# AN APPLICATION OF THE DELPHI METHOD TO DETERMINE THE REQUIREMENTS FOR A PROTOTYPING CENTRE FOR THE PROVINCE OF NEWFOUNDLAND AND LABRADOR



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# AN APPLICATION OF THE DELPHI METHOD TO DETERMINE THE REQUIREMENTS FOR A PROTOTYPING CENTRE FOR THE PROVINCE OF NEWFOUNDLAND AND LABRADOR

by

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Abstract

The purpose of this study was to determine the need for a Provincial Prototyping Centre that would be capable of producing high quality manufacturable prototypes in the least amount of time. At the same time, the study sought to determine the specific systems, resources, and requirements necessary for the operation of a Provincial Prototyping Centre.

This study was conducted from March 1995 to July 1995 utilizing a modified Delphi technique. Two rounds of this Delphi study were completed. Round one asked three questions to which respondents were free to give open-ended responses. Information gathered from the first round was utilized to develop a second questionnaire submitted as round two in the Delphi process. Each round utilized a different panel of experts. Questionnaires for both rounds were electronically transmitted utilizing the E-mail services of the Internet.

Results of the study indicated that a steering committee representing the interests of government,

industry, entrepreneurs, the university, post-secondary institutions, and other interested parties should be formed to further investigate the feasibility of a Provincial Prototyping Centre. The results indicated consensus among the respndents for the goals and objectives of a Provincial Prototyping Centre. These are as follows:

1. To provide the technical support to inventors in developing a prototype,
2. To facilitate and guide inventors' product development efforts,
3. To link inventors with financial support agencies,
4. To encourage and facilitate inventors by linking them with other inventors who have been through the product development process,
5. To encourage inventors to develop a marketing plan,
6. To assist small business in developing production prototypes quickly and at an affordable price,
7. To facilitate the development of existing capabilities and businesses in the province, and

8. To develop prototypes based on its own market intelligence.

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# CHAPTER ONE

## Background of the Project

### Introduction

On October 14, 1994, the Honourable Brian Tobin, Minister of Fisheries and Oceans, launched National Science and Technology Week at the grand opening ceremony for the Engineering Technology Centre of Cabot College. In his address Tobin stated:

> Canada needs innovation if Canada is going to create new wealth...and to be competitive, to be able to compete and win with new products and services around the world. Fostering innovation today, requires a culture in which communities, individuals, and institutions value and embrace science, engineering, and technology. That is an important challenge today for Newfoundland and Labrador. (Tobin, B., personal communication, October 14, 1994)

However, emerging high technology companies are in their infancy in Newfoundland and Labrador, and all too often workers with newly obtained skills in information technologies and in other emerging technologies must seek work outside the province. The infrastructure required to support fledgling high technology companies is not yet fully in place. According to Hoffe, Manager of the Cabot College Office of Industrial Assistance, innovations developed by Newfoundland entrepreneurs often require considerable support from outside the Province to build and develop the manufacturable prototypes that are a necessary step in the product development process. (Hoffe, personal communication, January, 1993)

## The Prototype Concept

Pugh (1991) cites that models or prototypes serve three main functions:

(1) They establish the technical feasibility of the product.

(2) They give members of the design team a tentative understanding of the interactions between the components embodied in the product, which collectively make up the whole.

(3) They help members of the team to gain an understanding of the possible functions of the product. This becomes more and more important and

> essential as the design becomes more and more innovative. (p. 175)

The term prototype is defined as the first or primary type of anything: a pattern, model, standard, exemplar, archetype (Shorter Oxford English Dictionary, p. 1606). An alternative definition is, "a model suitable for use in complete evaluation of form, design, and performance" (Dictionary of Scientific And Technical Terms, 1984, p. 1270). A more comprehensive definition for a prototype that will be used in this study is:

> ...the term used at that stage in the design process when the component has been realized physically in a form that satisfies the functional, environmental, reliability, maintainability, packaging, and other requirements, but when the design does not necessarily reflect the techniques of manufacture by which it will be ultimately produced in quantity. (Mann, 1987, p. 423)

A sequential process is normally utilized in the development, and commercialization of a new product that includes the activities of idea generation, testing, prototyping, development and introduction (Zahra, Nash, & Bickford, 1994, p. 83). An alternative to this approach suggests that such activities can be done concurrently.

> In a parallel process, the engineering, marketing, and manufacturing personnel work closely on completing a given activity or phase, thereby encouraging the speedy development of the technology. This approach also reduces interdepartmental conflicts, disseminates information quickly, and eliminates the bottlenecks created by different schedules. (Zahra et al., p. 83)

## Statement of the Problem

The use of advanced technology in manufacturing in Newfoundland and Labrador is in its infancy. Simple tasks such as constructing a plastic mold or fabricating an electronic printed circuit board had to be referred to experts and fabricators located outside of the Province. Projects funded by the Office of Industrial Assistance, such as those found in the medical device sector, are exemplary (Inkpen, 1993). Such examples could serve to provide evidence that niche manufacturing markets developed for

Newfoundland and Labrador have much potential for further development.

However, there is no Centre located in the Province to assist entrepreneurs in developing the manufacturable prototypes that are required prior to commercializing products. It was proposed, therefore, that a study commence to specifically address the following questions:

1. What systems and resources should be incorporated into a prototyping centre?
2. Is there a need for a Provincial Prototyping Centre in Newfoundland and Labrador?

## Significance of the Study

Since a Provincial Prototyping Centre did not exist in Newfoundland and Labrador, this study provides both federal and provincial agencies with information to assist in decision making prior to implemention of a manufacturable prototyping centre for high technology companies in this province. The study also provides information regarding benefits to be derived from implementing a Provincial Prototyping Centre. As well, the administration of the Cabot

College can benefit from the information in this study and may consider expanding the capabilities of the Office of Industrial Assistance.

The expansion of the Office of Industrial Assistance is in keeping with the articles governing the Colleges of Applied Arts, Technology, and Continuing Education. Specifically, one article states:

> To meet the needs of the labour market by assisting with the development of the skills of the labour force to respond to economic and technological change and to create a capacity for technology transfer. (Government of Newfoundland and Labrador, 1991, p. 2)

## Delimitations of the Study

This study was delimited to ascertaining the need for and the resources that would be required for a Prototyping Centre by accessing expert opinion from national experts. The information gathered from these national experts was then applied to ascertaining the need for a Prototypng Centre in Newfoundland and Labrador. No attempt was made to carry out a cost-analysis of the implementation of such a

Provincial Prototyping Centre.

## Limitations of the Study

While conducting this study, the following limitations were recognized:

1. The study depended upon the cooperation of the respondents.
2. The study was limited by the expert knowledge of the Delphi panelists available and accessible to the researcher.
3. The study was limited by the selection process utilized to determine the Delphi panelists.
4. The study was limited to the months of April, May, June, and July of 1995.

## Definition of Terms

For the purposes of this study, the following terms and definitions apply.

**Computer Aided Design (CAD):** Software packages that utilize the capabilities of computers to create architectural, mechanical, and electronics drawings. Essentially the computer is used as a design and drafting tool where design modifications and improvements can easily be made. (Reiss, 1989, p. 196)

**Computer aided engineering (CAE)**: The analysis and evaluation of the engineering design using computer-based techniques to calculate product operational, functional, and manufacturing parameters too complex for classical methods. (Rehg, 1994, p.138)

**Computer Aided Manufacturing (CAM)**: The effective use of computer technology in the planning, management, and control of production for the enterprise. (Rehg, 1994, p. 171)

**Computer Integrated Manufacturing (CIM)**: Integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency. (Rehg, 1994, p. 16)

**Concurrent Engineering (CE)**: A systematic approach to the integrated, simultaneous design of both products and their related processes, including manufacturing, test, and support. (Turino, 1992, p. 3)

**Delphi Method:** The Delphi technique is a form of structured interaction that has been utilized for an assortment of needs assessment studies. It has been used for the setting of priorities as well as establishing a certain level of consensus.

**Electromedical Equipment:** Electrically powered equipment or equipment that generates electrical potentials for use in the medical diagnosis, treatment, mitigation, or prevention of a disease or the symptoms thereof in a patient. (Canadian Standards Association [CSA], 1984, p. 13)

**Flexible Manufacturing System (FMS):** A fully, or nearly fully automated system which consists of at least two numerically controlled machine tools interconnected by means of an automated system for the handling and storage of material and sometimes tools, and controlled by an integrated computer system or a programmable logical circuit. (Ehrnberg and Jacobsson, 1993, p. 33)

**Fused Deposition Modelling (FDM)**: A rapid prototyping technique that builds up each cross section by moving a thin extruded "wire" of plastic or wax just above the part location and heating it to its melting point. (Rehg, 1994, p. 158)

**Innovation**: The costly process of launching a new idea and its products in the market place. (Braunstein, Baumol, & Mansfield, 1980, p. 25)

**Internet**: The technical term for connecting a network of networks. The Internet was started by the U.S. Advanced Research Projects Agency as a means to economize on the use of broadband telephone lines by utilizing a packet-switching network. (Dern, 1994, p. 12)

**Laminated Object Manufacturing (LOM)**: A rapid prototyping technique that builds up cross sections that are cut from thin sheets of stock. Each sheet is glued with adhesive to the already constructed part, then trimmed with a laser. (Rehg, 1994, p. 159)

**Medical Device**: The term device means an instrument, apparatus, implement, machine, contrivance, implant, invitro reagent, or other similar or related article, including any component, part, or accessory, which is--

1) recognized in the official National Formulary, or the United States Pharmacopoeia, or any supplement to them,

2) intended for use in the diagnosis of disease or other conditions, or in the cure, mitigation, treatment, or prevention of disease, in man or other animals, or

3) intended to affect the structure or any function of the body of man or other animals, and which does not achieve any of its principal intended purposes through chemical action within or on the body of man or other animals and which is not dependent upon being metabolized for the achievement of any of its principal intended

purposes. (U.S. Department of Health and Human Services, 1992, p. 37)

**Medium-sized company**: A company with between 100 and 999 employees. (Canada's Technology Industries in the 1990s, 1991, p. 11)

**Prototype**: The term used at that stage in the design process when the component has been realized physically in a form that satisfies the functional, environmental, reliability, maintainability, packaging, and other requirements, but when the design does not necessarily reflect the techniques of manufacture by which it will be ultimately produced in quantity. (Mann, 1987, p. 423)

**Rapid Prototyping**: A technique used to build a sample of a new design quickly by partitioning a 3-D CAD model of a part into horizontal cross-sectional slices and then transforming the design, layer by layer into a physical model or prototype. (Rehg, 1994, p. 156)

**Round**: A set of questions posed to a Delphi panel.

Information obtained from this set of questions is analyzed and returned to the Delphi panelists in order to achieve a level of consensus.

**Selective laser sintering (SLS)**: A technique that employs a high energy laser to fuse or sinter powder into a solid object. (Rehg, 1994, p. 157)

**Small-sized company**: A company with less than 100 employees. (Canada's Technology Industries in the 1990s, 1991, p. 11)

**Stereolithography (STL)**: A rapid prototyping technique that utilizes a tank of photosensitive polymer and a servo-controlled laser that is focused on the surface of the liquid polymer all linked to a 3-D CAD system. The computer reads the CAD file for the prototype part and causes the laser to trace the area of the bottom cross section on the liquid polymer. The laser light causes the polymer to harden. By lowering a table in the vat of liquid polymer successive layers of the prototype part can be built up until the entire part is created from the hardened polymer.

(Rehg, 1994, p. 156)

**Systems engineering**: The process of identifying an operational requirement, translating the statement of need into a series of parameters which describe the structure and performance of a system, and finally constructing and testing a useful prototype of the system for deployment and user satisfaction. (Wenker, 1987, p. 103)

**Total Quality Management (TQM)**: A philosophy and a set of guiding principles that represent the foundation of a continuously improving organization. It is the application of quantitative methods and human resources to improve all the processes within an organization and exceed customer needs now and in the future. (Besterfield, 1994, p. 443)

## Organization of the Study

This study is organized in the following manner:

Chapter 2 contains a review of the relevant literature regarding prototyping, intellectual property considerations, total quality management, computer integrated manufacturing, and concurrent engineering practises currently being practised.

Chapter 3 profiles the methodology used in the conducting of this study.

Chapter 4 reports and provides a qualitative analysis of the results of the data gathered during the study.

Chapter 5 draws conclusions from the study and makes recommendations for future study.

