehicle’s operating speed.

Some high performance vehicles, notably Ferrari, have developed a three-dimensional cam profile. As the engine RPM increases, the cam shaft can move forward or backwards on its axis, exposing the valves to a differently shaped cam profile. This allows Ferrari to design a valve timing schedule which is optimal across all ranges of engine speeds.
However, advances in control system technology have allowed auto makers to pursue a new approach – camless engines. The idea is to replace the cam with another means of manipulating the valve position. A position sensor on the drive shaft would allow a central computer to know where the drive shaft is located. The control computer then would send a signal to an actuator to position the valve in the desired location. Prototypes have been built which use either hydraulic or electromagnetic actuators. Camless engines require extraordinarily fast and accurate control system algorithms to be successful and thus computational speed has been the bottleneck in the design up until now. An engine running at 4,000 RPM will have the valves opening and closing 2,000 times a minute, or 33 times a second. The electronic control system needs to be able to sense the drive shaft position, send a signal to the valves for positioning, and then ensure, through a feedback loop, that the valve is in the correct position, all while operating at these high speeds with 100% reliability over the life of the vehicle. The advantages of such a system are fantastic, however. Real time optimization of the engine can happen across all engine speeds. Real time cylinder deactivation (described above) can be implemented. Engine control can be accomplished through valve timing, removing the need for a throttle body, and removing the pumping losses associated with the throttle body. The flexibility of engine performance optimized across all engine speeds is extremely attractive. Developers have had success with trial units and are optimistic that this new technology will be available in the coming years.

3.2.3 42V Systems

One of the key trends for cars in the future is increased amount of electrical power demanded on the vehicle. Features like heated windshields, new devices for cutting noxious emissions, and advanced suspensions will require more power than the current 14-volt
automobile electrical system can handle. Because of this there is a move to replace the vehicle architecture with a 42-volt system. With this higher voltage, and subsequently high power, many existing features will function better than with a 14-volt system. 42V is more of an enabling architecture. A 42V system will allow the camless engine technology described above to work better, but it will also allow for a number of other technologies\textsuperscript{19}. Many people see an integrated starter/alternator to be part of a 42V system. With the power available it will be possible for an engine to stop once a vehicle is stopped (for example, at a traffic light) and then be started instantly once the driver presses the accelerator. This system would also be more efficient generating electricity, with lower resistance losses due to the higher voltage used. These innovations would further improve vehicle fuel economy.

With improvements in control technology as well as increased power availability, automakers can use a 42V system for other vehicle improvements beyond the power train. With these technologies automakers would like to move into different types of suspension systems. Vehicles now use a passive suspension system wherein a damped spring is used to attenuate the road vibration. However, an active suspension system is one which uses a sensor to determine the wheel position, and then through the use of actuators, positions the wheel such that it perfectly follows the road profile, completely eliminating the road vibration. Other technologies desired include drive by-wire systems such as steer-by-wire or brake-by-wire. The more of the vehicle control that is handled through an electronic link, the more options a vehicle designer has around performance and packaging. However, each of the systems will further increase the electrical demand on a vehicle thus furthering the attractiveness of higher voltage systems. Moving even beyond 42V systems are 300V systems, such as those seen in the following two sections, hybrid and fuel cell vehicles.
3.3 Hybrid Electric Vehicles

Hybrid electric vehicles (HEV) combine two or more energy conversion technologies, such as heat engines or fuel cells with one or more energy storage technologies, such as batteries, ultracapacitors or flywheels. The most typical HEV architectures involves a battery array and an internal combustion engine (ICE), which can be used together or independently, depending on the design.

The advantages of hybrid electric vehicles are that they can provide the benefits of pure electric drive (increased fuel economy, reduced emissions, and quiet operation), while still providing the advantages of an ICE vehicle (sufficient range, adequate fuelling infrastructure, and rapid refuelling times).

3.3.1 How Hybrid Electric Vehicles Work

There are two architectures for hybrid vehicles, parallel and series. A series hybrid vehicle is one where a small engine runs a generator to create electricity. The electricity is either used to power the wheels or is stored in the battery array. The vehicle has the ability to run in zero-emission mode, whereby the batteries completely power the engine. An important benefit of series operation is that when the engine operates, it can run at its most efficient point, allowing the batteries to meet the variable demand for power. Engine efficiency varies by operating speed and applied torque. Rarely do engines operate in their most efficient regime. The series hybrid architecture allows the engine itself to be its most efficient, in addition to the benefits gained from electric operation.
Parallel hybrid vehicles have the two energy sources separated, such that there are two power paths. The engine or the electric propulsion system, or both can be operated to provide shaft power to the wheels. This arrangement can be used to allow for a smaller engine design, allowing the battery to provide the necessary power when climbing or accelerating. The benefits of reduced engine size include savings in weight resulting in further increases in fuel efficiency. Both the Toyota Prius and the Honda Insight use a parallel hybrid power train. While the power trains are decoupled, they are not disconnected. For both vehicles the use of the engine or batteries is determined by the vehicle controller and power can be directed from the engine or the batteries in whichever is the most optimal manner.

Figure 5 - Series Hybrid Vehicle Configuration
3.4 Fuel Cell Vehicles

At the heart of a fuel cell vehicle is a device called a fuel cell. A fuel cell is an energy conversion device, and therefore a fuel cell vehicle does not, strictly speaking, dictate the vehicle architecture. In other words, it is certainly possible to have a fuel cell hybrid electric vehicle, combining both fuel cells and batteries to provide performance.

Fuel cells are devices which convert fuel and air through an electrochemical reaction to produce electricity. Fuel cells are inherently more efficient than a heat engine process, and depending on the fuel used can emit substantially low to zero emissions. The main difference between a fuel cell and a electric battery, which also uses an electrochemical reaction to produce electricity, is that a battery operates until its reactants are depleted and the battery is either
disposed or recharged. Therefore a battery cannot continuously act as a source of power. A fuel cell, by contrast, can act as a continuous source of power. As long as the reactants are supplied (fuel and oxygen) the fuel cell will continue to generate electricity, for the fuel cell is simply the device which promotes the reaction; the fuel cell does not contain any of the reactants itself.

The first major practical application of fuel cell technology was during the Apollo missions in the 1960s. However, cost barriers prevented their adoption into the automotive sector. In the last six years, however, substantial improvements on fuel cell performance and reductions in cost have generated interest from the automotive manufacturers. Now, although many feel that fuel cells are the most distant of three technologies examined (advanced ICE, hybrid electric, and fuel cell), most of the major automobile companies are investing some efforts in developing fuel cell vehicles.

3.4.1 Thermodynamics

Inside a fuel cell is an electrochemical reaction between a fuel and an oxidant. This is in contrast to the chemical reaction of combustion, which also occurs between a fuel and an oxidant (typically, air or oxygen). What is attractive about fuel cells is that the fuel cell reaction is inherently more efficient than a combustion reaction at producing useful work. The reason for this is that the production of entropy in a fuel cell reaction is less than in a combustion reaction. With less entropy production, less useful work (sometimes called availability or exergy) is destroyed. A fuel cell is able to produce electricity directly, which can be used as useful work, which is a more efficient process than generating heat through combustion, and then generating useful work from that heat through the use of a heat engine. The ideal first-law efficiency of a heat engine is limited by its operating temperature. This is referred to as the Carnot efficiency:
\[ \eta = 1 - \frac{T_c}{T_h} \]  \hspace{1cm} (1)

where \( T_c \) is the ambient (cold) temperature

\( T_h \) is the reaction (hot) temperature

Fuel cells, not being heat engines, are not limited by the Carnot efficiency. The efficiency of a fuel cell is given by the more general equation:

\[ \eta = \frac{\Delta H - T \Delta S}{\Delta H} \]  \hspace{1cm} (2)

where \( \Delta H \) is the change in enthalpy from a reaction

\( \Delta S \) is the change in entropy from the reaction

\( T \) is the temperature of the reaction.

It can be seen that as the entropy produced (\( \Delta S \)) goes to zero the efficiency of a fuel cell approaches 100\%. For a heat engine, as the entropy produced goes zero, the efficiency of the heat engine approaches the Carnot efficiency (equation (1)). This makes the fuel cell a very attractive technology as an energy conversion device.

3.4.2 Operation

A fuel cell can either utilize an acid or an alkaline electrolyte. The overall reaction of the fuel cell is unchanged, however the internal reactions within the cell differ. In addition, there are five main types of fuel cells, each operating in a different temperature regime, and each with different advantages and disadvantages.
The five types and their applicability to transportation applications are listed below:

<table>
<thead>
<tr>
<th>Fuel Cell Type</th>
<th>Mobile Ion</th>
<th>Operating Temp.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton Exchange Membrane (PEM)</td>
<td>H⁺</td>
<td>50-100°C</td>
<td>Most popular technology in development for transportation</td>
</tr>
<tr>
<td>Phosphoric Acid (PAFC)</td>
<td>H⁺</td>
<td>~200°C</td>
<td>Liquid electrolyte is cumbersome</td>
</tr>
<tr>
<td>Alkaline (AFC)</td>
<td>OH⁻</td>
<td>50-200°C</td>
<td>Concerns about CO₂ poisoning of cathode</td>
</tr>
<tr>
<td>Molton Carbonate (MCFC)</td>
<td>CO₃²⁻</td>
<td>&gt;600°C</td>
<td>High temperature limits applicability to transportation</td>
</tr>
<tr>
<td>Solid Oxide (SOFC)</td>
<td>O₂⁻</td>
<td>500-1000°C</td>
<td>Has been used for transportation applications as auxiliary power unit, not prime mover</td>
</tr>
</tbody>
</table>

The most common fuel used in a fuel cell is hydrogen. The reason for this is that hydrogen is one of the few fuels that provides an acceptable reaction rate at low temperatures. A fuel cell reaction can occur at much lower temperatures than a combustion reaction. The higher temperature fuel cells, such as SOFC and MCFC have the ability to internally reform some hydrocarbon fuels, that is, they can use them directly. However, the disadvantage with higher temperature fuel cells for transportation applications is the excessive start up time for operation because of the thermal lag.