# CHAPTER TWO

## Review of Related Literature

### Introduction

Research and development (R&D) can be considered to be a series of activities or stages. Schumpeter (as cited in Braunstein et al., 1980) divided the process of research and development into stages which were identified as: invention, innovation, and diffusion (imitation). Scherer (cited in Braunstein et al., 1980) suggested that modern R&D activities can benefit from a further classification of these three stages into invention, entrepreneurship, investment, development, and diffusion. The entrepreneurship stage occurs when a business person seeks out the inventor's idea and starts the process of commercialization. Investment is the dedication of resources to implement the R&D process, and development is the activity required to move the innovation into the real world.

The purpose of research is to reveal new knowledge, but the purpose of design - product design at least - is to create new products. The meaning of development varies from sector to sector, but normally has to do with product improvement. (Constable, 1994, p. 81)

## Background to the Study

A recommendation by the Study Group on Technicians and Technologists (1990) focuses on a plausible scenario for the future development of Canada. They suggested:

> ...to prosper in the years ahead, Canada will have to successfully compete in a knowledge-based, technology driven world. Our future economic survival will increasingly depend on our ability to develop and apply new forms of technology, as well as our capacity to provide goods and services that are research, information, and knowledge-intensive. Indeed science and technology are emerging as an important basis of national comparative advantage. (p. 16)

As the above suggests, research and development activity is considered vital to the economy of Canada. However, this vital activity is underemphasized by some Canadian companies. According to Canada's Technology Industries in the 1990s, "Successful technology companies must maintain a strong research and development (R&D) effort, working continually to improve the quality of their products, to speed up their development processes and their distribution channels" (1991, p. 1).

Table 1 shows a drop of 0.5% in expenditures as a percentage of revenues between 1988 and 1990 in Canadian technology intensive companies. For start-up, small, and medium-sized companies, this trend is ominous. In the United States, however, overall expenditure as a percentage of revenue on R&D is expected to increase from 9.5% to 9.8% in five years.

| R&D Expenditures as a Percentage of Revenues | | | |
|---|---|---|---|
| Canada | | | |
| Company Size | 1988 | 1989 | 1990 |
| Small | 13.2 | 12.8 | 11.2 |
| Medium | 5.9 | 5.1 | 4.4 |
| Large | 5.7 | 5.7 | 5.9 |
| All Companies | 6.3 | 6.0 | 5.8 |
| Source: Ernst & Young/Hutchison Research Canadian study | | | |
| United States | | | |
| Company Size | Current | In five years | |
| Developing | 20.8 | 13.9 | |
| Small | 12.8 | 10.8 | |
| Mid-size | 10.2 | 9.9 | |
| Large | 8.8 | 8.9 | |
| Top Tier | 9.3 | 9.8 | |
| All Companies | 9.5 | 9.8 | |
| Source: Ernst & Young United States study | | | |

Table 1: Research and Development Expenditures

(<u>Canada's Technology Industries in the 1990s</u>, p. 11)

These small and medium-sized companies, as well as start-up firms, are challenged to become competitive on an international scale quickly due to the threat of increased global competition that is fuelled by advancing technologies. By quickly becoming internationally competitive, these companies will no longer be dependent on a small local market for their survival.

The same challenges that face Canada as a result of the changing global economy also affect Newfoundland and Labrador. In fact, a new vision for this Province's economy has been articulated in the document entitled Change and Challenge: A Strategic Economic Plan for Newfoundland and Labrador, "Our economic vision for Newfoundland and Labrador is that of an enterprising, educated, distinctive and prosperous people working together to create a competitive economy based on innovation, creativity, productivity, and quality" (Government of Newfoundland and Labrador, 1992, p. 13).

In this document, the Provincial government recommends that the private sector address the advantages of innovation through the use of new technological development and adaptation. The report identifies programs to transfer technology that will be made available to the private sector to enhance their competitive advantage.

> In partnership with the Federal government implement programs to commercialize and market new technologies, products and processes, and to encourage quality enhancement, plant modernization and training. (Government of Newfoundland and Labrador, 1992, p. 37)

The Provincial government recommends that Memorial University of Newfoundland and the other post-secondary institutions develop better links and partnerships with the private sector. By doing so,the local research and development capabilities inherent in these organizations can be utilized more aggressively (Government of Newfoundland and Labrador, 1992).

The National Research Council (NRC) in Canada is designed to play a key role in enhancing manufacturers' ability to compete in the global economy. According to

Inkpen (1993), the NRC supports 16 different institutes, 11 based in Ottawa and the remainder located across the country, including the Institute for Marine Dynamics in St. John's, Newfoundland. The Industrial Research Assistance Programme (IRAP) was established by the NRC in 1964 to support and encourage applied research and development. IRAP has its own presence in Newfoundland through ten Industrial Technology Advisors (ITA's) who help companies identify opportunities, solve problems, and identify expertise in the community that could be tapped to address such problems and opportunities. Some of these ITA's are directly employed by the NRC, while others are employees of Enterprise Newfoundland and Labrador. Inkpen (1993) cites D. Rideout, Regional Director for IRAP in Newfoundland and Labrador:

> Last year, we had a three million dollar budget, of which, two million was allocated to some 250 projects in the Province. A large portion of this money was dispensed through the Contribution Agreements that we have with various organizations, such as the Cabot

College. (p. 2)

The Office of Industrial Assistance uses the Contribution Agreement funding as a means to initiate various projects so that there is no monetary cost to clients at the preliminary stages of a project. Beyond this preliminary stage, if a project is considered feasible, funding can be sought from various agencies such as IRAP and the Atlantic Canada Opportunities Agency (ACOA) and the client is encouraged to fund approximately 25% of the cost. At the present time, the Office of Industrial Assistance has completed approximately 20 projects that have contributed to the economic activity of the province (D. Heale, personal communication, September, 1994). One project in particular was significant enough to trigger and increase the staffing of a small company from 3 to 10 people.

The goals and objectives of the Office of Industrial Assistance are to, "Establish Cabot College as a leading edge Applied Research Organization offering a full complement of Industrial Assistance services" (Cabot College of Applied Arts, Technology, and Continuing Education, 1992,

p. 2). In order for the Office of Industrial Assistance to attain this goal, all the elements related to a state of the art full prototyping capability may need consideration.

## Intellectual Property

One of the considerations that must be incorporated into the management structure of a Provincial Prototyping Centre is the protection of any form of intellectual property of the client. There are several techniques that have been utilized to protect such property. These are patents, copyright, trademarking, and industrial design registration. All of these techniques have had their share of successes and failures.

When a firm comes up with a valuable idea, it is attractive to those who do not wish to duplicate the original research. Therefore, hitching a free ride on the original firm's research is a possibility that degrades the investment process. The end result of this practise is that firms are less willing to make the investment required to evolve valuable ideas, regardless of their benefit to society.

A monopoly is conducive to research because it captures all of the rewards from such research rather than having to share them with those who did not participate in the origination of the innovation. The concept of monopolized innovation, however, may defeat its intent. Companies that have an effective monopoly will have little or no incentive to innovate. This lack of innovation leads to stagnation and loss of market share. Braunstein et al. (1980) described this phenomenon and postulated why a company should take on the risk of further research when they have a safe market monopoly and profits. Additional research into the innovation may discover cheaper and easier ways to produce the innovation which would make the entry of rivals even more possible. Only competitive pressures, it seems, can force innovation upon an industry. With competition, a company must innovate or risk being non-competitive in its own market. According to Kamien and Schwartz (cited in Braunstein et al., 1980), a new empirically inspired hypothesis has emerged to explain that a market structure intermediate between monopoly and perfect competition would promote the highest rate of inventive activity.

The patent system was developed to circumvent this free-rider problem associated with R&D. Essentially, a monopoly in the form of exclusive rights over the financial benefits of the innovation is awarded to the innovator for the life of the patent in the hope of eliminating the free-rider problem. An additional purpose of the patent system is to provide disclosure of new inventions. Patented ideas are made available to the public through offices such as the Office of Industrial Assistance at the Cabot College which serves as a patent intermediary for clients. This office is also capable of performing patent innovation searches for its clients.

Zahra, Nash, and Bickford (1994) state that companies continue to apply for patents in record numbers or to ask courts to protect their patents. Even so, patents offer poor protection of a pioneer's technology. In a survey of 650 managers in 130 industries, Zahra et al. (1994) found that of the different approaches that companies might use to protect their intellectual property (e.g., patents, trade secrets, and copyrights), these executives rated patents as the least effective form of protection. Patents leaked vital information to competitors. Patents can, however, be a source of revenue through the process of licensing.

The software industry is also plagued with violations of copyright. Several of the large technological pioneers in the software industry are currently embroiled in this debate over intellectual property protection (Zahra et al., 1994). Perhaps the best form of protection for technological pioneering is the technology itself. The more proprietary features that are incorporated into the innovation, the more difficult it is for rivals to reverse engineer or copy it.

In the medical device industry, according to Harris & Associates (1982), a survey of medical device manufacturers documented an extraordinary level of innovative activity.

> Nearly half (45%) of the establishments report that their establishments have introduced a really new medical device product since 1972 that would generally

> be considered a significant innovation in the field. This is a profile of an industry where innovation is the norm rather than the exception. (p. 106)

New product introduction, according to Harris & Associates (1982), may be a better measure of innovation than patent awards in the medical device sector. This is due to the time, costs and staffing requirements necessary to pursue patent activity which may discourage smaller companies from applying for patents.

## Total Quality Management

> On average, American products cost too much to design, develop, and build. On average, American goods have also lagged in quality - first in quality of manufacture (conformance to design specifications), more recently in quality of design (functional performance and customer appeal). (Alic, J.A., 1993, 359-360)

Growing trade and financial deficits faced North American firms after the economic recession of the early

1980's. Kano (1993) stated that this situation motivated top management in several leading companies in America to play an important role in leading the quality movement. As a result, management commitment to quality became a requirement for survival in the midst of world-class competition. Quality began to emerge as a key management focus which has influenced nearly every industry asserts Easton (1993). According to Belohlav (1993) quality became a tangible concept that ensures the delivery of value as customers needs change; and a mechanism to mobilize and maintain the intensity of individual action.

> Creation of the Malcolm Baldrige National Quality Award by Congress in 1987 contributed to the national visibility of quality management and thus to the momentum of the U.S. quality management movement. (Easton, p. 32)

This type of organizational milieu or corporate culture can be developed by a technique called Total Quality Management. TQM, according to Besterfield (1994), is both a philosophy and a set of guiding principles that outlines the foundation of a continuously improving organization. TQM is quality driven and, most importantly, oriented towards meeting or exceeding customer satisfaction. The key to an effective TQM program is that the whole enterprise must focus on the customer.

The TQM movement has its roots in the concept of the Theory Z organization postulated by Ouchi (1981). Ouchi stated that Theory Z companies:

> ...have the objective of developing the ability of the organization to coordinate people, not technology, to achieve productivity. In part, this involves developing people's skills, but in part it also involves the creation of new structures, incentives, and a new philosophy of management. (p. 83)

According to Martin Starr (1988), "improving the quality of such customer integrated process becomes the tool to assure customer satisfaction and to amplify the customer's role as a driving force of the enterprise" (p. 142). Emerging high-technology companies that could utilize the resources of a Provincial Prototyping Centre would be faced with the challenge of obtaining long-term sustainable success or in other words becoming a viable business. Price & Chen (1993) state that TQM sets the foundation for the two critical success factors for such companies: rapid time-to-market and product differentiation. TQM adoption has become an essential ingredient in encouraging creativity, initiative, and ensuring that the organization can react quickly to change.

A TQM organization seeks to continually improve upon the quality of its products and/or processes. In the context of TQM, quality has a precise meaning and is defined by the International Standards Organization (ISO 8402-1986: Quality-Vocabulary) as:

> The totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs. (cited in Stebbing, 1989, p. 1)

Additionally, there are many standards associated with the concept of quality and quality assurance, which are often used synonymously with TQM.

Finally, the TQM approach involves the worker as the method for continuously improving. Customers know what they want, but the employees often know how to deliver it. Easton (1993) states that there must be widespread employee involvement in quality improvement teams.

The trend of seeking continuous improvement implies that the organization must continuously respond to intentional changes as well as adjusting to the unexpected consequences of predictable changes. Therefore, flexibility within an organization is not only desirable but also a necessity. Flexibility, according to Bahrami (1993), is a multidimensional concept that demands agility and versatility that is associated with innovation, change, and novelty. It is also coupled with robustness and resilience implying stability, sustainable advantage, and capabilities that may evolve over time. Continuous improvement concepts must focus on the organization as a whole, and on providing flexibility allowing workers, at all levels, to suggest and act on improvements to the work flow of the organization.

Total Quality Management is, therefore, a technique that focuses on meeting or exceeding customer expectations by involving the work force in continually improving the way work is performed within the organization. Much of the TQM movement is based on tools and techniques developed by Japanese quality management over the past forty years, such as statistical process control, Taguchi methods, and quality function deployment.

Belohlav (1993) noted that as quality increases, costs will go down because people, floor space, and resources used for finding and fixing things, which should have been done right the first time, are no longer required. Motorola (as cited in Belohlav, 1993) noted that an average organization tends to operate in a 4 sigma range (a method of classifying error or defect rates) or about 6210 defects per million parts, while a 6 sigma organization creates only about 3.4 defects per million parts. "Motorola's experience has also shown that a 4 sigma manufacturer will spend in excess of 10% of the sales dollar on internal and external repair. A 6 sigma manufacturer will spend less than 1%" (Belohlav, 1993). Quality, therefore, reduces cost.

MacCormack, Newman, and Rosenfield (1994), cite a 1990 survey of senior managers in 260 American high technology firms that indicated that 22% had TQM programs in all manufacturing areas. This indicates that the leaders in high technology innovation value the contribution and effectiveness of the total quality management philosophy.

## Concurrent Engineering

Product cost is highly dependent upon the design decision made at an early stage of a product life cycle.

> For instance, the automobile industries reported that although only about 5% of the total cost of an automobile is spent on the design activity itself, the design decision determines about 70% of the total product cost. (Oh & Park, 1994, p. 279)

It becomes necessary, according to Crease and Moore (as cited in Oh & Park, 1994) to employ a philosophy for improving quality, reducing costs, and reducing the lead time from product conception to product development for new products as well as product modifications. By the late

1970's, Alic (1993) stated that Xerox Corporation discovered that its manufacturing costs were 50% or higher than its competitors from Japan. Xerox traced about half of its cost disadvantages to product design, noting that its overseas rivals could design a new copier and get it into production in 12-18 months, compared to 24-36 months for Xerox.

The concept of continuous improvement has led to the development of a new engineering management technique termed concurrent engineering. This is a cortinuous design improvement process that allows organizations to reduce time-to-market and to improve both design and product quality while improving company profitability and competitiveness (Turino, 1992). Customer satisfaction can also increase through the adoption of concurrent engineering practises.

> Concurrent engineering is the direct involvement of all parts of an organization into the conceptualization, specification, development, manufacturing and support of new products. Successful new product development is not longer the sole responsibility of the R&D

department, but is the combination of the efforts, teamwork and cooperation of the entire organization. (Shina, 1991, p. 2)

Alic (1993) postulates that reintegrating design and production is partly a matter of management, partly a matter of purely technical tools and techniques. The classical approach to the product development process is shown in Figure 1.

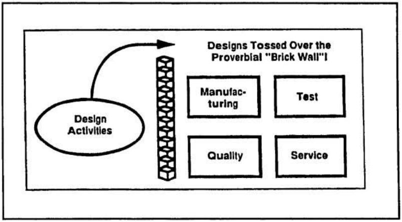


Figure 1. Classical Design Approach (Turino, 1992, p. 4)

The R&D department (as shown in Figure 1) was separated from the other departments who might be keenly interested in providing input to the design process. Product designs were developed in isolation by engineers who did not receive input from other groups. The completed design with fully detailed engineering drawings was passed over to the production engineers in manufacturing who then developed the production systems in isolation. Eventually, this section passed the completed production information to the shop floor shortly before the onset of production activity. Those groups responsible for documentation and servicing strategies often were not involved in the product development process until it left the factory. Disposal of the product in a way that would not harm the environment after a useful life was rarely considered.

The problem with this approach is that the further along the pathway to production that a fault occurs, or another iteration is needed, the more costly will be the necessary re-work. In a concurrent engineering environment, it is the responsibility of everyone within the organization to ensure maximum efficiency, economy, and quality throughout the stages of product innovation, development, marketing, and disposal (Turino, 1992).

The concurrent engineering process, as elucidated by Turino (1992), consists of five activities:

1. Design for performance (DFP) - ensures that all useful functions that are customer-required are implemented; that the product has met or surpassed all reliability goals; that safety and ergonomic

issues have been addressed; and that the product performs as specified.

2. Design for manufacturability (DFM) - ensures that the product utilizes a minimum number of standard parts. This facilitates error-free assembly as well as fitting the product design into the process that will perform assembly.
3. Design for testability (DFT) - ensures that all possible faults that can occur in a product are tested for during manufacturing and also during the product's useful life in a timely and efficient manner.
4. Design for serviceability (DFS) - ensures that the product can be serviced and maintained in a manner that is efficient and effective. Diagnostic software, built-in tests, remote diagnostics as well as partitioning designs into modular sections are examples of techniques that aid in this process. Although such items may inflate design cost initially, they serve to reduce overall

business costs throughout the product's useful life.

5. Design for compliance (DFC) - ensures that all regulatory requirements are met in those areas where the device will be marketed as well as planning for compliance with emerging regulations. This requires expertise in the regulations developed by various standards-producing organizations throughout the world such as the CSA, Underwriters Laboratory , and the International Standards Organization.

By combining all of the above-mentioned five points, a model of the concurrent engineering process can be developed. This model is shown in Figure 2. This model can be implemented manually or with CAE tools. The model is not meant to be capital intensive; rather, it 's communications intensive. Everyone in the organization must be trained in the concurrent engineering doctrine; they must speak the same language and share agreed upon common goals. New CAE and networking tools can simplify the change to a concurrent engineering environment, but are not necessary to implement this cross-functional, teams-oriented approach to product design engineering.

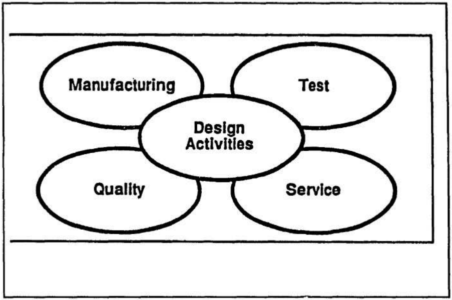


Figure 2: Concurrent Engineering Model (Turino, p. 69).

Individuals using concurrent engineering principles in product design give consideration to the totality of the product from innovation to disposal. This includes design related customer needs, quality, and overall business costs.

It also requires that the expertise of the design engineer be multi-functional and promotes the use of teams. Bahrami (1993) states:

> ...teams are intrinsically flexible; they can be formed, reformed, and disbanded with relative ease; they can bypass the traditional hierarchy; and their composition can evolve over time in order to blend different skills to address changing priorities. (p. 25)

A change to a concurrent engineering process, as Berardinis (1994) suggests, involves the adaptation of new tools, new technology and a new development process. Older CAD/CAM tools promoted sequential product development; while a more streamlined development process involves automated design and manufacturing tools that promote concurrent engineering and rapid design iterations. A method for ensuring that all of the design efforts are collaborative and focused on satisfying customers' requirements (i.e. implementing the CE philosophy) is termed quality function deployment (QFD). According to Jackson and Frigon (1994), QFD utilizes a series of management and planning tools to identify and prioritize customer requirements, and to translate these requirements into engineering requirements for product development and/or improvement. QFD assures that the CE philosophy results in an increased responsiveness to customer needs, shortened product design times and little or no redesign.

An economic analysis which reflected some of the benefits of concurrent engineering was performed by Oh and Park (1994). Remarkable improvements in operating performances were observed, including considerable reduction in defect rates, notable declines in throughput times and improved responsiveness and quality.

## Computer Integrated Manufacturing

Product life cycles are rapidly declining and customers increasingly prefer customized rather than generic products assert MacCormack, Newman, and Rosenfield (1994). In order to provide manufacturable prototypes of high quality to customers, there is a need for advanced manufacturing capabilities. Dean & Snell (1991) state that advanced manufacturing technology includes such computer-based technologies as computer-aided design, engineering and manufacturing (CAD, CAE, CAM). The potential for integration is a key characteristic of advanced manufacturing technology.

> Advanced manufacturing technology provides the means for the computerized integration of previously distinct stages. For example, information about a particular part collected at one stage of a process may be fed forward to a later stage to adjust how the part is treated at that stage. (Boddy & Buchanan cited in Dean & Snell, 1991)

A subset of advanced manufacturing technology is flexible manufacturing systems (FMS). FMS integrates computer-controlled tools and material handling systems with a centralized monitoring and scheduling function. Whenever the nature of product demand requires differentiation, FMS offer significant advantages over other manufacturing methods. "In Europe, the established base has grown at around 33 percent annually. In the United States and Japan, diffusion has been even faster; the number of installed FMS's appears to be doubling every two years" (MacCormack, Newman, & Rosenfield, 1994, p. 72).

Elango & Meinhart (1994) assert that the implementation of an FMS increases the chances of product differentiation, market segmentation, and reduces product life cycles. Enhanced entry potential in other industries where similar products are produced is also an advantage of the implementation of an FMS.

Costs, quality, and flexibility depend on work organization, training, and management as well as on product design and the equipment found on the factory floor. Alic (1993) asserts that management bears the responsibility for the linkages between software and hardware that determine how well a firm utilizes the skills of its employees.

An illustration of the integration of the total manufacturing enterprise with new managerial philosophies that improve organizational and personnel efficiency is shown in Figure 3. Sobczak, as cited in Rehg (1994), states that this figure was developed by the Computer and Automation Systems Association of the Society of Manufacturing Engineers in 1984 and is referred to as the CIM wheel. Manufacturers seeking to improve in one area of the CIM wheel often do so at the expense of other areas. An island of automation may exist, but the overall productivity of the enterprise may slip. All aspects of the CIM wheel must be attended to in order to boost productivity.

The CIM wheel uses a set of nested circles to describe the computer integrated manufacturing process. The outer circle which is composed of the four segments of marketing, strategic planning, finance and manufacturing management/human resource management represents the general business aspects of the enterprise. The middle circle which is made up of the three process segments of product and process definition, manufacturing planning and control, and factory automation takes the concept from innovation through to completed merchandise. Finally, the inner circle consists of two segments (common data base and information resource management and communications) that describe the infrastructure and resources required to support the activities of the outer layers of the model.

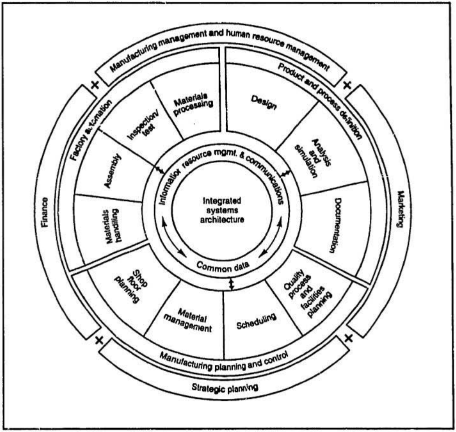


Figure 3: CIM Wheel (Rehg, p. 17).

One of the new developments in CAD/CAM systems is the emerging technology of three dimensional printing that allows design engineers to sculpt an object on their computer screens utilizing CAD techniques and then, minutes later, hold a plastic, ceramic, or paper version of that shape in their hands. This process of solid modelling is termed rapid prototyping. Wheeler (1992) states that this technique can shorten the time between the product's conception to its execution on the factory floor. Rapid prototyping allows engineers, designers, sales personnel, technical publication writers, and clients to check form, fit, and function in a matter of hours. All of the systems currently available such as SLS, FDM, LOM, and STL are based on the idea that three-dimensional objects can be built up layer by layer. The difference is in the way the layers are built up.

As the rapid prototyping concept increases its capability to generate more complex shapes, the software required to support such activities has also had to increase in complexity.

Standard computer programs and `slicing' algorithms, which break down graphic representations of objects into layers, have been devised to help ease the conversion of shapes described in three-dimensional software to finished objects. Increasingly, those who write graphics programs are also planning for three-dimensional output. (Wheeler, 1992, p. A)

Rapid prototyping, states Cassista (cited in Wood, 1991), is only a small part of the possibilities of solid-object modelling. Due to the volumetric information it supplies, one can do tolerance analyses, evaluate what-if scenarios for manufacturing, or try different materials before making the part. Wood (1991) contends that there are over 40 CAD packages available that support the stereolithography format of rapid prototyping.