If a fuel such as natural gas, gasoline, or methanol is to be used with lower temperature fuel cells, a device called a reformer is necessary to extract the hydrogen from the fuel before the hydrogen flows into the fuel cell. Reformers greatly increase the complexity of the fuel cell system and therefore many people view reformers as an intermediate solution until a hydrogen infrastructure can be developed. Other people view reformer technology as necessary to avoid
the cost of huge changes to the infrastructure. General Motors has invested huge sums of money trying to build intellectual property around gasoline reformer technology\textsuperscript{24}.

There are some experiments with a fuel cell called a direct methanol fuel cell (DMFC) which has the capability to operate with methanol as the feedstock, without reforming, however DMFC research is even more early stage than hydrogen fuel cell research.

3.4.3 Electrochemistry

For a hydrogen fuel cell, the overall reaction is

\[ 2\text{H}_2 + \text{O}_2 = 2\text{H}_2\text{O} + \text{electricity} \] (3)

For acid based electrolytes, the two half-cell reactions are

\[ 2\text{H}_2 = 4\text{H}^+ + 4\text{e}^- \text{ (anode)} \] (4)

\[ \text{O}_2 + 4\text{e}^- + 4\text{H}^+ = 2\text{H}_2\text{O} \text{ (cathode)} \] (5)

Whereas for alkaline electrolytes, the reaction is

\[ 2\text{H}_2 + 4\text{OH}^- = 4\text{H}_2\text{O} + 4\text{e}^- \text{ (anode)} \] (6)

\[ \text{O}_2 + 4\text{e}^- + 2\text{H}_2\text{O} = 4\text{OH}^- \text{ (cathode)} \] (7)

It can be seen that once the two half-cell reactions are combined, the overall reaction is the same in both cases.

3.4.4 Hardware

A single hydrogen fuel cell can produce, ideally, an open-circuit voltage of 1.2V. Operational voltages are typically half that value. In order to provide sufficient power the size of the fuel cell needs to be increased. By increasing the active area of reaction the fuel cell current is increased; by connecting multiple individual cells in series, the voltage can be increased. Therefore a fuel cell stack will consist of dozens to hundreds of cells in order to generate the
voltage required for operation. Transportation fuel cells need a power rating around 70 kW for automobiles, and up to 250 kW to match the performance of a transit bus diesel engine. For comparison the Cummins ISM 330 transit bus engine boasts 330 hp or 246 kW of power\textsuperscript{25} and the 1998 Ford Escort engine provided 110 hp or 82 kW of power\textsuperscript{26}.

The centre of the fuel cell is the electrolyte. For the purposes of this discussion the proton exchange membrane fuel cell will be used as an example. While there are differences in hardware between all fuel cell types, much of the fuel cell research for transportation applications uses PEM hardware. The electrolyte in a PEM cell is, as the name implies, a proton exchange membrane. It is a thin membrane which, when hydrated, appears conductive to protons, yet acts electrically insulating. The membrane acts as a physical barrier between the two reactant gases (hydrogen and oxygen) and therefore the two gases never actually contact each other in the fuel cell reaction. On both sides of the membrane is placed a porous, electrically conductive backing, called the gas diffusion layer (GDL). Between the gas diffusion layer and the membrane is placed a thin layer of catalyst, formed usually with platinum and other metals. The GDL has three purposes. First, it provides structural support to the membrane and reaction area; without it the membrane would be susceptible to dimensional change through moisture and thermal gradients across its surface. Second, it provides a means of conducting heat. The membrane will not survive long under hot conditions and the GDL provides a means of conductive heat transfer for removal of the heat generated from the fuel cell exothermic reaction. Third, the GDL acts as an electrical path. The electricity produced from the fuel cell needs to travel from the reaction site to the electrical load and the pathway begins with the GDL.
The complete assembly is then bonded together and this thin, wafer-like sandwich is called a membrane electrode assembly (MEA). Some fuel cell manufacturers call this an membrane electrode unit (MEU).

![Figure 7 - Membrane Electrode Assembly](image)

Placed on both sides of the MEA are the flow field plates. These are conductive plates that provide reactants to the MEA and remove the products (air and water). The flow field plates are typically flat plates with small channels cut into their surface. When an MEA is sandwiched between two flow field plates a complete, single cell, fuel cell is created. Multiple cells combined together form a multi-cell fuel cell stack. The electrons from one cell simply feed the reaction of the neighbouring cell. Like the GDL, the flow field plates must be electrically conductive to provide a current path. In addition, the design of the channels is very important to ensure even and continuous distribution of reactants to the fuel cell reaction sites.
3.4.5 System Requirements

To put together a complete fuel cell system involves many more components than just the fuel cell itself. Often the fuel cell will seem pathetically simple when buried under layers of necessary supporting equipment! For a transportation application a fuel cell system requires a fuel tank, distribution lines, fuel delivery control system, possibly an air compressor, power conditioning unit consisting of a DC-DC converter, DC-AC (inverter), and an electric motor. In addition to all of that could also be a complete fuel reformer system to extract hydrogen from another type of fuel. One of the greatest challenges with electric vehicles, either pure electric,
hybrid electric, or fuel cell, is the cost of the power electronics. For reasons of efficiency and performance, AC (alternating current) motors are preferred for high-power, high-torque applications, such as automobiles. Batteries and fuel cells produce DC current. Therefore, in every vehicle design there is at least a DC to AC converter, called an inverter (and possibly a DC-DC converter which may be used if the voltage produced from the batteries or fuel cell does not match the voltage demanded). Inverter technology uses components called FETs (field-effect transistor) or IGBTs (insulated gate bipolar transistor). These are semi-conducting devices used to rapidly switch currents. While semi-conducting devices are inexpensive for low power applications (indeed, millions of diodes and transistors make up everyday electronic devices), they are much more expensive when made to handle the greater currents that automotive applications require. As long as these components remain expensive, the cost of power conditioning and inverter components will hinder the economic viability of electric vehicles of all types.

3.4.6 Safety

Public perception and safety surrounding fuel cells is worth mentioning. The public, at large, has been very supportive of fuel cell technology. Using the popular press as an indication, the public feels that fuel cell vehicles are futuristic cars which will solve all of our pollution and economic problems. However, the public is also very single minded when it comes to many issues and the fact that fuel cells use hydrogen causes a few people to think slowly and then say, “Isn’t that what hydrogen bombs are made from?” If they make it past the fact that a fuel cell vehicle is not an unclassified thermonuclear weapon, the next point of reference for most people is the Hindenburg, and most people associate the fiery destruction of that ship with hydrogen (truth be told, hydrogen had less to do with the fire than the fact that the skin of the vessel was,
in effect, coated with rocket fuel, a mixture of iron oxide and aluminum paint). When Ballard
Power Systems debuted their first fuel cell bus in the early 1990s, the local television news
reported “hydrogen and oxygen, both extremely explosive materials separately, are being
combined in this safe application…”27 So, hydrogen has a bad reputation and it has been stuck
with it for the last hundred years. The fact of the matter is that hydrogen is far safer in a
flammable situation than gasoline. People have long since grown comfortable with gasoline, but
the energy content and explosive nature of both fuels bears respect. With proper precautions,
hydrogen certainly presents no extraordinary threat over using a gasoline fuel.

The following pictures were taken from a test done by Dr. Micheal Swain of the
University of Miami28. He allows two cars, one fuelled with hydrogen, the other with gasoline to
be ignited. The destructive effects of the two flame fronts is clearly seen. The marked
difference between the two is the not only the combustion of the fuels, but the secondary
combustion of other materials (upholstery, plastic, carpeting, etc.) brought on by the combustion
of the fuel. Hydrogen is not only extremely buoyant, such that is rapidly dissipates upwards and
away from the vehicle, its flame typically burns clear and therefore transmits heat through
radiation very poorly (it was determined that the flame is visible in the photos because of
naturally occurring sodium in the air). Gasoline, by contrast, pools to lower points of the
vehicle. As well, gasoline transfers heat effectively enough to start secondary combustion
throughout the vehicle. As is seen, soon more than the gasoline is burning, the other car
materials are burning as well. This demonstration is interesting because it puts to rest a lot of the
specific fears people have about hydrogen. However, the fact remains that neither of these
failures (combustion of gasoline or hydrogen) is a common failure mode and with necessary
precautions, both fuels can be used safely.
Figure 9 - Fuel combustion: Time = 3 seconds
H₂ flow=2100 SCFM, Gasoline flow=680 cc/min (Swain, 2001)

Figure 10 - Fuel combustion: Time = 1 minute
H₂ flow subsiding, external combustion of gasoline vehicle continues (Swain, 2001)
3.4.7 Barriers to Commercialization

The greatest issues to be overcome for successful fuel cell deployment is the cost of the product, cold start-up, and installed infrastructure. Fuel cells have enjoyed a long history as a research phenomenon or specialized technology. Most technical barriers such as performance, lifetime, power density, and reliability have been overcome. However, the cost of fuel cell materials has long prevented their commercial acceptance. Higher volume production, better manufacturing techniques, and improved development and cost reduction from fuel cell suppliers are needed to lower the current prices. In order to compete with an automotive engine fuel cell costs need to be about $50/kW (based on ICE performance and price). Fuel cell costs are over an order of magnitude greater than this. The one major technical barrier not effectively solved remains cold start-up. Because fuel cells product water, they are susceptible to freezing temperatures. During steady state operation, the heat produced by a fuel cell will prevent water from freezing within the device. However, start-up times for a frozen fuel cell yet do not compare to the rapid start time of an ICE. Finally, there remains the question of infrastructure. This is one of the most challenging aspects of growing an installed base of fuel cell vehicles. Because fuel cells cannot easily use gasoline as a fuel, there needs to be either a hydrogen infrastructure, or some infrastructure of fuel reformers to meet the needs of fuel cell vehicles. This chicken and egg dilemma of infrastructure before vehicles will need to be addressed before any great change in fuel cell vehicle adoption will take place.