A successful CIM implementation, according to Rehg (1994), must follow a three step process:

1. assessment of the enterprise in the three areas of technology, human resources, and systems.
2. simplification - elimination of waste;
3. implementation with performance measures.

Although the CIM wheel concept is based upon manufacturing industry requirements, the objective of the Provincial Prototyping Centre would be to deliver to the customer a satisfactory manufacturable prototype.

Rehg (1994) classifies the manufacturing process into five groups:

1. **Project:** Products in this category are large, complex, and most often are one of a kind such as cruise ships, passenger aircraft, or large office buildings.
2. **Job shop:** This category produces low volume products. Distinguishing features of job shop products include: less than 20 percent repeat production on the same part, and raw material is usually purchased against an order and not kept in stock.
3. **Repetitive:** Orders for repeat business usually reach 100 percent and contracts with customers for multi-years occur frequently in this group. Automotive subcontractors are examples of this

category.

4. **Line:** The line manufacturing system can be identified by a variety of options or models existing within the product line and a supply of subassemblies usually being stocked. Car and truck manufacturers utilize this strategy.

5. **Continuous:** The following characteristics distinguish this category: manufacturing lead time is greater than the lead time stated to the customer; product demand is predictable; product inventory is maintained, volume is high; and there are few options for the product. The production of chemical and petroleum products are examples of this type.

Manufacturers would normally employ a mixture of one or more of these five techniques. Rarely would a manufacturer have only one system utilized on the factory floor. By using a mixture of systems, the manufacturer can best suit the assembly process to the special requirements dictated by that specific product.

Once a manufacturing system is decided upon, the organization has a choice of three different approaches to plant layout: fixed position, process, and product flow. Figure 4 shows each of these plant layouts.

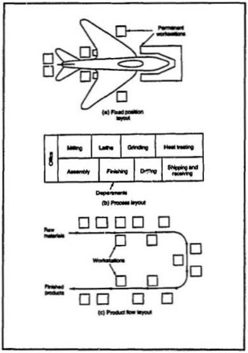


Figure 4: Production Process Layouts (Rehg, p. 27).

The manufacturing system that best describes the production of manufacturable prototypes would be the job shop category. This category would utilize the process layout shown in Figure 4, section (b). Parts would be moved or routed between fixed production work cells for the purpose of producing the manufacturable prototype.

The selection of the manufacturing system or systems and the plant layout influences the choice of automation equipment and CAD/CAE/CAM software that the product development process would require. Therefore, the choice of the specific way that the product will be assembled should be made prior to the selection of computer systems and automation software that will run on these computer platforms.

The majority of product design departments have enthusiastically embraced the use of new CAD/CAE technologies that eliminate a variety of tedious tasks in the design process. One such example of this type of emerging technology is an integrated solid modeller software package called I-DEAS that was developed by Structural Dynamics Research Corporation (Solomon, 1994). The I-DEAS software, when utilized in a concurrent engineering environment, can help the concurrent team determine alternative ways of defining packaging volumes, manufacturing techniques, and assembly methods prior to the rapid prototyping implementation.

For example, Figgie Medical Systems utilizes I-DEAS to improve upon the design of a prosthetic hip. Figgie Medical System engineers utilize the I-DEAS modelling software to custom fit hip prostheses for the specific anatomical bone structure of each patient. A Computerized Axial Tomography scan is taken of the patient's hip requiring replacement. Bone densities and tissue information is downloaded to the computer platform that contains the I-DEAS software and a solid model of a made-to-measure hip can be produced in hours. Such new software technology can also be utilized to visualize and model electromedical equipment that requires implantation into the human body. These implantable electromedical devices require specialized packaging in unusual shapes in order to be implanted unobtrusively into the body.

This, however, is only one section involved in the complete product development process. The utilization of CAD/CAE systems is one stage in the path to enhance enterprise-wide productivity. The computer systems that support the CAD/CAE software systems must also be fully compatible with all automated departments of the organization otherwise significant time may be wasted by transferring computer software files from one department to another.

For example, the design department may utilize one type of software for their CAD/CAE processes, but the production floor may utilize another software package for the computerized numerical control (CNC) milling machines. If these software packages are incompatible, software developed by a third party may be required to transfer detailed design specifications from the design department to the CNC machine. This third party vendor software can often provide the required interface between computer systems, but may not be fully capable of integrating all of the required features of the originating software.

With the advent of the single master model concept (Solomon, 1994), which is supported by fully integrated software systems, all members of the concurrent engineering team can utilize the same computer generated model for a variety of purposes. The master model would be available to the R&D department for further design modifications, as well as to the production engineering department, so that they could view a profile of the model and determine from that view further requirements necessary for the production process. In fact, all those who may be involved in the product implementation process would have access to the master model. Changes to the master model made by anyone in the organization are automatically updated and routed to other users within the organization.

There is a danger involved in the master model approach. The fact that current software allows changes to the master model by anyone in the organization with access to the computer system, means that the person who makes the last change wins. If these changes are not anticipated, key features of the production process that should also be changed to accommodate such changes to the model may not be anticipated. This could cause significant waste of time re-tooling on the shop floor. A concurrent engineering process minimizes this risk.

> Only one team member makes changes at a time, and only when authorized. At the same time, the master model can continue to undergo refinement. As new versions are created, team members working with the previous version are notified and can choose to automatically update their work. (Solomon, p. 36)

Newly developed CAD software allows modelling and mathematical analysis that utilizes embedded expert systems. These on-line experts or simulated advisors are capable of providing advice to design engineers on the best practise for analysis. Another helpful feature of these new software systems is optimization.

> Optimization gives designers another advanced analytical tool. When provided with constraints and alterable conditions, the software helps engineers modify designs to satisfy criteria such as least

weight, minimum stress, or maximum stiffness. (Solomon, p. 38)

## Conceptual Model for a Prototyping Centre

Building a prototype to visualize a design in three-dimensions is an age old practise. Engineers and designers can use the prototype to evaluate operational features prior to the start of production. Changes to the design are much cheaper and easier to accomplish with a model rather than during production. Due to the ever increasing complexity of plastic injection-molded parts in new products, the prototyping process is becoming even more difficult, expensive, and time consuming. Prototyping is, therefore, a critical aspect of the design and development process. Vivien maintains that there are normally four stages involved in the prototyping process: proof-of-concept, pre-production model, production prototype, and finally the manufacturable prototype (R. Vivien, personal communication, September, 1994). These stages in the prototyping process often involve many iterations. When new factors are involved in an engineered design, then iteration is both normal and desirable throughout the design process. If, however, as Love (1980) elucidates, these new factors are not taken into account early in the design life cycle, the impact could be significant and cost factors could increase. If the designers did not consider manufacturability in their design, there is a possibility of unforeseen problems occurring during assembly, testing, and using. The cost of correcting such problems late in the product development process, by redesigning for manufacturability, testability, and serviceability will be significant.

Utilizing rapid prototyping techniques linked with Computer Aided Design and Computer Aided Engineering, and employing the management techniques of concurrent engineering, and total quality management within the framework of computer integrated manufacturing, a Provincial Prototyping Centre could be developed. This prototyping centre would be a significant focal point capable of developing state-of-the-art manufacturable prototypes while reducing time-to-market for client innovations. The prototyping centre concept would follow the model shown in Figure 5.

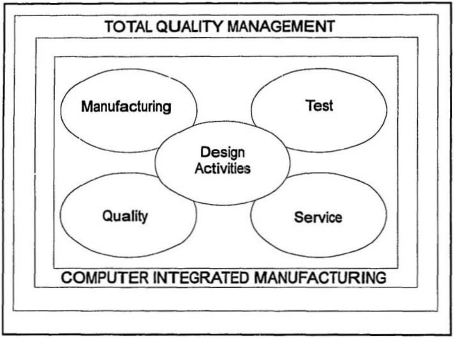


Figure 5: Prototyping Centre Model.

The focus of this model is to deliver quality manufacturable prototypes by reducing the number of design iterations through advanced simulation techniques, thereby reducing both product development costs for Newfoundland and

Labrador entrepreneurs as well as shortening the time-to-market for these new products. This model involved the integration of three major aspects: concurrent engineering, total quality management, and computer integrated manufacturing. Not only is each aspect important on its own, but the incorporation of all of these activities is necessary to produce quality manufacturable prototypes that can lead to earlier commercialization of the innovation.

## Needs Assessment

A qualitative approach was considered to be the best method of achieving the objectives of this study. Jeffery, Hache´, and Lehr (1993) state that qualitative measurement strategies are the basis of most research and developmental studies aimed at the determination of needs. Mariano (1990) described the qualitative approach as:

> The qualitative approach is interactive; context dependent; holistic; flexible, dynamic, and evolving; naturalistic; process oriented; primarily inductive; and descriptive. It has, as its foci, perspectives,

> meanings, uniqueness, and subjective lived experiences. Its aim is understanding. (p. 354)

Borg and Gall (1989) consider the determination of needs as a quantitative method viewing a need as a gap or discrepancy between measures or perceptions of desired performance and observed or actual performance. Stufflebeam, McCormick, Brinkerhoff, and Nelson (1985) counter that this approach tends to reduce needs assessment to a simplistic, mechanical process of comparing quantifiable observations or perceptions to standards or criteria and describing the resulting gaps which limits the needs assessment process to a consideration of achievements, products, or outputs to the exclusion of assessments of inputs or processes.

A needs assessment represents an effort to provide a decision maker or policy maker with information for action. "A need can be defined as a discrepancy between an existing set of conditions and a desired set of conditions" (Borg & Gall, 1989, p. 761). This definition of a need could be categorized as a discrepancy view. It is characterized as a gap between measures or perceptions of desired performance and observed performance.

The problem with this approach is that it is applied in areas where norms or standards are easily available. The tendency then is to avoid the less easily measured areas. Stufflebeam et al. (1985) cites Webster's Third International Dictionary (1976) definition that "a need is something that is necessary or useful for the fulfilment of a defensible purpose" (p. 12). A defensible purpose can be considered to be one that meets certain evaluative criteria. There are, according to Stufflebeam et al. (1985), four types of criteria that can be used to evaluate the defensibility of purposes:

1. **Propriety criteria**. The rights of individuals are not abridged; the environment is unharmed; and the purposes should not be unethical.
2. **Utility criteria**. There is a benefit to society; it should be responsive to some aspect of improving upon the human condition.
3. **Feasibility criteria**. The purpose is indeed

achievable in the real world, considering such factors as cost and political viability.

4. **Virtuosity criteria.** The prospect for fostering excellence, enhancing the development of knowledge, or technical skills may be realized. (Stufflebeam et al., p. 13)

Utilizing this concept of a need, a needs assessment can be defined as "the process of determining the things that are necessary or useful for the fulfilment of a defensible purpose" (Stufflebeam et al., p. 16). The four criteria noted above will, therefore, be utilized to evaluate the defensibility of the objectives of this study.

The methods of a needs assessment may vary considerably in complexity, cost, and length of time required to perform the study asserts Polit and Hungler (1991). Common guidelines that identify a best general strategy for undertaking a needs assessment study are non-existent according to Price, 1985; Myers, 1988; Kaufman & English, 1979; McKillip, 1987; and Butler & Howell, 1980 (as cited in

Jefferey et al, 1993).

The technique chosen for this study is termed the key informant approach. "This approach collects information concerning the needs of a group from key individuals who are presumed to be in a position to know those needs" (Polit and Hungler, p. 203).

## Delphi Technique

The study was conducted to identify issues of concern, resources, administrative systems, knowledge and skills required to implement a Provincial Prototyping Centre. Unsuccessful strategies as well as those strategies that were considered to be successful were also sought. The Delphi technique was utilized.

The Delphi technique is a form of structured interaction developed by a research group at the Rand Corporation in the 1950's (Paliwoda, 1983). Delphi techniques have been utilized for an assortment of needs assessment studies.

The main aim of the Delphi technique was to achieve consensus while reducing the effect of those who, regardless of opinion, could be expected to influence planning decisions. Jeffery et al (1993) cited several studies (Helmer, 1966; Myers, 1988; Kaufman & English, 1979; Butler, 1980; McKillip, 1987) that showed that Delphi techniques are often utilized for setting priorities and establishing a certain level of consensus.