Finally, before leaving this issue sometimes it is insightful to examine historical cases to bring current events into the correct perspective. In the book Fuel Cells: Power for the Future, written in 1960 (which already says something about the length of time this technology has been
The author quotes the following excerpt from the Congressional Record of 1875 regarding the internal combustion engine:

"A new source of power, which burns a distillate of kerosene called gasoline, has been produced by a Boston engineer. Instead of burning the fuel under a boiler, it is exploded inside the cylinder of an engine. This so-called internal combustion engine may be used under certain conditions to supplement steam engines. Experiments are under way to use an engine to propel a vehicle.

"This discovery begins a new era in the history of civilization. It may some day prove to be more revolutionary in the development of human society than the invention of the wheel, the use of metals, or the steam engine. Never in history has society been confronted with a power so full of potential danger and at the same time so full of promise for the future of man and for the peace of the world.

"The dangers are obvious. Stores of gasoline in the hands of the people interested primarily in profit, would constitute a fire and explosive hazard of the first rank. Horseless carriages propelled by gasoline engines might attain speeds of 14 or even 20 miles per hour. The menace to our people of vehicles of this type hurrying through our streets and along our roads and poisoning the atmosphere would call for prompt legislative action even if the military and economic implications were not so overwhelming. The Secretary of War has testified before us and has pointed out the destructive effects of the use of such vehicles in battle. Furthermore, our supplies of petroleum, from which gasoline can be extracted only in limited quantities, make it imperative that the defense forces should have first call on the limited supply. Furthermore, the cost of producing it is far beyond the financial capacity of private industry, yet the safety of the nation demands that an adequate supply should be produced. In addition, the development of this new power may displace the use of horses, which would wreck our agriculture.

"...the discovery with which we are dealing involves forces of a nature too dangerous to fit into any of our usual concepts."

### 3.5 Adoption Rates Witnessed in the Auto Industry

When considering new technologies it is useful to have some idea of how technology is adopted in a particular industry. In the microprocessor industry, Moore's Law (which states that the number of transistors on wafer will double every 18 months) is such an extreme that it can act as a production schedule. At the other end of the spectrum, successes in drug development or wildcat oil drilling are so random that the best way to approach those enterprises is to diversify risk with a portfolio of simultaneous projects. The auto industry is neither as rapid as the microprocessor industry, nor as unpredictable as drug development. By examining the adoption rates of various technologies in the past, we can see patterns and trends which can be useful in...
Adoption Curves of Select Technologies

Figure 11 - Adoption Curves of Select Technologies\textsuperscript{30}
understanding the industry dynamics. Figure 11 shows adoption curves for the U.S. auto
industry from 1953 to 1997 using data from Ward’s Automotive Yearbook.

What is immediately apparent is the different adoption rate of luxury items versus safety
related items. Automakers have an incentive to continue to charge a premium price for a luxury
good as long as possible, before eventually reducing the price and including the feature in their
lower-end cars. We can see that forty years passed for power steering to move from a niche
product with 10% vehicle share to becoming equipped in almost 100% of vehicles produced. Air
conditioning had a similarly long s-curve for adoption. Like power steering, air conditioning
required forty years to be fully adopted from a high-end, niche market, luxury option to a
standard feature.

Vehicle transmission exhibits another interesting effect. Data from Ward’s was only
available back to 1953, and at this time automatic transmissions were in half the vehicles being
produced. It would appear that they also have had a slow adoption rate, but the fact is that
fifteen years later, 85% of vehicles would have automatic transmissions, a ratio that has stayed
roughly constant until today. We can presume that vehicles without automatic transmissions had
a standard transmission, and although it is not shown on the chart the vehicles without automatic,
or 4-speed manual transmissions used a 3-speed manual transmission. What this shows is that
there is a market for people who prefer manual transmissions (keep in mind, this chart only
shows U.S. production for the U.S. market – the global market would show a much higher
popularity for manual transmissions). Once automatic transmission reached its saturation based
on the value it offered, roughly 10% to 15% of the market still demanded manual transmissions.

An interesting effect can be witnessed in the transmission adoption data. We end up
seeing a predator/prey dynamic occurring in this 10% to 15% market. If we assume, that all
vehicles without automatic, 4-speed, or 5-speed transmissions have 3-speed transmissions we get the data shown in Figure 12. We can see that from the early 1950s until the early 1960s, automatic transmissions continued to erode the market share of 3-speed transmissions. For almost fifteen years, 4-speed transmissions remained as niche products with about 5% of the market and 3-speed transmissions continued to decline. Then, from the late 1970s until the early 1980s, 4-speed transmission became a predator to the automatic transmission market, possibly due to the fuel economy concerns at the time. Then, 4-speed transmissions themselves began to decline with the introduction of the 5-speed transmission. Automatic transmissions have begun to creep up in popularity but since 1985 the market for automatic and 5-speed manual transmissions has been fairly constant.

![Predator/Prey Behavior in Vehicle Transmissions](image)

**Figure 12 - Predator/Prey Behaviour in Transmissions (Ward's Automotive Yearbook)**
There are two more curves worth presenting. The first shows the rate of adoption of anti-lock breaking system technology (Figure 13) and the second shows a strong predator/prey relationship between driver's side and dual side airbags (Figure 14). This two graphs show both the domestic and import percentages. The reason examining both these curves is interesting is that both curves have a similar rate of adoption. For both curves the rate of adoption is substantially quicker than previously seen for luxury items such as power steering and air conditioning. However, vehicle airbags were a technology promoted through legislative regulation whereas antilock brakes were promoted through free market demands.

![Adoption Curve for Anti-lock Braking System (ABS)](image)

*Figure 13 - Adoption Curves for ABS, Driven by Market Forces*
Within 10 years ABS goes from introduction to saturation conditions. While it is too early to tell if the market has completely saturated, it does appear that the rapid growth of the s-curve has completed and that a market penetration of around 70% has been established. A similar 10 year timeframe can be seen for airbags. However, in this case the market saturation occurs with 100% of vehicles being equipped with airbags. Obviously a dramatic predator/prey relationship can be witnessed between single and dual airbag installations.

What does this mean for new technology? For starters, government regulations can have a far more profound impact on technology adoption than market forces for luxury goods would dictate. In 1991, Congress included a provision in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) directing the National Highway Traffic Safety Administration (NHTSA) to amend Standard No. 208 to require that all passenger cars and light trucks provide
automatic protection by means of air bags\textsuperscript{31}. ISTEA required at least 95 percent of each manufacturer's passenger cars manufactured on or after September 1, 1996, and before September 1, 1997, to be equipped with an air bag and a manual lap/shoulder belt at both the driver and right front passenger seating positions, and 100% of passenger cars manufactured on or after September 1, 1997, must be so equipped. The same basic requirements were phased-in for light trucks one year later.

However, it would be foolish to assume that rapid adoption is only possible through government intervention. Since 1985, antilock braking systems have been voluntarily installed by manufacturers on millions of cars and light trucks. They have been rapidly adopted by consumers without regulation and have already become standard equipment in many new cars and most light trucks\textsuperscript{32}. While the Highway Safety Act of 1991 instructed the National Highway Traffic Safety Administration (NHTSA) to contemplate requiring ABS in all passenger vehicles, no regulation has been passed. Examining these two cases shows that consumer preference can be as powerful a market force as government regulations.

Interestingly enough, in an interview with Bill Ford, Jr., CEO and Chairman of the Ford Motor Company and an automotive visionary with a strong environmental commitment, he was asked what his preferred strategy was for the adoption of more efficient vehicles. His answer was resoundingly against government intervention. He stated that the only sustainable path for customer acceptance was through open market competition. It is his conviction that customers will demand cleaner vehicles and be willing to pay for them and that forcing them through government regulations is not the correct approach to take for their adoption\textsuperscript{33}.

Finally, what of predator/prey dynamics and how will this affect the vehicle power train? Obviously since 100% of the vehicles are now using an internal combustion engine, any
vehicles produced with hybrid or fuel cell technology will act as a predator. The question is, will the adoption of such technologies be overwhelming, such as the adoption of air bags, or will it closer mirror the dynamic between automatic and manual transmissions, with internal combustion engines still holding a sizeable market share? There have been a number of reports examining this phenomenon. Since changing the vehicle architecture, or changing the vehicle \textit{fuel} (with regards to a fuel cell vehicle), is such a dramatic shift, involving so many other factors, it would be incorrect to try to draw too much of an analogy with the relatively simple, component-based, technologies presented here. A number of reports attempt to study this phenomenon\textsuperscript{34,35}, but the general understanding is that such a dramatic shift will happen slowly, due to the number of challenges which need to be overcome as the technology develops. However, this does not mean a complacent attitude may be adopted, for as slow as the market responds, the auto industry’s development cycle can prove to be even slower, and if dramatic changes which may shake the auto industry to its foundations (which, moving away from the internal combustion engine certainly would) are coming in 10 to 15 years time, then upfront product development needs to start in earnest soon. Honda and Toyota have had hybrid vehicles out long enough to go through a complete design cycle; Honda is now bringing out a hybrid Civic, Honda's best selling line of car, in 2003. It will incorporate many of the technologies described in this chapter – cylinder deactivation, integrated starter/alternator with automatic engine shutoff\textsuperscript{36}. GM plans to boost its fleet fuel economy by 1% per year beginning 2003, introducing cylinder deactivation in 2006 and implementing continuously variable transmissions (CVTs) in 2007\textsuperscript{37}. The industry is changing and whether it changes rapidly or slowly will still require the foresight of industry leaders to know how to react, lest they risk losing substantial market share scrambling in the “catch up” game.

56
4.0 RESEARCH METHODOLOGY

The previous three chapters of this thesis have described innovation, technological change, and the future of the automotive industry. With this background it is time to now turn to the fundamental research which was the guiding force behind this document. An organization requires many things become effective at developing new products. One of the most fundamental of these is adopting the right organizational policies to promote innovation and product development.

Incremental change within an organization is not always easy, but it is what an organization is attuned to do. An incremental change which follows the same systems set up in an organization, a technology which uses the same equipment owned by an organization, or a product which utilizes the same supply chain established by an organization will be much more easy to adopt than changes which require fundamentally different structures. Yet, the very mechanism that the automotive industry has used to promote its success is to establish very tightly integrated architectures, in product, process, and supply chain, which are very difficult to change. Radical change requires an organizational structure which supports that change and it is for that reason that the organizational policies of one automotive supplier were examined to help gain insight into organizational policies which promote innovation in the product development process.

4.1 Research Goal

When examining organizational factors that promote innovation within companies, data was taken from an in-depth analysis of a newly created automotive components supplier. This company was chosen as a case study because they are located in the highly competitive
automotive component supplier business. In addition, they are in the exciting position of reinventing themselves. Recently, they were spun-off from a larger automotive OEM. While a part of the parent company, it was their responsibility to meet the cost and delivery targets needed for automotive components. It was not their responsibility to assess market needs and independently develop products. Now independent, they are developing their own innovation process to promote new product development and innovation to meet the needs of customers in open market competition. It is exciting to examine the company as it develops through these phases.

The automotive components business is typically categorized by low margins on individual products, with profits achieved through high volumes. Competition within the component supplier industry is forcing companies to compete with innovative products, as well as with cost structure. This company understands that it has a competitive advantage with the breadth of vehicle knowledge available within the company, far more so than typical component suppliers, and wants to best use that knowledge to create innovative products for the marketplace. However, the structure of the company just after the spin-off was concentrated around different component divisions. The company has restructured and is moving towards a system of better coordination across divisions.

The primary goal of this study was to understand what the current status of the company was, and to understand which policies were effective and which were ineffective at promoting innovation and productive work processes. The best way to do this was to interview employees across many functions and divisions within the company. Due to the size of the company (over 80,000 employees), it was important to speak to as many employees as possible. Rather than relying on a simple survey, or rather than speaking only to high level managers, the intent was to
go out and meet with almost 100 people at various levels within the company to find out what their opinions were.

4.2 Data Selection

The data collection occurred in two stages. The first included one-hour long interviews with almost 100 employees. The second stage was a follow up survey to obtain quantitative data not available in the interviews. The goal of 100 people was arbitrarily chosen. However, given the breadth of employees in this company, it was felt that it would be necessary to talk to at least that many people to attempt to capture the full range of issues in this company relating to product development.

To choose the 100 interviewees, an organizational chart was obtained and employees from the various divisions were mapped out. Employees were then chosen in a pseudo-random manner. By this it is meant that although the employee names were picked at random, the distribution of employees was chosen roughly to reflect the relative percentages of employees within different departments. For example, a larger percentage of supervisors and professionals were chosen over director level employees. A greater percentage of those interviewed were from the Product Development groups, rather than from Marketing. Representatives from all the major organizations within Product Development were approached (Climate, Chassis, Power train, etc.) as well, representatives from the Customer Business Groups (CBGs) and from Manufacturing provided their input. The majority of the people interviewed were in the U.S.; however, a sample of non-U.S. employees were telephoned to obtain some feedback from the international sites.
4.3 Interview

Once the distribution of employees was chosen, an interview script was drafted. Input from the Market Research group was used to help capture some of their expertise on unbiased data collection. As well, representatives of InnovationWorks, a group within the company actively working to promote innovative behavior within the company, became interested in this investigation and provided their input. The interview script is provided in Appendix A.

The interviews concentrated on a number of areas. Some sections were more relevant than others depending on who was being interviewed. The first part of the interview asked the respondent for their name and description of their duties. This was to provide a context for their comments. Following this were several questions relating to innovation. The first of which was for the person’s definition of innovation. This was to determine if there was a consistent understanding of what innovation meant to people in the company. Following this the interviewee was asked questions to determine what policies the company has which support or hinder innovation, and what the company can do to improve.

The next section of the interview was to determine how people were communicating within the company. The person was first asked what sources they used to get the information needed for their job. Then they were asked in what form and how effectively did they communicate with the three groups, Marketing, Product Development (PD), and the Customer Business Groups (CBGs). Finally, they were asked what changes would help improve these links.

The next question related to the company’s goal of becoming a systems supplier. Because of their knowledge across many vehicle systems, the company has the goal to understand how to better meet customer’s needs through the development of complete
automotive systems in addition to automotive components. The interviewee was asked what the biggest challenge will be for the company to become a system supplier. As well, they were asked how effectively they find they can communicate and work across different product lines within the company.

People were then asked their opinions of a triangular structure whereby Marketing, PD, and the CBGs communicated as a point on a triangle, each to the other two groups (Figure 15). They were asked in what means would this linkage make sense from their particular role and how would they best like to see this implemented. The purpose of this question was to evaluate the effectiveness of increasing the communication density within the company. Marketing, PD, and the CBGs all need to work together to deliver customer solutions; however, due to historical factors the amount this is occurring in the company has been inconsistent.

![Figure 15 - Proposed Communication Mechanism Between Functional Groups](image)

Finally, they were asked if they had any final thoughts or comments on what could be done to promote innovation and improve work processes at the company. This question was intended to gather intelligence on anything that had not come up in the interview. In some cases this was very enlightening.
Upon completion, a total of 91 people were interviewed. The distribution of employees is shown below.

Figure 16 - Distribution of Employees Interviewed

4.4 Survey

Based on the interviews, as well as input from InnovationWorks and the Market Research group the survey questions were developed. The goal of the survey was twofold. It was to provide some quantitative data to compliment the results of the interviews. As well, the survey was to provide a baseline so that the same survey, or a similar one, could be used some time in the future to evaluate what improvements the company has made. Because of this, in some cases, the data has value in its own right, yet conclusions cannot be drawn until a follow-up study is performed in the future.

The structure of the survey is described below (the complete survey is in Appendix B):
The first seven questions in the survey related to people’s understanding of how innovation and new products were developed at the company. The first two were suggested by members of InnovationWorks, whereas the specific investigation of the company Product Development System and the Concept Development Process (CDP) were included to establish a baseline of understanding of current practices. The company has a current product development process that they use to bring a product through development and into production. CDP is a new process being introduced. While a part of their parent organization, they were given very detailed information about the components required, therefore a concept development stage was not required. However, now that they are experimenting with their own product offerings, the company has created CDP as a means of generating and developing concepts, before a full-blown product development initiative is started.

The following nine questions (8 through 16) were included to determine the degree of awareness that various groups across the company had of the Marketing, PD, and CBG organizations. As well, they were included to establish how each group saw the others and themselves, as well as to determine how was the effectiveness or ineffectiveness of the current working relationship between the groups.

Question 17 came about after a discussion with people in Marketing regarding the direction of the senior leadership of this company. It was included to determine what people thought was important to the company’s senior leadership.

The final 12 questions (18 through 29) came from the management book, *First Break All the Rules*. This book includes 12 questions used by the Gallup organization to assess the organizational effectiveness of companies. It was thought that this would be an excellent way to capture the pulse of the company now, and in the future. The main measurements are how
effective people feel in their jobs, how fulfilled they are at what they do, and how committed they are to the company’s success.

The final question of the survey was open ended. It asked, “Although I have had a chance to speak with you directly, if you could identify the one thing at the company which most hampers our ability to promote innovation and new products, what would it be?” The purpose of this question was to isolate the single greatest issue that was on people’s minds. This was necessary to help provide a framework for the voluminous responses received from the interview data.

In total over 80% of the surveys were returned, which is an astonishing response rate, and provided a good sample size from which to draw conclusions.
5.0 RESULTS

There were three sources of data collected – individual interviews, a survey with 29 agree/disagree questions, and one open ended question – “If you could identify the one thing at the company which most hampers our ability to promote innovation and new products, what would it be?” The results from that open ended question were grouped around common themes to identify the most pressing issues. From this grouping a Pareto chart was created, prioritizing the issues (Figure 18).

The results of the interviews were combined with the responses to the open ended question. These helped generate sub-categories, providing detail on specific issues. A discussion of each of these major areas is below.

![Pareto Chart of Most Pertinent Issues Relating to Successful Innovation as Identified by Company Employees](image)

Figure 18 - Issues most relevant to the company's ability to promote innovation and new products
5.1 Business Planning Time Horizon

All businesses can say that they have a problem with a lack of resources, or insufficient resources. However, what is really important is how resources are allocated to different business needs. The number one mechanism that employees identified for promoting innovative behaviour is to balance pressures for near-term business results with those of longer term gains. With too many resources directed to solving immediate needs, then resources are directed from new product development projects, which will make meeting customer needs even more difficult in the long run.

5.1.1 High Priority of Near Term Business Pressures

There was a general perception that most resources are directed to existing business committed to customers as a result of immediate business needs. As engineering efforts are allocated to meet customer needs there can be less freedom available to explore new products. A mindset has developed among people in non-Advanced PD groups that being innovative is a role that is not theirs to play. In a few cases the engineers did not feel that being innovative was as important as meeting the immediate customer demand. However, the greater majority of engineers expressed a desire to develop innovative ideas, but felt that meeting current product commitments had a much greater priority of their time.

This feeling was echoed in comments from members of the CBGs. When asked about the CBGs ability to assess customer’s future needs and feed that information back into the company, one CBG representative felt a priority, given the business climate, to excel at meeting customers’ current needs rather than spending time on future issues.
A practical issue was identified along the lines of budgeting. Several groups identified the importance of having a good connection between the customer groups and the budgeting process. As business is being booked and commitments are set it is important for that information to be reflected in the budgeting process. If budgets and resources are set independently, and if business increases beyond that expected, there will be a shortfall in resources which will further promote efforts to meet immediate needs at the expense of longer term prospects.