Delphi is used to deal with uncertainty in an area of imperfect knowledge and is, in essence, an intuitive method of forecasting. Preble (1984) states that the Delphi technique has often been used by strategic planners to develop environmental forecasts, which are then used as assumptions upon which plans can be based. Studies conducted by Garde and Patel (1985) and Yuxiang, Donghua, and Changgeng (1990) utilized the Delphi technique as a method of technological forecasting.

As this study was an attempt to ascertain technological needs involved in the development of manufacturable prototypes, the Delphi technique was considered to be an appropriate tool. Delphi has been used in this manner since inception (Garde and Patel, 1985; Preble, 1984; Paliwoda, 1983).

The Delphi process involves the generation of a list of individuals, knowledgeable in a specialist area, who are invited to respond to a series of questions which depict a specific scenario in their specialist area. The responses from these individuals are combined and the findings are returned to either the original group of experts for refinement or, in the modified Delphi technique, are "sent to a second group for further comment and revision" (Jeffery et al. 1993, p. 8). After several rounds, a level of consensus results.

The evaluation of reliability and validity, according to Woudenberg (1991), is seriously hampered by the existence of situation and person-specific biases, varying from study to study. The concept of Delphi covers a wide range of applications (classic, policy, decision Delphi) and procedural variations such as the selection procedure of respondents, level of expertise, group size, character of round one, clarity of questions, consensus versus complexity, and provision of feedback. For these reasons, the reliability and validity of Delphi is difficult to generalize and is normally determined on an individual basis. Kastein, Jacobs, Van Der Hell, Luttik and Touw-Otten (1993) determined a high level of reliability for the Delphi process utilizing the intraclass correlation coefficient. They also suggest that such results are generalizable to any Delphi.

> When numerical ratings of respondents are available and these ratings are normally distributed, reliability of Delphi can be evaluated in a more accurate and effective way by means of the ICC. The use of this statistic is widely accepted in regular generalizability methodology. (p. 322)

## Summary

A Provincial Prototyping Centre should incorporate a variety of features in order to be capable of delivering quality manufacturable prototypes to the customer within a time span that would reduce the overall time-to-market for the product. Not only must automated tooling systems supported by computer aided design and computer aided engineering systems be utilized, but new developments in the field of technology management must also be inculcated into the philosophy and culture of such a Centre. Protection of the intellectual property of the client must be addressed as well.

The model outlined in Figure 5 was developed to incorporate all of the features considered to be necessary to implement a Provincial Prototyping Centre. This model is an amalgamation of several other models.

Specifically, the model utilizes nested rectangles with the innermost rectangle being the concurrent engineering model shown in Figure 2, the middle rectangle is the model for Computer Integrated Manufacturing, shown in Figure 3, while the outermost rectangle incorporates the Total Quality Management philosophy. All three of these models nestled within the Prototyping Centre model can work in harmony to achieve the objectives of a Provincial Prototyping Centre. These objectives would be to deliver manufacturable prototypes of the highest possible quality that meet or exceed customer expectations, and to reduce overall time-to-market for the commercialization of innovations developed by Newfoundland and Labrador entrepreneurs.

To assess the need for a Provincial Prototyping Centre for the province of Newfoundland and Labrador, a modified Delphi technique was determined to be the most appropriate method. As this study deals was an attempt to ascertain technological needs involved in the development of manufacturable prototypes, input from persons with expertise in prototyping and product development was considered necessary.

# CHAPTER THREE

## Methodology of the Study

### Introduction

This study utilized a modified Delphi technique to assess the need for a Provincial Prototyping Centre capable of producing quality manufacturable prototypes in the least amount of time. The study attempted to determine specific systems, resources, and requirements necessary for the operation of a Provincial Prototyping Centre by the use of this Delphi technique.

A national panel of experts was chosen to gather information on the specialized needs, systems, and resources required for the successful operation of a Provincial Prototyping Centre. Subsequently, a Provincial panel of experts was chosen to address the issue of the need for a Provincial Prototyping Centre.

### Development of the Interview Guides

Two structured interview guides were developed for the two Rounds of the Delphi process. The three items for Round One were developed from the original research questions of this study (Appendix One). The items for Round Two were developed from the information received from the respondents in Round One and some items were adapted from Dean & Snell (1991). The interview guides used by Dean & Snell (1991) were utilized to elicit information concerning the concept of computer integrated manufacturing. Items involving just-in-time manufacturing in the Dean & Snell (1991) questionnaire were deleted as these topics were not considered appropriate for the study.

## Determination of the Panel of Experts

Jolson and Rossow (as cited in Paliwoda, 1983) pointed out that knowledge of the subject matter is necessary for Delphi to work properly. In order to arrive at a panel of experts, a list of persons knowledgeable in the arenas of prototyping, product development, computer integrated manufacturing, and rapid prototyping from across Canada was developed. This initial list included directors, managers, engineers, and entrepreneurs working with c · for various Prototyping Centres currently in existence in Canada.

In an effort to reduce the potential for bias, these knowledgeable persons were then asked, in turn, to submit the names of several additional persons with expertise in the subject matter of this study. All persons on this list were contacted by telephone and those who had the time and were willing to involve themselves in the study became the panel of experts for Round One (the National Delphi panel).

In Round Two of this modified Delphi technique, a similar process was utilized to formulate the panel of experts that would concentrate their efforts on the research questions specific to the province of Newfoundland and Labrador. The following three people were asked to submit the names of persons with expertise in the manufacturing industry of Newfoundland and Labrador for this Round:

1. A representative of the National Research Council involved in the IRAP programs.
2. The President of the Association of Professional Engineers and Geoscientists of Newfoundland and Labrador.
3. The President of the Association of Engineering

Technologists and Technicians of Newfoundland and Labrador.

From a combined list provided by the above-mentioned people, a new Delphi panel was formed.

The questionnaire developed for Round One was sent via electronic mail to three knowledgeable people in the field of engineering design and prototyping across Canada as a pilot for this round. A similar approach was utilized for Round Two. The questionnaire was piloted on the Internet to two people familiar with the engineering concepts involved with product development. After changes were incorporated into the questionnaires for both rounds as a result of the piloting process, the questionnaires for both rounds of the study were E-mailed to their respective Delphi panels.

## Administration of the Study

Through the capability of the Internet system, questionnaires to distant sites were sent using E-mail. Van Dijk (1990) concluded that the interview process was superior to the Delphi process in terms of motivation of the expert panel, however, he also concluded that the Delphi process needs techniques that stimulate argument and discussion. The Internet was utilized for this study as a means of providing such a vehicle of stimulation. An advantage of this electronic mail approach was that the respondents could reflect upon the question(s) with minimal interruption in their work activities prior to formulating a response. Anonymity was also assured by the utilization of this process.

The study occurred throughout the Spring of 1995. The questionnaire developed for Round One was distributed via electronic mail on April 10, 1995, while Round Two E-mailing occured on June 13, 1995. Two panel members of Round Two (Provincial Delphi panel) did not have E-mail access to the Internet. These two panel members received their questionnaires via facsimile transmission and were asked to respond in the same manner.

## Data Analysis Procedure

Raw data generated by the questionnaires in all stages of the modified Delphi process was in an electronic form. This procedure had the benefit of efficiently and effectively capturing the data without the necessity of clarifying such data. This contrasts with the more traditional approach of first tape-recording and then transcribing the data into text form. Often, in the practise of this traditional technique, the transcriber would need to paraphrase sections of data and then contact interviewees for clarification (Hache´, personal communication, March, 1995). With the use of electronic mail, the interviewees raw data would be edited as the interviewee was also the transcriber.

Analysis of the data gathered during this study included organizing the data for both rounds by first extracting all respondents comments from electronic mail and transferring these comments to a new document a question at a time. Merriam (1988) discusses data analysis as beginning during data collection. During the data analysis, the data that have been gathered should be organized topically or chronologically so that "Patterns and regularities then are transformed into categories into which all subsequent items are sorted" (p. 131). The next step was to categorize the data accumulated, according to the common elements of the prototyping model developed within this study.

Specifically, in Round One, the data gathered was categorized through a total quality management approach called affinity. According to Brassard (1989), this approach is useful when the major themes out of a large number of ideas, opinions, or issues are sought. It groups those items that are naturally related and then identifies the one concept that ties each grouping together. A list of key words was generated and the documents that contained the extracted data were then searched on these key words. This approach produces consensus by sorting topics rather than by discussion.

Prior to E-mailing the categorized information back to the Round One Delphi panel, it was transmitted to two persons with expertise in the application of the affinity

TQM tool to ensure that the process was correctly applied. After this stage, the categorized information was then returned via E-mail to the Round One panel. Panel members were then invited to modify their views or opinions to achieve a consensus opinion. The collection of these consensual views were then compared to the four criteria of propriety, utility, feasibility, and virtuosity to assure that these opinions did indeed fit the definition of a need.

CHAPTER FOUR

# Findings of the Study

## Introduction

The objective of this study was to determine the need for a Provincial Prototyping Centre capable of producing quality manufacturable prototypes in the least amount of time. At the same time, the study attempted to determine the specific systems, resources, and requirements necessary for the operation of a Provincial Prototyping Centre.

Data were obtained from this study utilizing the Delphi technique that consisted of two rounds. In Round one, a questionnaire was first electronically mailed and transmitted via the Internet to a Delphi panel consisting of ten persons located across Canada with expertise in the areas of the study. This panel was termed the National Delphi panel. The questionnaire asked only three broad questions to facilitate the data collection. The respondents were free to give open-ended responses to the questions posed. Of the ten members of this National Delphi panel, eight responded to the questionnaire; but one of these eight respondents noted that he would be out of the country and, therefore, unavailable.

A second Delphi panel was formed with seven persons from Newfoundland and Labrador with expertise in the areas of the study to respond to a second questionnaire that was developed from the data gathered from the first Delphi round. This panel was termed the Provincial Delphi panel. The process of using the emerging information collected from previous rounds as input data for further rounds is, according to Jeffery et al. (1993), typical in Delphi studies as it serves to generate more complete lists of solutions. The questionnaire for this second round was also electronically mailed and transmitted via the Internet to the Provincial Delphi panel with the exception of two members who did not have access to the Internet. In these two cases, the questionnaire was transmitted by facsimile to the respondents. Of the seven members of this panel, all responded; but one respondent indicated that due to unforeseen work commitments, he would not be able to complete the questionnaire. To maintain confidentiality, the respondents for the National Delphi panel have been identified as Respondent 1, Respondent 2, Respondent 3, etc., while the respondents for the Provincial Delphi panel have been identified as Respondent A, Respondent B, Respondent C, etc. The questions posed in the statement of the problem are organized and discussed in sequence.

## Research Questions

There were two main questions posed in the statement of the problem. These were:

1. What systems and resources should be incorporated into a Provincial Prototyping Centre?
2. Is there a need for a Provincial Prototyping Centre in Newfoundland and Labrador?

## National Delphi Panel Responses

Research question one of the study, which asked, "What systems and resources should be incorporated into a Provincial Prototyping Centre?" was addressed by the National Delphi panel.A National Delphi panel questionnaire (Appendix A) was designed to determine response to this question.

This questionnaire was transmitted to the ten National Delphi panelists using the Internet.

A follow-up letter (Appendix B) was electronically transmitted using the Internet to the National Delphi panel asking if they concurred with the resulting classification, if all information provided was considered necessary for a Provincial Prototyping Centre, and if they had any further comments or suggestions. Consensus was determined to be achieved when the National panelists agreed with the assigned classification and did not add any further comments or suggestions.

The information collected, and subsequently organized, from the National Delphi panel is discussed below. Each item form the National Delphi panel questionnaire is discussed in numerical order below.

Item 1

Item 1 of the National Delphi panel questionnaire asked, "What issues should be addressed regarding the implementation of a prototyping Centre?" The responses from the National Delphi panelists on this item were separated into the following five sections: Mission, Governance, Business Plan, Location and Implementation.

Mission. This section included all aspects of mission statement, vision, values, goals, and objectives of a Provincial Prototyping Centre.

Identifying customers and achieving customer satisfaction were of paramount importance to all respondents. Respondents 1, 2, 5, and 6 all noted the importance of determining who the customers for this possible Provincial Prototyping Centre would be and assuring that the mission of the Centre targeted the appropriate groups. Respondent 5 suggested that a list of all the industries, manufacturers, and other organizations that would be supported by the Provincial Prototyping Centre be developed in order to identify the customers. Respondent 5 added that the size of these industries should be significant to the viability of the Centre. Building upon the strengths of these industries was also considered to be of vital importance to the success of the Centre.