In addition, product development budgets are set once a year to meet the development projects the company feels are worth funding. However, if a good idea arises that should be supported, it is important to have a means of doing so without waiting until the next budgeting cycle. Otherwise, it becomes necessary to find money from other projects’ budgets to support the new idea until it can obtain approvals officially. Substantially every person interviewed mentioned that the bulk of innovations come from a bottom up approach where an engineer has an idea and pushes it forward, usually using resources from a different budget. It is important for companies to adopt policies to find and support these ideas, rather than allowing people to pursue projects on “borrowed” resources, otherwise it becomes difficult to manage innovation spending and difficult to effectively manage the innovative product portfolio.

Headcount is a resource which also requires clever management. While adding additional staff is a costly procedure, there can be a very effective means of allocating resources through effective mobility of labour. Good mobility of labour is also an excellent way to break down departmental barriers and promote cross divisional communication. As one person stated, since people best communicated through private networks of who they knew, good rotation through various areas of the company is very effective at spreading company knowledge.
Through the interview process it was discovered that without effective labour mobility it is possible for people to feel underutilized but be afraid to say anything due to fear of layoffs. An engineer in one of the Advanced programs suggested that an internal engineering consultancy position would be a fantastic program. Allow people with specific skills to assist several programs for short periods of time. The program would only be billed for the time worked, removing the headcount budget restriction, and there would be much greater transfer of ideas as people worked in various areas of the company.

5.2 Strategic Focus

Many people stated that they find a clear idea of what is strategically important for the company to be very useful. With a broad portfolio of products and increasing necessity for skilled allocation of resources it becomes ever more important to have the ability to ascertain what direction best fills the future needs of the company. The CBGs are motivated to obtain as much business they can get to bring in revenue to the company. However, the profit potential, which is sometimes difficult to assess, and the strategic direction of the company need to be factored in when pursuing business. Linking back to the resource constraints discussed above, it is especially important to plan projects and pick customers wisely.

During the recent years from the spin-off there has been a lot of experimentation as to what the best business model for the organization would be. At one time the company was more than just automotive systems, considering all engine and energy transformation systems. Recently, that view has focused and the company is back to being strictly automotive. While there are clear benefits to being the technology leader, there is great interest to also be the low cost leader. It is very important to not try to half-way do both, otherwise neither strategy will be effective. Previously the company was eager to test its new found freedom and diversify away
from their parent organization; now, with changing business pressures, it is making more sense to keep as much of their previous business as possible. These shifting priorities, while necessary, make it difficult for groups to commit in any one direction for fear that the company goals will once again shift. This makes spontaneous innovation difficult.

It is possible to pursue multiple strategies (low cost / high performance) as long as it is clear which sector each of the strategies applies. For example, some products are best sold to the customer as low cost items, whereas others might require high performance to be competitive. This does not contradict the need for a strategy; if anything, it enhances it. As long as people understand the competitive forces guiding product strategy, they can react accordingly, even if that strategy differs across the product portfolio.

Many people have suggested that it would be useful to know where the company wants to be in 3 years, 5 years, and 10 years. They can then know under what framework they should be thinking to contribute to those goals. They need to know which products the company wants to emphasize and which ones to move away from; which customers are strategic and which to emphasize less. This will allow people more confidence when pursuing innovative projects that their intentions are aligned with what will be best for the future needs of the company.

5.3 Clear Go/No Go Decision Gateway

The third priority identified to promote innovation in the product development process is having a clear go/no go decision gateway. While this may appear to be adding constraints to what some people feel should be an unconstrained creative process, the fact is that having a clear understanding of which projects the company feels are important, and which projects the company has decided are out of the strategic realm, allows employees to focus their efforts in the
right direction. With a clear go/no go decision process, employees can be more certain that the innovative projects they are pursuing are in the right direction, which is a motivating force to succeed.

5.3.1 Financial Tracking System

This is tied into the importance of a clear budgeting process, identified above. Employees within the company recognize the value of being able to track expenses to a specific project to help in the budget planning cycle. Without this intelligence the allocation of resources becomes decoupled from the product development process and projects that are undesirable cannot be stopped while projects that are strategic cannot be moved forward.

With a clear strategic direction and a defined budgeting process it becomes easy to determine which projects the company feels are appropriate, and which ones are not in the direction worth heading. Without this information, people maintain their pet projects, and it is impossible to detect and stop this drain on resources because there is no means of tracking the money being spent. As well, if there are shifting priorities, there can be little incentive to follow the strategic direction of the company if there is an underlying half-hearted expectation among the employees that any cut program may soon be restarted.

A great advantage of having a clear approval process is that it frees up a lot of time spent justifying a project for the development of the project itself. Many people recognize that in an uncertain environment, it becomes necessary to spend a great deal of time defending purchases and resources for products that have been given the green light. Without a clear approval process, different departments can have a different understanding of the priorities of the company, resulting in mismatched incentives. Therefore, a visible go/no go gate allows the whole company to get aligned in the correct direction.
It is important to understand that innovation is a creative process, so all of this discussion about budgets and approvals sounds completely contradictory to the “think out of the box”, “promote wild ideas” mentality of innovation. However, overall strategic direction can still provide guidance without adding constraints. Knowing that there is a growing market for one type of customer need while knowing that another type of market is something the company feels is worth avoiding can help guide ideas without constraining the process. This is the type of guidance being talked about here.

5.3.2 Sense of Urgency and Tolerance for Risk

The value of clearly communicated decision making was identified in the previous section. An aspect affecting people’s ability to make clear decisions is a developed sense of urgency and culture of tolerance for risk. If these two characteristics are such that there is a low sense of urgency and a low tolerance for risk the intelligent point of action for any decision will be to commit more and more effort reassessing the issue and gathering further data. This is the rational action plan when there are low search costs and high costs of failure. However, this can be at odds to a culture of innovation. While much can be accomplished through computer simulations and market studies, there is often no substitute for building a prototype or shipping a product. Often the market will not indicate what they want and the best discoveries are sometimes simply by accident. An inconsistent process of approving new projects, coupled with a concern of failure combined with limited resources will result in a situation that once a project is funded it will be subject to continual review resulting in time spent defending the funding for the program rather than actually working on the development. The best policy identified is to accept the risk of various projects and develop a product portfolio to diversify this risk. Then, after consideration, projects that are approved should have goals set for the next stage gate of
review and they should be funded and supported to succeed until that time when a further
decision can be made.

5.4 Organizational Understanding

The fourth greatest issue for promoting effecting innovation and product development
within an organization was identified to be a clear understanding of the organizational processes
themselves – who was responsible for what, what was expected from each group, who to see for
help, who to provide help to, etc. Reorganizations are never easy and companies should not
enter into them lightly because they jumble up the organizational knowledge of how things are
done. As new groups are formed and old groups are changed, people need to rebuild their
network of understanding. Organizations are like complicated factories, and if the factory
assembly process is changed, all of the workers need retraining and time for adjustment. The
company found the shift from the SBU to the CBG structure and the creation of a Marketing
organization absolutely imperative in their transition to becoming a more customer focused
company (see Section 1.2 for details). However the aftershocks can still be found rippling
throughout the company.

5.4.1 Understanding of the role of Marketing

The first place new organizational learning is required is with regard to the Marketing
organization. As an organization, the company was previously not required to understand the
market needs, nor determine customer demands. All of these efforts were being done within the
larger OEM. However, they had the foresight to recognize the value of this group and therefore
created this organization as part of the company restructuring. The challenge now is to ensure a
good connection to the rest of the company. The Marketing organization needs to prove their
value to the rest of the company and establish credibility. This is true for any new organization. People in the company not used to working with this group, or used to a Marketing function at all, need to be shown how to integrate the functionality of this group into their working process. Many groups interviewed showed a strong demand for a tighter link with people in Marketing, as shown in the following graphs.

Figure 19 - "I feel comfortable that the connection I have with the Marketing organization is sufficient."
5=Strongly Agree, 4=Agree, 3=Neither Agree nor Disagree, 2=Disagree, 1=Strongly Disagree

Figure 20 - "More connection with more people in Marketing would be relevant or useful to my group."

Of particular interest was the amount of people in PD who strongly agreed to the notion of a better connection with Marketing, showing that people in those groups recognize the potential value of a marketing function and are looking for the best means to integrate this talent.

An equally important consideration for progressing through a reorganization is the tendency of groups to resist the new structure. If groups within a company are large enough they may choose to ignore the new organizational structure and continue working under the old approach. This is unproductive as it undermines the efforts of the new organizational units, while reducing what effectiveness there was with the previous structure. This can happen if a number of people in the company are not shown the value of the new organization or do not understand how to fit the new organization into their development process. For these reasons it
is all the more important to begin an educational process and a credibility building process to help cement in the relationships of the newly formed organization.

5.4.2 Clarity Over Who Approves Innovation

The previous section explained why it is important to have a clear understanding of which projects the company wants to support and which projects the company thinks are not strategic. Complementary to that is the fact that the people involved in determining which innovative directions the company wants to pursue need to be visible and accessible.

Observations were made that if people had an innovative idea, or something they thought should be investigated, but did not know who to discuss the idea with to determine its impact on company strategy, the only thing they could do is try to sell it to their supervisor, who would then continue to push the idea further up the chain. This “push” method, while common in organizations, requires that the innovator not only be a good innovator (to come up with the idea in the first place) but that he or she also needs to have tremendous confidence, political ability, and persistence, where required. In addition, without a means of sharing an innovative idea with the right people, who have a view of the whole company, a person with only a narrow departmental view may have no means of furthering their idea if their idea does not fit in their immediate area of work. Many people suggested that a forum to pool ideas would be very useful. This came in two forms: local review, and web database.

With a local review it was thought that a regular brainstorming session and review of ideas within a specific area of PD would be worthwhile. Indeed, some PD groups had already begun doing this. One important characteristic that some people stressed to help alleviate fears of failure would be to collect ideas and have them reviewed anonymously. Sometimes ideas can
be supported based on the seniority of the person who suggested the idea, not on the merit of the idea itself. To avoid this syndrome an anonymous review would help.

The web database was suggested so that different groups within PD would be able to submit or review ideas that were broader than a local functional area. They have enabled a patent submission process which allows ideas to be evaluated for their worthiness of patent protection. Many people thought that the patent submission form was a partial solution; however, the difficulties with using that system are that many ideas may not be appropriate for patents in that other forms of intellectual property protection might be better suited. As well, the patent submission database is better suited for legal review as opposed to technical review and therefore is not used as an effective means of sharing ideas with other members of the company. As some of the best ideas come from combining two or three approaches, the most important thing is to allow people to be aware of what their colleagues are doing.

Many people did not feel there was a shortage of ideas within the company. Through investigation it was determined that most people had or knew of a good innovation that should be pursued. However, without an effective process to develop ideas into commercial products it can be difficult to move past the ideation stage. The above mentioned reasons describe some of the challenges present in trying to execute when developing a product.

5.4.3 Effective Communication and Information Dissemination

Throughout most of the company there was a general agreement that communication across divisions and within divisions was key. While many areas of the company had effective communication within the groups of people who regularly worked together, the most common case was where the communication would occur primarily horizontally, but not vertically. The sentiment around this situation was that managers would typically talk to managers, for example,
but less with people above or below. This phenomenon was prevalent in other levels of the company. It is in part due to these vertical barriers that many people expressed a desire for more empowerment at the local level. One drawback with a predominantly horizontal communication structure, combined with less effective cross-group communication, is that it can mask the true sense that various groups are linked. One particular discussion with a senior person in Product Development indicated that it was thought there was a strong connection with Marketing because there was great communication with the appropriate senior marketing person. However, descending through the organization on both sides of the connection showed that neither the PD group, nor the Marketing group felt they had established a viable working relationship. With most communication being funnelled through senior people, and with senior people primarily communicating at their level, their schedules can become so booked full of meetings with various other senior people, that a bottleneck can be generated, reducing communication of what is discussed at those meetings to the people down below.

This importance of information flow vertically in the company can be seen in some of the data from the surveys. In the two questions where people were asked how well they knew what was expected of them at work, and how important their job was given the mission of the company, there was a clear trend in both cases showing less satisfaction at each progressively lower layer in the organization. Basically, as people descend in the ranks of the company they can feel less connected to the workings of the organization and feel less confident about the importance of their job.
Figure 21 - “I know what is expected of me at work” – Decreasing agreement at lower organizational levels

Figure 22 - “The mission of my company makes me feel my job is important” – Decreasing agreement at lower organizational levels
The final point worth mentioning with regards to communication is the importance of free information dissemination. Ideas and knowledge are strongly valued within the company and the company rewards those people “in the know”. The more information that an employee can appear to have, the greater their status will be. While this stems from the notion that information and knowledge are valuable, which is positive, there can be a dangerous side effect. Unchecked, this can encourages a culture of information hoarding. In this environment, nobody wants to simply give away the information that they have when it could be better bartered for prestige. It is valuable to be seen as the expert on something, so the more widespread anyone’s expertise is, the less it will be valued. While this is such a damaging outcome of such a desirable goal, people can behave in many ways to enforce this and it is not uncommon in large organizations. If information is not referenced or documented well, or if research that people have done is presented without credit, or if there is a habit of people throwing together presentations of previous slides without referencing or checking sources, then the information control becomes sloppy, data integrity is lost and this mentality can develop. Engineers in the Advanced PD groups have the incentive to conceal information from the CBGs for fear that the CBGs will try to sell products that are not yet ready; the CBGs, knowing this is the case have found ways to do their own sleuthing to determine what future products are being working on, in order to be able to convince the customers about the company’s long term viability. With a great amount of lore and undocumented information, poor decisions are made. At the very least, a decision cannot easily be reviewed as to why it was made. If this is combined with a risk intolerant attitude that promotes frequent review of decisions then very quickly the rate of advancement can slow down. If mistrust and secrecy of information do exist, people have to expend extra effort to find things out, and then there is great risk of misinformation being spread.
the company. In a presentation at MIT’s Sloan school, a senior executive at General Electric once stated that to combat this problem, GE established a policy that information hoarding was tantamount to stealing from the company, as ideas are considered company property. If someone has an idea, or information, it is their duty to communicate and document that as well as possible. This effort was implemented to change the culture and drive out this disincentive which had existed in that organization.

5.5 Incentives for Cross Divisional Collaboration

An important goal of the company is to expand beyond automotive components and move towards sub-systems and complete vehicle systems. Customers are demanding this, there is more ability to generate better products through integral design, and there is more value to be captured in complete systems. As well, one of the strengths they possess which distinguishes this company from other automotive suppliers is the breadth of experience across products and the potential to combine that knowledge to produce automotive systems which can take advantage of synergies from different product areas.

However, the second greatest barrier to becoming a systems supplier was identified to be the challenge in having people collaborate across divisional lines (the primary difficulty identified by people was the inability of the OEM to purchase systems instead of specific components – although this is what the customers say they eventually want, until their processes change this will remain challenging). The move from the SBU structure was intended to help break down these functional chimneys. No longer would Chassis, or Power train, or Climate exist in their own functional business unit, but instead everyone would be under one umbrella called “Product Development.” This was an important step and certainly a necessary one. However, due to the current practice of ordering components from the OEMs, people have not
adjusted to this shift yet. Under the PD umbrella, people are still within the Chassis, or Power train, or Climate Control divisions.

There are a couple of reasons for this. Primarily all existing business has been booked for components, and components reside within a certain division. Therefore, while still meeting current commitments, it is easy to stay under this structure. As mentioned above, many of the roles of the SBUs still exist in this new organization. There has not been the mental shift to work across the company. As well, there are not effective mechanisms in place to initiate this mental shift. Many groups in PD identified that they would like to know more about what is going on elsewhere in PD in the other groups, because they feel that, right now, they have little contact with other PD groups.

The second reason is the focus of financial reporting within each division. Each division has an incentive to report successful financial figures for their own division. If a project will be profitable for one division, but lose money for another, then there is no incentive set up to support it. People make decisions based on optimizing their own situation rather than a company as a whole. This is not to say they are malicious. They may not have all the information and are only making the most rational choices. Regardless of the reason, misaligned incentives can be a powerful barrier.

There has been a push by Product Marketing and Power train to support the notion of “attribute based solutions” in the areas of NVH (noise, vibration and harshness), Comfort, Emissions, Fuel Economy, etc. The notion is that the company is not trying to provide a Climate product, or a Chassis product, but is instead trying to provide a “solution” (i.e., either component, subsystem, or system) which meets a specific customer attribute. While this is difficult to know how to lead going forward, this is certainly an excellent starting point.
moves the mindset away from specific functions, and gets people thinking along the lines of
delivering something the customer wants, regardless of how it crosses functional borders.

This focus on local financial optimums occurs in the CBGs as well. Each CBG is
charged with reporting a positive financial situation for their particular customer and chasing
down business in their particular area. Therefore, there is less of a means of coordinating and
evaluating projects that could span several CBGs. As well, if there is a project that may be
useful for one CBG but makes less money for another there are simply no incentives set up to
promote this. For example, if a product would be cost negative for the Ford CBG but make more
than enough money to counter this with the GM and Asian (Toyota, Honda, etc.) CBG, there is
not the means of evaluating this global optimum. With everyone concerned about reporting a
local profit, decisions are not made as intelligently as they could be, or the company loses out on
opportunities. There is not the incentive structure in place for CBGs to work together on
intelligent product compromise, allowing the widest customer audience to be reached at the
lowest cost. Each has the goal of delivering to their specific customer. One of the benefits of
spinning off the company was that it would be free to develop products for a whole range of
customers other than their previous OEM. However, the current mindset is still to develop
specific products for specific customers, and this does not take advantage of the potential cost
savings which could occur if products were able to be developed for multiple customers, with
input from across several CBGs.

One of the marketing managers stated a very intelligent plan which would require this
cross-CBG collaboration. This was to identify different OEMs and roll out products based on
their particular adoption profile. Advanced technology products could go to the earlier adopters
such as Honda or BMW. Then, as the product matured it could be sold to more conservative
companies such as Ford or Toyota. However, the idea would be to have a customer rollout strategy which was coordinated across CBGs to take advantage of each customer’s technology adoption profile. This type of effort would require the coordination of multiple CBGs being able to work together.

5.6 Personnel Skill Set and Motivation

The final area that people identified as important to promote for the company to succeed is related to personnel issues. People within the company have a general feeling that the company employs talented staff. When asked if they agreed with the statement “My co-workers are committed to doing quality work,” 88% responded that they either Agreed or Strongly Agreed. However, there is a feeling that the company could do more to make the most out of its resources.

The primary action of importance is that innovation is nurtured or rewarded. As well, it is important that failure be effectively managed. While it is appropriate to take a critical view on negligent behaviour, or a failure wherein nothing was learned, the failure of a project simply because it was a risk of product development needs to be understood. There can be a strong incentive in product development programs to succeed the first time through. In fact, many would argue that the purpose of a product development process is to promote successes. However, to be innovative, to develop new products, requires taking risks and if that is not supported, people will have an incentive to avoid innovation. Suggestions several people had were to tie performance evaluations to either showing innovative behaviour or to assisting with innovation in the company. A company needs to accept the risk of failure – if there was a lesson learned and if it came while progressing towards a goal. The only true failure is failing to learn from something and repeating a mistake.
A company that is in a state of flux can have a further challenge which they must work furiously to overcome. If incentives are structured to minimize risk, and the company is working through a state of readjustment, there can be great concern amongst employees to toe the company line. This can be the most difficult phase to encourage innovative behaviour because if there is concern about layoffs there will be a strong incentive for people to simply lie low. Therefore, encouraging an innovative environment in these conditions is even more critical than when a company is healthy.