Another important factor noted by Respondent 5 would be to determine what other Centres of this type have become successful, what determined their success, and what kind of relationship should be fostered with these other similar Centres. Respondent 5 also suggested that the Centre determine whether such a relationship would be competitive or cooperative.

Respondent 6 considered customer satisfaction to be the overriding operations issue surrounding a prototyping business. In the experience of this Respondent, most of the clientele of their Centre are those developing a first product, or at least those without modelling facilities in-house. Respondent 6 also noted that:

> The process of developing a first working model of a new product concept is not well understood by the client. Specifically, the degree of discovery and the number of mid-point design adjustments are not well understood. The client may expect a fixed-price quotation in advance of the project commencement, and may expect that only one design and modelling iteration

will be necessary. This is almost never the case in reality, and with the uninitiated client this can lead to frustration and disappointment with implications that the performance of the prototyper was less than it should have been.

It should be noted that customer satisfaction is one of the three fundamental principles of the Total Quality Management concept as noted by Price & Chen (1993). Respondent 6 believed that to achieve a high level of customer satisfaction, education, and diligent, consistent, and frequent customer feedback, along with projecting total prototyping cost estimates at the onset of product development is essential.

Respondent 3 stated that another goal of the Provincial Prototyping Centre should be to determine criteria considered by companies that can improve response time needed to maintain a competitive edge in the development of products. Respondent 2 suggested that a goal of the Provincial Prototyping Centre should be to support engineering education and training at local post-secondary institutions because this could greatly increase the potential for new local industries. The support of local industries was also considered important by Respondent 2 and assuring this support should be a mandate of the Provincial Prototyping Centre.

Governance. This section included issues involved with how the proposed Centre should be administered; what form or model of organization should be utilized; and what issues involving a Board of Governors should be addressed.

Respondent 1 queried whether the Centre should be part of an existing University or post-secondary institution, or a stand-alone facility. Respondent 5 suggested the possibility that a steering committee representing the interests of government, industry, entrepreneurs, the university, post-secondary institutions, and other interested parties could be formed to address the terms of reference for such a Provincial Prototyping Centre. This respondent also noted that the issues of to whom this steering committee should report, who should drive or guide the formation of the steering committee, and who should chair the committee are concerns that could significantly impact upon the formation and implementation of a Centre.

Business Plan. This section included those issues that addressed operational aspects of the Centre such as marketing, targeting user groups, and funding.

Respondents 1, 2, 3, and 7 all noted that a basis for cost recovery was important to the long term viability of a Provincial Prototyping Centre. Respondent 2 thought that users of the Centre should pay full cost and that all possible efforts be made to assure that the Centre did not become another government subsidized project.

Respondent 3 suggested that in order to assure that the Centre becomes self-supporting, alternative approaches for the operation of the Centre be considered. The following four factors were deemed to be important by this Respondent for the financial viability of the Centre:

i) the Centre must be responsive to industry,

ii) the Centre must also act as an academic centre of excellence to support University and post-secondary research and development,

iii) external funding support must be sought, and

iv) client confidentiality must be protected and assured.

Respondent 3 stated that associated activities that can provide a source of work and income to the Centre be identified. The market areas of Newfoundland and Labrador must be recognized and the specialized skills developed over the years in this local geographic area, and other close geographic areas must be considered. For example, niche markets that build upon the specialized skills already developed in the region should be the focal point of the Centre. Once these activities have been recognized, a business plan should be developed around them.

Location. The purpose of this section was to categorize comments about where the Centre should be located.

Respondent 3 noted that such a Centre should be located both near the University and local industry. This location would be in close proximity to currently existing sources of specialized equipment, software services, and capabilities so that there could be greater utilization of existing services by the sharing of capabilities between facilities.

Implementation Plan. This section addressed implementation issues such as the allocation of specialized resources, and the scheduling of tasks needed to assure timely completion of the Centre.

Respondent 5 suggested that a time frame for the development of an implementation plan be established and an additional time frame for the actual implementation of the Centre be considered. Respondent 3 stated that the contents of a Provincial Prototyping Centre should be defined. According to Respondent 3, "A matrix could be developed where each element would represent different requirements, equipment, software services, capabilities, and associated costs. The skills, staffing, and organization required to support a Centre of this nature must also be identified."

Item 2

Item 2 of the National Delphi panel questionnaire asked, "What resources are required in implementing a prototyping Centre?"

The information collected on this item was categorized into the following three sections; Human Resources, Facilities, and Funds.

Human Resources. This section included those comments that involved people whether as administrators, directors, managers, engineers, technical support, and or clerical support as well as the specific training requirements of personnel involved in the operation of the Centre.

Respondents 2 and 5 noted that the most significant resource should be a director who knows what the Provincial Prototyping Centre should focus on and how to promote it. This director should also be technically sound with a proven track record in prototyping and or product development. This director would have responsibility for managing, planning, and business technology development.

Respondents 1 and 3 noted that people with skills in marketing and the ability to sell technical services would be a necessity. Respondent 6 mentioned the fact the designers and project liaison officer(s) may be required. Respondent 5 also suggested that clerical staff could be needed.

Respondents 1, 5, 6, and 7 noted the importance of skilled technical persons. Respondent 5 stated that the Centre would require:

- Professional Engineers (1 or 2) with 5-10 years experience in prototyping, proficient in surface modelling and CNC machine programming;
- Mechanical and or Electronic Technologists (1 or 2) with 5-10 years experience in machine design and fabrication, surface modelling, CNC machine programming and operation. Experience in the setup, jigging and tooling associated with prototyping equipment would be necessary.

Respondents 1, 5, and 6 also noted that a journeyman machinist with 5 to 10 years experience in precision machining, welding applications, and CNC mill, lathe experience was necessary to assist with operating equipment, fabricating machine jigs and fixtures, and maintaining equipment.

Facilities. This section explored the issues involved in the required physical structures, specialized equipment, storage space, and machinery necessary for the operation of a Provincial Prototyping Centre.

Respondents 1, 3, 5, 6, and 7 all remarked on the necessity of adequate facilities to house the required machinery and specialized systems utilized in the product development process. Respondent 5 also noted that shop space would be required that has easy and large access to the outside for equipment installation purposes. The facilities must provide the proper environment and spacing necessary for the correct operation of prototyping and manufacturing systems such as engineering and or solid modelling software and associated workstations, test equipment, lathes, milling machines and rapid prototyping systems.

Funds. This section covered the area of financing and revenue generation issues deemed necessary for the success of the Centre.

Respondents 3 and 5 stated that the funding would depend on the number and qualifications of personnel, equipment size and type, and the necessity of producing credible services. Respondent 6 stated that a close working relationship with an NRC ITA would be beneficial. This individual may even be utilized as a project liaison officer. Respondent 5 asserted that apart from the capital cost considerations of the facility, the following operating expenses must be accounted for:

i) salaries

ii) equipment and tooling

iii) materials and maintenance

iv) upgrades to equipment

v) utilities

vi) and a discretionary research budget.

Item 3

Item 3 of the National Delphi panel questionnaire asked, "What specialized systems are needed for the operation of a prototyping Centre?"

The information collected on this question was categorized into the following four sections; Specialized Systems, Equipment, Computers and Software, and Management Systems.

Specialized Systems. This section dealt with comments regarding technology management, special purpose engineering support systems and quality control, and quality assurance systems.

Respondent 3 stated that systems that would facilitate the management of technological changes rather than focusing on specific specialized systems or needs should be first addressed. Respondent 6 noted that the need for close customer liaison would manifest itself as a unique management system. These two comments support the proposed Prototyping Centre model that was previously discussed. This model incorporated the management systems of TQM, CIM, and concurrent engineering.

All respondents noted the need for rapid prototyping systems. Respondents 1 and 2 also suggested that advanced coordinate measurement systems for reverse engineering and quality control of parts may be required.

Equipment. This section included comments that dealt specifically with machinery, tooling, test equipment, and specialized equipment utilized for product development purposes.

The following list of equipment was determined to be required for the operation of a Provincial Prototyping Centre by all respondents:

1. rapid prototyping system and the associated equipment for this system,
2. special-purpose materials handling equipment,
3. 5 axis CNC milling machine and associated tooling,
4. 3 axis CNC milling machine and associated tooling,
5. small plastics processing machines,
6. hardware for the production of circuit boards,
7. articulated arm welding robot and associated equipment,
8. wire electronic discharge machining and associated equipment,
9. engineering workstations and associated software,
10. test equipment.

Computers and Software. This section covered hardware and software for computer systems that may not have been included in any of the above categories.

Respondent 2 mentioned that state of the art software and hardware for the design of micro-electromechanical systems (MEMS) may be advantageous. Respondent 7 suggested that simulation software as well as engineering and or solid modelling software could be utilized by the Centre.

Management systems. This section covered the utilization of specific methods of management that will ensure the success of the Prototyping Centre.

Respondent 3 noted that companies requesting the services of a Prototyping Centre want to deal with knowledgeable people.

> Customers of a prototyping business want results and they want to get value for their money. Communication is a vital management tool required to overcome and bridge differences in technical and financial understanding in the development of products and the expectations of clients.

At this point in the study, when all of the data from the National Delphi panel was classified, a new questionnaire was developed from this data. This questionnaire was then transmitted to the Provincial Delphi panel via the Internet.

Research question 2 of the study, which asked, "Is there a need for a Provincial Prototyping Centre in Newfoundland and Labrador?" was addressed by the Provincial Delphi panel. The responses from the Provincial Delphi panel are discussed in the following section.

## Provincial Delphi Panel Responses

Part one of the Provincial Delphi panel questionnaire, (as seen in Appendix C) which contained one question set, was designed to gather data on the nature of the prototyping and product development activities and experiences of the panelists. Part two of the Provincial Delphi panel questionnaire contained three separate question sets. Part two, question set one, was designed to gather data on the sections identified by the National Delphi panel as Mission, Role, and Governance. Part two, question set two, of the Provincial Delphi panel was designed to gather data on the sections identified by the National Delphi panel as Business

Plan, Location, and Implementation. One respondent did not provide detailed information on the items included in this part, but did include a list of comments. This list of comments was considered to be more relevant to the final item in part two, question set three, and therefore, was included as a response to part two, question set three, item 2. Part two, question set three, of the Provincial Delphi panel questionnaire was designed to gather data on CIM technology requirements for a Provincial Prototyping Centre.

Part One, Question Set One, Item 1

Item one of this questionnaire asked, "What products or prototypes are being developed by your company at the present time?"

Only one panelist did not respond to this item. The information gathered on this item would jeopardize the confidentiality of the panelists as well as potentially revealing information on proprietary products that may be currently under development. Six of the panelists did have prototyping and product development experience and are currently involved in the development of new devices.

Part One, Question Set One, Item 2

Item 2, of the Provincial Delphi panel questionnaire, part one asked, "Where is the activity involved in the development of these products or prototypes carried on?" Table 2 depicts the locations of such activities.

Table 2

Location of Prototyping Activity - Provincial Panel Responses

| Location | n = 5 |
|---|---|
| In-house | 5 |
| In the province | 3 |
| Elsewhere | 2 |

Five respondents affirmed that they do product and prototype development in-house, but only two of these respondents only utilized in-house facilities. One respondent did not answer this item. Three respondents also made use of existing Provincial facilities, while two respondents utilized facilities not located in the province.

Part One, Question Set One, Item 3

Item 3 of part one of the Provincial Delphi panel asked, "How much of the product or prototype do you fabricate in your plant?" Table 3 shows that the majority of the panelists utilize in-house capabilities for the development of new devices. One Respondent stated that only 0 - 25% of prototype development was conducted in-house, but 75 - 100% of product development was carried on in-house. Respondent E stated that a range of 25 - 75% for product and or prototype development is more consistent with their current practises. One respondent did not answer this item.

Table 3

Amount of In-house Prototype Fabrication - Provincial Panel Responses

| Percentage | n = 5 |
|---|---|
| 0-25% | 1 |
| 25-50% | 1 |
| 50-75% | 2 |
| 75-100% | 2 |

Part One, Question Set One, Item 4

Item 4 of part one of the Provincial Delphi panel questionnaire asked, "To what extent do you use mathematical modelling for your product or prototype development process?" Table 4 shows that the Respondents who replied to this question utilize mathematical modelling in their developmental activities. Three Respondents stated that they utilize mathematical modelling extensively. One panelist did not respond to this question.