Finally, many employees stated that one necessary ingredient for innovation in product development is to provide a senior technical career path for people. Without this, there can be the expectation that advancement within the company requires pursuing a path through management. However, many engineers may find this limiting and allowing career progress in a technical role can send a strong signal to either retain or attract really good talent. Emphasizing and rewarding technical skills is necessary to become a technology leadership company.
6.0 DISCUSSION AND RECOMMENDATIONS

The information provided in this thesis has covered three main areas so far. The first is innovation, what it is, what types there are, how it can affect companies and how to promote it within organizations. The second is future automotive technologies, what is coming in the near, mid, and long term view, and how some other technologies have been adopted in the industry. The third is the results from a specific case study identifying six key areas on which to concentrate when promoting innovation and product development in a large, diverse organization.

Given all that information, what are some of the recommendations and suggestions which best address issues that companies like this can face? To address that question, it is useful to revisit some of the areas discussed previously in this thesis, address some of the issues discovered in the investigation of the company, and finally report out on what the employees, themselves, recommend.

The first type of innovation examined was incremental versus breakthrough innovation. Many people think of innovation only as breakthrough innovation and think of incremental innovation as some ineffective impostor. While it can be a positive thing for people to want to strive for breakthrough innovation, that type of mindset can be damaging. Incremental innovation can account for as many performance gains as breakthrough innovation and therefore neglecting or misunderstanding this important contribution can be damaging to product improvement. As well, people who feel that breakthrough innovation is the only type of innovation will feel that they have nothing to contribute if they do not see themselves to be early in the product development process. Many of the people interviewed who were responsible for
many of the later vehicle development issues such as packaging for components felt that their job had no room for innovation, and that that was only for people within R&D groups. While these people may not be in a position to influence a breakthrough innovation, they are well suited to examine and discover many incremental innovations, if they have the appropriate mindset.

When considering incremental vs. breakthrough innovation, it is important to understand what limitations a company might face. Organizational and technical rigidities may promote regular innovation, but dramatically hinder breakthrough or architectural innovations. Much of automotive product development has been to gain as many performance and cost improvements as possible. This has been done through large capital investment and high volume production. However, as companies try to become more and more efficient through specialized processes and specific investments, it becomes more and more difficult to make breakthrough changes. For example, if a company invests millions in a process for manufacturing steel bodies that is only applicable to steel, then it would be very difficult to change over to any other kind of material, regardless of the cost savings or performance gains. Likewise, if a company’s product development process is streamlined to support incremental innovations, then a breakthrough innovation which does not fit in this process is very difficult to develop. As corporate rigidities are established, a company becomes better and better at doing what they typically do. However, radical changes from the established practices become harder and harder to make. With this in mind, it is important for people within organizations who are responsible for promoting innovation to be aware of this reinforcing cycle.

Another type of innovation which is relevant is the distinction between autonomous and systemic innovation. As a component supplier, in some ways the company examined can concentrate on autonomous innovations by improving the performance of specific components
without effect to the rest of the vehicle. However, the interface between automotive components and the vehicle are not as standardized as, say, computer components within a desktop. So, even when components are being supplied, coordination with the OEM is required to succeed. Now, as the company moves beyond components into larger subsystems and eventually vehicle systems an even greater amount of coordination will take place – first with the OEM, and secondly, internal to the company itself. However, because they have the opportunity to sell to multiple OEMs they should try to develop systems which can be used in multiple OEMs’ products. Auto manufacturers are extremely demanding about the uniqueness of their vehicle and therefore the customer interface features of the system need to reinforce the distinctiveness of each automaker. However, behind the interface, common components and architecture will allow for cost savings through economies of scale. The easiest example of this is an audio system whereby all the electronics are common and different faceplates can be applied to the front. While most automotive systems rely far more on integral design than the audio system example, it is still a goal with which to approach each design. The mindset that needs to change in product development for this to successfully occur is the local optimization for each OEM. By globally optimizing and taking advantage of economies of scale, price reductions can take place. Depending on the product, if the value of the cost savings is greater than the loss due to a non-locally optimized product then there is still more value created for the OEM and this is the route to pursue.

The biggest reason that a modular product development architecture has not been extensively pursued can be seen from the fact that the automobile has been designed to be an integrated product. Clay Christensen, of Harvard Business School, explains in the following example. Recently two automotive companies were looking to use a ceramic material in
automobile engines. The material had very exciting material properties for use in automotive
engines. By implementing a ceramic, the material properties would greatly benefit engine
performance. One automotive company decided that the best initial use would be for connecting
rods for the pistons. By reducing the reciprocating mass, a tremendous amount of energy would
be saved in frictional losses. However, when the ceramic parts were placed in the engine instead
of the regular steel components, it was found that the entire engine was thrown out of balance.
Through incremental changes, the complete engine had been optimized as an integrated whole
and it was not be possible to simply replace a part, no matter how small, without considering a
complete engine redesign, which was far too expensive for the company’s purposes. Now,
another automotive company decided that the engine balancing issue was obviously going to be a
problem, so they decided to use the ceramic as a piston wall coating. This would take advantage
of the excellent thermally insulating behaviour of the material, which would allow for higher
combustion temperatures and higher engine performance. However, when this was tried it was
discovered that the higher engine temperatures, while excellent for engine performance, were too
high for any engine lubricant. To utilize the ceramic in this fashion would require a research
program to develop an entirely new engine lubricant. Both companies found that the changes
they were hoping to make were tied up in even greater system changes and neither company
pursued the ceramic material. Therefore, while a tightly integrated product architecture exists, it
will be difficult to move to modular components. However, in order to benefit from the gains
which occur using a modular product structure, these are the types of hurdles which must be
overcome.

The next question that bears addressing is with regards to future technologies. Many
people in this industry have heard about the dangers of ignoring technological shifts hundreds of
times. Heard less often, but of equal importance, are the numbers of businesses who have rapidly embraced a technology that did not arrive and suffered huge losses as a result. General Motors made huge investments into electric vehicle technology and was unable to succeed in its commercialization. GM is now actively pursuing fuel cells, but rather than setting the goal of being the first to market (and risk there being no market), GM has set the goal to be the first to sell one million fuel cell vehicles. They feel that this still shows a commitment to the technology while allowing others to develop the market. The fact that one of the references of this thesis is called *Fuel Cells: Power For the Future* and was published in 1960, forty-two years ago, demonstrates the risks of embracing new technology.

So what is the best approach to handle new technologies? Like any type of risk, the best approach is to diversify the risk with a portfolio. The advances in 42V technology will help developments for a 300V architecture used by hybrid electric or fuel cell vehicles. Hybrid vehicle components and systems such as power conditioning units and electric motors can be used in fuel cell vehicles. Advanced ICE developments can be used in hybrid vehicles. The best approach is therefore to look for developments that can bridge between a technology that will more likely be successful and a technology that is more uncertain. As well, in order to diversify risk it is important to develop multiple products simultaneously to better increase the chances of developing a product that will be a hit. Finally, it is also important to play an active role in ensuring the success of the products being pursued. By this it is important to make strategic alliances, set up demonstration programs, attract positive media buzz, lobby the government, publish academic papers, and engage in a number of other activities to influence the forces that will eventually determine the ultimate success of a product in a favourable manner.
However, when pursuing a portfolio strategy of products it is imperative that the portfolio be kept small enough to ensure that each product in that portfolio has adequate support to succeed. This can be difficult because the smaller the portfolio becomes, the less risk is being diversified. Because of this, products should be chosen that have the greatest chance of success, or that provide an opportunity to gain expertise in a broad area. The important thing is for the company to pursue a path such that when exposed to the probable set of future events, allows for the greatest expected degree of success.

The reason that keeping the portfolio set small, to ensure adequate support for projects, is important is that if the portfolio is too large it does two things. First, it dilutes the clarity of the strategic direction of the company, which we have seen earlier, hinders the innovative process. Without knowing in which areas of the company to really focus, employees are less certain where to concentrate their efforts. Second, dabbling in a variety of products without assigning clear goals and deliverables for the products’ development allows products to wallow around as a research curiosity for a long time, without ever being moved forward into production. If this is allowed to continue a mentality can set in whereby it is assumed that the point of R&D groups is to stay abreast of the technology and dabble in certain areas without needing the commitment to move forward. This then robs the company of the sense of urgency it needs to develop, and is also frustrating for the innovative employees involved who may feel as if there is no eventual payoffs for their efforts. Pick some technologies to promote, lay out a development path with key milestones to hit, and then light a fire under people to meet the stretch targets set.

When examining technological improvements, it is important to be aware of process changes in other industries. Technological change within the automotive industry is essential to understand; however, it is the technologies which become available in other industries that can
be transferred to the automotive industry which also bear monitoring. Many technologies which are not used in automotive applications are overlooked because of impracticalities in cost or performance. However, other industries can provide the bridge to reduce cost levels in a certain technology. Once the cost level, or performance barrier, has been breached, a technology can be rapidly adopted into an automotive application. The suddenness of this adoption can be disruptive to companies unprepared for the new technological change. It is for this reason that complementary industries to the automotive industry can be fertile grounds for predicting the future.

One other danger for a company in this position is that of the dynamic between incumbent and attacking firms. This company examined is in the interesting situation of being both types of companies simultaneously. On one hand they have an established customer base with an established product portfolio, capital assets, workers, factories, company culture, many of the things you would expect in an incumbent firm. On the other hand this company is trying to establish a whole new customer base, revamp its product portfolio, develop a new culture and grow into its own company, similar to an attacking firm. What advantages and pitfalls are present in these two scenarios? Incumbent firms can fall prey to disruptive technologies. A disruptive technology is a technology that does not compete well on any of the metrics most carefully observed by the incumbent firm. The technology will not be seen as a threat and the incumbent firm will have financial incentives to avoid pursuing this type of technology. On a more extreme scale, an incumbent firm could have millions of dollars invested in capital equipment to develop and manufacture its existing product line and therefore will have a strong financial incentive not to change. Of course, the attacking firm can take advantage of the incumbent firm’s situation. While the attacking firm will still have to make investments to
develop new technology, as does the incumbent firm, usually the incumbent firm has financial hurdles in place which prevent it from entering markets below a certain size. In this situation the attacking firm has a chance to gain a toehold on a new market and develop. By the time the market is “big enough to be interesting” the incumbent firm is in the situation of having to play catch-up. This company has addressed this problem well in certain cases. Recognizing the benefits to be gained in the Aftermarket business of automotive components, they have established an group to develop products for that business. While the volumes are substantially lower than those seen in its mainstream businesses, by supporting these development efforts they can gain several synergies – access to profitable, higher margin business, access to technology which can benefit other company businesses, and a chance to build the company brand name and improve the market position of the company overall. Another example of efforts they are making to capitalize on its “attacking company” status is the fact that they have formed an internal group called “InnovationWorks”. Like the Lockheed’s Skunk Works organization the goal of InnovationWorks is to be able to work on projects, separate from the financial constraints of the rest of the company. The goal is to allow InnovationWorks to be able to communicate across all departments in the company and develop projects that would not be able to be developed under the pressures and financial targets in place in the rest of the company.