Table 4

Mathematical Modelling Usage - Provincial Panel Responses

| Usage of mathematical modelling | n = 5 |
|---|---|
| not at all | 0 |
| very little | 1 |
| a moderate amount | 1 |
| a great deal | 3 |

Part One, Question Set One, Item 5

Item 5 of part one of the Provincial Delphi panel questionnaire asked, "What strategy do you utilize in the development of new products?"

All respondents suggested that they base their activities on the identification of needs. Respondent C clarified their approach with the following comment:

> They start with a client or invitation to solve a particular strategic issue. They then proceed to a comprehensive problem definition phase followed by a theoretical study, computer-aided design, rapid pre-prototype of components, extensive experimentation, formal design, formal prototyping, fabrication, assembly, testing, certification, proof of concept, manufacturing engineering, and finally quality assurance and product testing.

Respondent D stated that they base their software development on their previously written coding so that code sharing is featured on their entire software product line. Respondent E noted that they no longer try to develop products based upon their perception of what is required, but instead include the client in all aspects of the product development process. This comment provides support for the inclusion of TQM in the management of a Provincial Prototyping Centre.

Part One, Question Set One, Item 6

Item 6 of part one of the Provincial Delphi panel questionnaire asked, "How long does it take for you to introduce a new product to market?" Table 5 details the responses to this item. Two respondents did not provide any responses on this item. Two of the Respondents stated that all of the indicated times were utilized and that the entry time depended on the particular product, its complexity, and the client requirements.

Table 5

Introduction Time of New Product - Provincial Panel Responses

| Introduction time | n = 4 |
|---|---|
| Less than 6 months | 2 |
| 6 to 12 months | 3 |
| 1 to 2 years | 3 |
| Longer than 2 years | 3 |

Part One, Question Set One, Item 7

Item 7 of part one of the Provincial Delphi panel questionnaire asked, "What strategy do you utilize to assure that a quality product is being developed?"
Respondents A and E stated that they operate quality assurance programs. Respondents B and C utilized user evaluation methods. Respondent C noted that they include the client in the project management team, as well as relying heavily on physics at the start of the project.

Part One, Question Set One, Item 8

Item 8 of the Provincial Delphi panel questionnaire part one asked, "How do you measure the quality of the products you produce?" Respondent A stated that they perform hands-on testing and compare their product to similar products on the market. Respondent B asserted that performance measures depend on the product. Respondent C noted that they define clear targets at the start and follow a classic design-experiment-design scenario with international peer review during key stages of the project. Respondents D and E stated that they utilize statistical analysis.

Part One, Question Set One, Item 9

Item 9 of the Provincial Delphi panel questionnaire part one asked, "What strategy do you use to assure that customer input is incorporated into the products that you develop and produce?" All Respondents incorporate the customer into the product development activity. Respondent E clarified this process with the following comment;

> ...by requiring that the customer either generate a statement of work (SOW) or at least approve the SOW generated by them. Next a full scale development specification (FAD) is prepared which identifies in detail how the SOW will be fulfilled and the customer approves the FAD. During the development cycle there are also a number of design review meetings with the client present and his or her input is requested.

Part One, Question Set One, Item 10

Item 10 of the Provincial Delphi panel questionnaire part one asked, "What are the deficiencies that currently inhibit the timely entry of new products to market in the

Province?" Respondents A and B noted that the manufacturing sector and the productive infrastructure in the province is too small. Respondents A and E noted that the local market is non-viable in that it is not as of yet very large. Opening export markets is "time and cost exhaustive" and success is difficult to predict. Respondents A, B, and E suggested that they are inhibited by the lack of capital investors. Respondent D noted that there is always difficulty in recruiting skilled people because the pay scale outside of Newfoundland and Labrador is difficult to compete with.

Part Two, Question Set One, Item 1

Item 1 of the Provincial Delphi panel questionnaire part two, question set one, asked, "What should the goals and or objectives of the Centre be?" Respondent A stated that the Centre should assist small business in developing production prototypes quickly and at an affordable price through the utilization of state of the art technology. Respondent B suggested that the Centre should facilitate the development of existing capabilities and businesses in

Newfoundland and Labrador. Additionally, the Centre should develop prototypes on the basis of its own market intelligence and on spec. Respondent F suggested five other goals and or objectives for the Centre:

1. to provide the technical support to inventors in developing a prototype,
2. to facilitate and guide inventors' product development efforts,
3. to link inventors with financial support agencies,
4. to encourage and facilitate inventors by linking them with other inventors who have been through the product development process,
5. to encourage inventors' to develop a marketing plan.

Part Two, Question Set One, Item 2

Item 2, part two, of question set one of the Provincial Delphi panel questionnaire asked, "What should the role of such a Centre be with respect to your organization?" Respondent A suggested that the Centre should be flexible with respect to design and willing to work in conjunction with the organization's engineering department as the prototype is being constructed. There must be continuous dialogue between both parties. All other respondent's had no comment.

Part Two, Question Set One, Item 3

Item 3, part two, of question set one of the Provincial Delphi panel questionnaire asked, "What services should be offered by the Centre?" Respondent F suggested three possible services:

1. to provide prototyping facilities covering engineering technologies including mechanical, electrical, electronics, processing, civil, and architectural,
2. to provide industrial design support to assist inventors to recognize design problems and to conceptualize potential solutions,
3. to provide facilitation and mentorship services.

Respondent A suggested two additional services:

4. to provide patent assistance, and

5. to provide business and marketing studies.

Part Two, Question Set One, Item 4

Item 4, part two, question set one of the Provincial Delphi panel asked, "How should the Centre be governed?" Respondents A, C, and F argued for a private sector dominated board of directors including representatives from local manufacturing companies, prototypers, and inventors who have been through the product development cycle, while Respondent B suggested a co-operative structure.

Part Two, Question Set One, Item 5

Item 5, part two, question set one of the Provincial Delphi panel asked, "What organizational structure should such a Centre have?" Respondent B suggested that the Centre might well be organized as a co-operative among users and government. Respondent C noted that the Centre should be managed by industry players and or investors and without University or government influence. Respondent F stated that a simple structure easily accessible by inventors, led by an energetic, creative manager with strong interpersonal and communication skills would be effective.

Part Two, Question Set One, Item 6

Item 6, part two, question set one of the Provincial Delphi panel questionnaire asked, "How should this Centre integrate with other research centres in the Province?" Respondent F suggested that memorandums of understanding with each of these other centres coupled with close personal contact between the Centre's manager and representatives of these other centres could be the basis for cooperation. Respondents A and B stated that the Centre could utilize the expertise available at other centres by contracting out some work. Respondent C felt that difficulties, duplication and extra bureaucracy would be encountered in the attempt to integrate into existing centres.

Part Two, Question Set One, Item 7

Item 7, part two, question set one of the Provincial Delphi panel asked, "How should intellectual property issues be addressed by this Centre?" All respondents stated that intellectual property should remain the sole ownership of the client and should be stated clearly in a non-disclosure agreement between the Centre and the client. The Centre should not be allowed to acquire intellectual properties that are in any way similar to or in conflict with the client's.

Part Two, Question Set One, Item 8

Item 8, part two, question set one of the Provincial Delphi panel questionnaire asked, "How should client confidentiality issues be addressed by this Centre?" All respondents noted that client confidentiality should be maintained unless written permission is obtained, from the client, indicating otherwise. Respondent C noted that all work should be at an industrial Secret II level with all employees certified.

Part Two, Question Set One, Item 9

Item 9, part two, question set one of the Provincial Delphi panel questionnaire asked, "Please elaborate on how this Centre could support education and training?" Respondent A suggested that the Centre could play a role in educating the client and the public in the process involved in bringing a new product to market. Respondents A, B, and F stated that by working closely with engineering technology capabilities at post-secondary institutions, the Centre could provide local manufacturers with new skilled technologists and with a skill upgrading program for existing employees.

Part Two, Question Set One, Item 10

Item 10, part two, question set one of the Provincial Delphi panel questionnaire asked, "What role should this Centre play in the improvement of the quality of products manufactured in Newfoundland and Labrador?" Respondents A and B noted that the Centre should be capable of applying its resources to improve the existing products as well as new ones through the utilization of state of the art technology and highly skilled people. Respondent C suggested that improving products is a broad, complex market-oriented issue that would be best handled by the companies themselves. Respondent F stated that the Centre could provide an industrial design capability, provide a manufacturing option within a three-year mechanical engineering technology program, and support continuing quality improvement initiatives by local manufacturers.

Part Two, Question Set One, Item 11

Item 11, part two, question set one of the Provincial Delphi panel questionnaire asked, "What role should this Centre play in the improvement of response time for the introduction of new products for industry?" Respondents A, B, and F noted that the Centre could indeed improve response time by;

1. offering quick, quality prototyping capabilities,
2. offering facilitation services, and by
3. offering industrial design capabilities.

Respondent F also suggested that the Centre could train engineering technologists for the manufacturing industry by linking with a post-secondary technical institution. Respondent C stated that this issue is one resolved by better client, industry, contractor, manufacturer contracting and better use of international talent when needed.

Part Two, Question Set One, Item 12

Item 12, part two, question set one of the Provincial Delphi panel questionnaire asked, "Should this Centre be established as part of an existing post-secondary institution?" Respondents A, B, and C were against this idea. Respondent A thought that private business would be reluctant to approach a post-secondary institution for product development and that prototypes and products may be considered more credible if established by a stand-alone firm specializing in this area. Respondent B mentioned that the Centre should be a clearinghouse providing services from existing facilities and should not compete with existing enterprises. Respondent D felt that if the Centre was not part of a post-secondary institution, then it should be closely associated with one. Respondent F considered that it should be part of a post-secondary technical institution.

Part Two, Question Set One, Item 13

Item 13, part two, question set one of the Provincial Delphi panel questionnaire asked, "Should this Centre be established as a private enterprise?" Respondents A and C agreed with this concept and that no government funding be utilized for its operation. Respondent B suggested that it could be established as a users' and provider's cooperative. Respondent F stated that the Centre should not be established as a private enterprise at this time. The Centre should be structured so that its activities can be assumed by private enterprise when it is financially feasible for the private sector to do so. It should be the mandate of the private sector dominated board of directors that this occurs as soon as it makes business sense to do so.

Part Two, Question Set One, Item 14

Item 14, part two, question set one of the Provincial Delphi panel questionnaire asked, "Should a steering committee with representation from industry, government agencies, and the post-secondary institutions be formed to address all issues involving the concept of a Provincial Prototyping Centre?" All Respondents agreed with this concept. Respondent B noted that prior to any move toward instituting such a Centre, the implications toward existing businesses and institutions should be carefully considered. Respondent C agreed because this could be used as a means to challenge the concept of such a Centre.

Part Two, Question Set Two, Item 1

Item 1, part two, question set two of the Provincial Delphi panel questionnaire asked, "What type of market should this Centre service?" Respondents A, B, and F suggested that the Centre should support local industry and small business. Respondent C was not sure it has a market. Respondent F also suggested that inventors, manufacturer employees and engineering technology students should be serviced.

Part Two, Question Set Two, Item 2

Item 2, part two, question set two of the Provincial Delphi panel questionnaire asked, "How should this Centre be financed?" Respondents A and C felt that the Centre should be financed and operated through private investment. Respondent B noted that it should be financed through existing programs. Respondent F thought that the initial infrastructure needs should be heavily supported by federal and provincial governments. Operating costs initially should be cost shared by governments and clients. Subsequent financing needs should be paid for by clients or beneficiaries and, at some point, the Centre's activities should be privatized.

Part Two, Question Set Two, Item 3

Item 3, part two, question set two of the Provincial Delphi panel questionnaire asked, "In what area(s) of the Province should this Centre be located?" Respondents A, C, D, and F considered St. John's the best location with possible branch offices in other major areas. Respondent B reiterated the statement that the Centre should be a clearinghouse of existing facilities already located throughout the Province.

Part Two, Question Set Two, Item 4

Item 4, part two, question set two of the Provincial Delphi panel questionnaire asked, "Should this Centre target new and emerging technologies only?" Respondents A, B, C, D, and F felt that the Centre should support and provide for all potential users. Respondent C stated that it may be better to examine existing companies and enhance the use of such sectors through better cooperation; targeting of new or emerging technologies is a poor approach to the marketplace as the industrial community of Newfoundland and Labrador is not that large. Respondent F countered this argument by stating that the Centre should target those technologies that are in demand and that are not available in the Province. If it is not financially or technically feasible to meet certain technology demands, then the Centre should facilitate the accessing of the required technology support outside of the Province.