In light of all of this information it is useful to turn to the recommendations determined from the study itself. These are specific actions which were suggested by company employees to even further improve the company given the issues identified.

**Establish a 3, 5, and 10 year plan and set departmental goals** – While the company has many immediate term concerns which require immediate action, the development of new products and new technology requires a stable, longer term view. We have seen that employees
are hesitant to develop new products and technology when they do not know where the company would like to be and which direction of technology development is most beneficial to the company. As well, in a volatile budgeting environment, if anything requiring funding for more than one year is at great risk of being cancelled then there is a further disincentive for new technology and product development. Therefore, a clearly stated goal of where the company wants to be, how it wants to be positioned in the market, what products it wants to have developed, and when those milestones should be reached will provide the direction for employees to operate and send a powerful signal to the marketplace and the company’s customers about the stability and long term potential of the company. Of the six most important issues identified, this addresses numbers 1, 2, and 3.

**Establish a better means of financial tracking for better decisions** – There can be difficulty making decisions if access to financial data on product profitability is difficult to obtain, making it challenging to know what products to emphasize. Likewise, the budgeting system that makes it difficult to stop work on projects that are to be cancelled, or to adequately promote projects which are approved hinders quick action. With an uncertain footing on where individual groups stand financially, and without authority for managers to approve and manage expenses, then inertia can develop and there can be little incentive to move quickly. (Addresses issues 1, 3, 4, 5)

**Promote greater rotation of labour or internal consultancy program** – Many people stressed that they would like to have a better understanding of what is happening in different areas of the company, or even different areas of PD. Likewise, various managers acknowledged that headcount budgets and monetary budgets were set separately, preventing them from obtaining program specific resources if only part-time support were needed. Greater mobility of labour
within the company would solve a variety of issues. It would promote greater cross divisional knowledge as employees were introduced to different areas of the company. It would promote greater cross divisional communication as employees private networks were strengthened. It would allow underutilized employees to shift to positions of greatest need. It would allow managers to fill positions temporarily, or on a part-time basis, to provide support when a full time employee is not required. As well, moving people between Advanced groups and Forward or Current model programs would provide better understanding of how to best move forward new technologies and innovations and allows both groups to work towards pushing new products through the pipeline. (Addresses issues 4, 5, 6)
7.0 CONCLUSIONS

Innovation, new product development, the future of the auto industry in the next twenty years, and an 80,000 employee, two year old start-up – that's quite a weighty topic area to explore in one document. The important thing to recognize is that these things are difficult. They are difficult for start-ups with less than one hundred people. They are difficult for multi-national conglomerates with trillions of dollars in revenue. They are difficult for industry experts, organizational experts, and the best managers and leaders among us.

However, this investigation has shown several things. The first is that these are not new topics of investigation. The fact that many companies, from many industries, are asking these questions provides fertile ground for learning. As well, they are a very young company and have managed to go through enormous changes in its short existence. One of the more impressive conclusions that can be drawn from this study is that it occurred at all. The employees interviewed were eager to improve the company and frustrated when they were hindered. Of the 95 people contacted for interviewing, only 1 did not take the time to interview with me. Of the 91 people actually interviewed, 73 responded to the survey.

Far more concerning would have been the situation if people were apathetic and resigned. If people would not discuss their views of the company, feeling they were insignificant, that would have represented a much greater danger to the organization. People came to this company to hopefully carve out a new company of their own and improve and establish their own culture, different from that of the previous OEM. The fact that they want to contribute but there are situations were they are unable to do so, or uninformed as to what the best thing to do for the company would be, is a distressing fact.
Given this, most are very supportive of changes that seem to clear away roadblocks and promote success. Initiatives that are implemented which would do that, with their benefits clear to everyone as to why the action is being taken, will have a good chance of success. By implementing processes discussed to promote innovation, by examining the future automotive industry, the strengths and pressures facing the company and determining the direction in which the company will head, and by promoting a culture which understands and accepts innovation, and the inherent risks and benefits of those actions, this company and companies like them can tap into their strengths and define the path for them which best ensures success in the future.
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APPENDIX A – INTERVIEW SCRIPT

Below is the interview script which was used when meeting with the employees. The script was not followed verbatim and the interview would emphasize some areas and avoid others as the conversation developed.

Innovation Interview

Name:
Title:
Duties:
Reporting Structure:
I’m here to find out what the company needs to do to be more innovative and what actions need to be taken to ensure a continual stream of new products.
I also want to assess how information is shared from the customer among the PD, Marketing and CBU groups.

Innovation Questions

What does innovation mean to you? How do you think innovation best applies to your job?

How do you think we develop ideas for new products? What do you know about the CDP, or the Product Development System itself?

Can you think of a time you had an innovative idea that was promoted? How did that happen?

Have you had an innovative idea that was stymied? What happened there?

How do you think new ideas should be created? How should they be captured? Do you find us to be Innovative?
What do you think we can do to improve things?

Information Networks Questions

How do you obtain the information you need to do your job? Who do you need information from and share it with?

PD: What means do you have to let marketing and customer groups know of your product design capability? How do you find out what Marketing or the CBUs believe customer demand/industry demand will be? How does this fit with new product design?

Marketing: What means do you have to learn what the customer is looking for or what PD is working on or can deliver? How do you deliver industry/customer information to PD or the CBUs? How does this fit in generating new product?

CBU: What means do you have to know what PD could do to meet the customer’s needs? How do you know what information marketing has about other customer groups and the industry as a whole? How do you identify and disseminate (to Marketing and PD) information and customer demands? How does this fit with new product design?

What is the typical information that you do share with PD/Mkt/CBU? (Time frame, detail of information – specific problems or longer term needs, current products only or future desires, immediate fixes or next generation features, manufacturing ease, consumer benefit, lower cost, what?)

What changes or structure do you think would be most useful to help you obtain this information?

One organizational proposal is for a triangular information sharing structure. How would this improve things for you and how do you think this best could be implemented to meet your needs?

Any final thoughts or comments about the changes needed to our culture/structure/procedures which can help improve information flow and promote innovation to continuously develop next generation products?

Thank you for your time.
## APPENDIX B – SURVEY QUESTIONNAIRE

This is a copy of the questionnaire sent to the people interviewed to collect quantitative data. The responses to the questions are on a five point scale from Strongly Disagree to Strongly Agree and are listed in the menus to the right.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>I know where to go to get support if I had an innovative idea I wanted to pursue.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I am familiar with a process for promoting innovative ideas.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I am aware of the Product Development Process.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I am familiar with the steps and procedures of the Product Development Process.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I am aware of the Concept Development Process (CDP).</td>
<td>Choose One</td>
</tr>
<tr>
<td>I am familiar with the steps and procedures of CDP.</td>
<td>Choose One</td>
</tr>
<tr>
<td>CDP is relevant and useful to my area of work.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I understand the purpose and benefit of the Marketing organization.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I feel comfortable that the connection I have with the Marketing organization is sufficient.</td>
<td>Choose One</td>
</tr>
<tr>
<td>More connection with more people in Marketing would be relevant or useful for my group.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I understand what the Product Development groups have to offer.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I feel comfortable that the connection I have to other PD groups is sufficient.</td>
<td>Choose One</td>
</tr>
<tr>
<td>More connection with more people in Product Development would be relevant or useful for my group.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I understand the purpose of the Customer Business Group (CBG) organization.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I feel comfortable that the connection I have with all CBG representatives is sufficient.</td>
<td>Choose One</td>
</tr>
<tr>
<td>More connection with more people in the CBGs would be relevant or useful for my group.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I feel that innovation within the company is a key priority of the senior leadership of this company.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I know what is expected of me at work.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I have the materials and equipment I need to do my work right.</td>
<td>Choose One</td>
</tr>
<tr>
<td>At work, I have the opportunity to do what I do best every day.</td>
<td>Choose One</td>
</tr>
<tr>
<td>In the last seven days, I have received recognition or praise for doing good work.</td>
<td>Choose One</td>
</tr>
<tr>
<td>My supervisor, or someone at work, seems to care about me as a person.</td>
<td>Choose One</td>
</tr>
<tr>
<td>There is someone at work who encourages my development.</td>
<td>Choose One</td>
</tr>
<tr>
<td>At work, my opinions seem to count.</td>
<td>Choose One</td>
</tr>
<tr>
<td>The mission/purpose of my company makes me feel my job is important.</td>
<td>Choose One</td>
</tr>
<tr>
<td>My co-workers are committed to doing quality work.</td>
<td>Choose One</td>
</tr>
<tr>
<td>I have a best friend at work.</td>
<td>Choose One</td>
</tr>
<tr>
<td>In the last six months, someone at work has talked to me about my progress.</td>
<td>Choose One</td>
</tr>
<tr>
<td>This last year, I have had opportunities at work to learn and grow.</td>
<td>Choose One</td>
</tr>
</tbody>
</table>
Although I have had a chance to speak with you directly, if you could identify the one thing at our company which most hampers our ability to promote innovation and new products, what would it be?