Part Two, Question Set Three, Item 1

Item 1 of the Provincial Delphi panel questionnaire, part 2, question set three, asked "To what extent are each of the following twelve technologies needed for a Prototyping Centre; Manufacturing resource planning, Computer-aided design, Numerical control, Computer numerical control, Direct numerical control, Flexible manufacturing systems, Robotics, Automated materials handling, Computer-aided test and inspection, Computer-aided process planning, Rapid prototyping, and Other technologies?"

Only three of the Respondents considered that they had sufficient expertise to address this question. Table 6 displays these three responses indicating that manufacturing resource planning, computer-aided design, numerical control, computer-aided test and inspection, and computer-aided process planning would all be needed extensively.

Table 6 also shows that direct numerical control, flexible manufacturing systems, and rapid prototyping are technologies that two respondents would also use extensively. One Respondent thought that automated materials handling systems and robotics systems, as seen in Table 6, would be technologies that would not be needed.

Table 6

CIM Technology Requirements - Provincial Panel Responses

| | Rating (n = 3) | | | |
|---|---|---|---|---|
| Requirement | 1 | 2 | 3 | 4 |
| Manufacturing resource planning | 0 | 0 | 0 | 3 |
| Computer-aided design | 0 | 0 | 0 | 3 |
| Numerical control | 0 | 0 | 0 | 3 |
| Computer numerical control | 0 | 0 | 0 | 3 |
| Direct numerical control | 0 | 1 | 0 | 2 |
| Flexible manufacturing systems | 0 | 0 | 1 | 2 |
| Robotics systems | 1 | 0 | 1 | 1 |
| Automated materials handling | 1 | 0 | 1 | 1 |
| Computer-aided test/inspection | 0 | 0 | 0 | 3 |
| Computer-aided process planning | 0 | 0 | 0 | 3 |
| Rapid prototyping | 0 | 1 | 0 | 2 |
| Other | 0 | 0 | 1 | 1 |

Part Two, Question Set Three, Item 2

Item 2, part two, question set three of the Provincial Delphi panel questionnaire asked, "What other concerns and comments do you have with respect to the idea of a Provincial Prototyping Centre?" Respondent A was concerned that this concept may just become another make-work project.

Respondent B noted that many of the facilities are already available in the Province and that their availability to outsiders could be improved upon. Competing with existing resources would only weaken them. The utilization of existing resources should be emphasized and the need for a new Centre should be carefully evaluated. Respondent C did not think that this was a viable idea, as it would not be servicing a very large market.

> It is better to push existing companies to marry talent on a broader base within Atlantic Canada. Go where the support exists, keep duplication of facilities down, don't duplicate what already exists in Canada at relatively low costs to industries. Don't subsidize yet another Centre which is not essential. We don't need a make-work Centre, thinking that this will save our local industries. We need to be smarter and more independent from government grants, and to form alliances into the international marketplace.

Respondent E considered that the Centre should not be created for the following reasons:

1. The product development cycle involves a great number of activities over an extended period of time. Production

of a prototype consumes only a very small portion of the budget and time schedule. Provincially there are not a great number of companies building prototypes and few have more than one development project at any one time active. Bottom line - the prototype Centre would be underutilized and unable to generate any reasonable revenue base.

2. Even with the use of high end CAD and CAE tools prior to prototype production, there is often something unforeseen during the prototype construction phase/assembly lessons to be learned, that requires the involvement of the design team. Physically separating the activities extends the cost and time budget due to delays, meetings, etc., neither of which are acceptable.
3. Prototyping is a step that developers try and minimize to save time and cost (as per point 1, that's one of the reasons it occupies so little of the total budget). This is achieved by maximizing the upfront design time and then building a prototype as close to the intended final product as possible and ultimately building as few

prototypes as possible. In maximizing the fidelity of the prototype, the developer will go right to the materials (usually) that will actually be used in the final product. As these can be quite varied, the skill set and capital investment the Centre would need will be very expensive if not impossible to obtain and then maintain. For example, CNC machining tools, Plastics forming - both mold and injection, electronics fabrication, ceramics, etc,. A further example; even two similar products (from a fabrication point of view) may have two very different fabrication quality standards so now not only do you have this massive investment in tooling and tool operators, but a further investment in being able to comply (and attest that you comply) with all the different quality standards the Centre's customer may require.

4. There is already a growing infrastructure in the Province that can provide some of the skills required for the prototyping process - eg. CNC machining. Much of this infrastructure has already received government

funding and should be given the opportunity to succeed. If a private investor wished to back this proposal with his own funds - that's fine, its capitalism. A Provincial Prototyping Centre would have to be created and then continually subsidized by public funds. These funds would be potentially stolen from the existing public supported private entrepreneurs.

## Summary

A National Delphi panel comprised of ten persons with expertise in the prototyping and product development fields was formed. The National Delphi panel was asked three open-ended questions. For each one of these questions, the responses were categorized utilizing a TQM affinity approach. Question 1 asked, "What issues should be addressed regarding the implementation of a prototyping Centre?" The responses were separated into the following five sections; Mission, Governance, Business Plan, Location, and Implementation.

Mission

The following four points were noted by the National Delphi panelists when discussing the Mission of the Centre:

1. Identifying customers and ensuring customer satisfaction are issues of paramount importance for the success of a Provincial Prototyping Centre,
2. Determining how similar Centres across Canada have become successful and emulating their success bearing in mind the market conditions in Newfoundland and Labrador,
3. Improving the response time for the entry of new products to the marketplace for clients so that they can maintain a competitive edge in their product line, and
4. Supporting engineering education and training at local post-secondary institutions is a necessity for the operation of a prototyping Centre.

Governance

A steering committee representing the interests of government, industry, entrepreneurs, the university, post-secondary institutions, and other interested parties could be formed to address the terms of reference and whether the facility should be allied with a post-secondary institution.

Business Plan

A basis for cost recovery was considered to be important by the National Delphi panelists for the long term viability of the Provincial Prototyping Centre. Several respondents thought that the Centre should become self- supporting and that alternative approaches for the operation of the Centre be investigated. Activities that can provide sources of work and income to the Centre should be identified. Niche markets that can work in the geographic location of the Centre must also be sought. Specialized skills that currently exist in the geographic area of the Centre must be identified and built upon. Once these steps have been completed, a business plan should be developed around them.

Location

All respondents considered that a Provincial Prototyping Centre should be located close to the majority of the potential users and close to a University or other post-secondary institution. This would enable the Provincial Prototyping Centre to assist in the research and development activities of such post-secondary institutions and provide quick access to the Centre's facilities for users.

Implementation Plan

The skills, staffing, organization, equipment, and other resources comprising a Provincial Prototyping Centre need to identified. When this activity is completed a time frame for the implementation of the Centre could be developed.

Question 2 of the National Delphi panel questionnaire asked, "What resources are required in implementing a prototyping Centre?" The data collected on this item was categorized into the following three sections: Human Resources, Facilities, and Funds.

Human Resources

The most significant resource would be a director with considerable technical expertise in the fields of prototyping and product development. This director would have responsibility for managing, planning, and business technology development. The centre would also require 1 or 2 Professional Engineers with 5 to 10 years of experience in the applicable fields, 1 or 2 mechanical electronic technologists with experience in machine design and the development of prototypes, and a journeyman machinist with 5 to 10 years of experience in precision machining, welding applications, and CNC mill lathe operation. Persons skilled in marketing technical services would be necessary. Designers and project liaison officers may be required. Clerical assistance would be an asset.

Facilities

The majority of respondents remarked on the necessity of adequate facilities to house the required machinery and specialized systems utilized in the product development process. The proper environment to operate all of the specialized systems utilized in a prototyping Centre is also recommended.

Funds

Funding would depend on the number and qualifications of the personnel, equipment size and type, materials and maintenance, upgrades to equipment, utilities, and a discretionary research budget. An association with an Industrial Technology Advisor could provide a source of additional funds.

Question 3 of the National Delphi panel questionnaire asked, "What specialized systems are needed for the operation of a prototyping Centre?"

Data collected on this item was categorized into the following four sections: Specialized Systems, Equipment, Computers and Software, and Management Systems.

Specialized Systems

Total Quality Management (TQM) and a system that would support the management of technological change were considered to be vital for the successful operation of a prototyping Centre. Rapid prototyping systems and advanced coordinate measurement systems were also mentioned.

Equipment

The following list of equipment was determined to be required for the operation of a Provincial Prototyping Centre by all respondents:

1. rapid prototyping system and the associated equipment for this system,
2. special-purpose materials handling equipment,
3. 5 axis CNC milling machine and associated tooling,
4. 3 axis CNC milling machine and associated tooling,
5. small plastics processing machines,

6. hardware for the production of circuit boards,
7. articulated arm welding robot and associated equipment,
8. wire electronic discharge machining and associated equipment,
9. engineering workstations and associated software,
10. test equipment.

Computers and Software

Some of the suggestions included hardware and software for the design of microelectromechanical systems, simulation software, and engineering and solid modelling software. These were mainly computerized systems that would be utilized in the fabrication of prototypes or products.

Management systems

Knowledgeable people who can get quality results in as short a time as possible. These persons must have consummate communication skills that cover the fields of business, engineering, and finance. Concurrent Engineering, Computer Integrated Manufacturing, and TQM are examples of management systems that require people with the above-noted skills.

A Provincial Delphi panel was formed when all responses from the National Delphi panel were received. This Provincial Delphi panel was comprised of individuals who had expertise in the development of prototypes and products in the province of Newfoundland. The data collected from the National Delphi panel responses was used to develop another questionnaire which was transmitted to the Provincial Delphi panel. The intention of the questionnaire to the Provincial Delphi panel was to provide data that could address the research question, "Is there a need for a Provincial Prototyping Centre in Newfoundland and Labrador?"

The questionnaire was comprised of two parts. Part one included one question set and part two included three sets of questions.

Part one dealt with current prototyping and product development activities of the panelists. The data collected revealed that the prototyping and product development activity in the province, at this particular time, was minimal. Very few of the respondents were involved in the development of multiple prototypes. The majority of this activity was confined to the province, although several respondents did utilize facilities located outside of the province. The time frame for product entry ranged from several months to several years and was dependent on the complexity of the project.

Mathematical modelling was used extensively by respondents. Involving the client in the product development process was agreed to by all respondents. The quality of the products produced were measured utilizing statistical analysis, user evaluation, peer review, and including the client in the process.

Deficiencies noted by the panelists, that inhibited timely entry of new products to market, were the lack of infrastructure and a small manufacturing sector. Recruiting skilled software specialists and a lack of capital investors were also inhibiting factors.

Part two, question set one, was concerned with Mission, Role and Governance issues. The respondents stated that the goals and or objectives of the Centre should be:

1. to provide the technical support to inventors in developing a prototype,
2. to facilitate and guide inventors' product development efforts,
3. to link inventors with financial support agencies,

4. to encourage and facilitate inventors by linking them with other inventors who have been through the product development process,
5. to encourage inventors to develop a marketing plan,
6. to assist small business in developing production prototypes quickly and at an affordable price,
7. to facilitate the development of existing capabilities and businesses in the province, and
8. to develop prototypes based on its own market intelligence.

Respondents stated that the Centre should offer the following services:

1. to provide prototyping facilities covering engineering technologies including mechanical, electrical, electronics, processing, civil, and architectural,
2. to provide industrial design support to assist inventors to recognize design problems and to conceptualize potential solutions,
3. to provide facilitation and mentorship services;
4. to provide patent assistance, and

5. to provide business and marketing studies.

There were suggestions for a private sector dominated board of directors and or a cooperative system. A simple structure, easily accessible by inventors, led by an energetic, creative manager with strong interpersonal and communication skills would be effective. Memorandums of understanding with other centres coupled with close personal contact between the Centre's manager and representatives of these other centres could be the basis for cooperation. Several respondents suggested that by working closely with engineering technology capabilities at post-secondary institutions, the Centre could provide local manufacturers with new skilled technologists and with a skill upgrading program for existing employees.

Several respondents noted that the Centre should be capable of applying its resources to improve existing products as well as new ones while Respondent C suggested that improving products is a broad, complex market-oriented issue that would be best handled by the companies themselves. Respondent F stated that the Centre could provide an industrial design capability, provide a manufacturing option within a three-year mechanical engineering technology program, and support continuing quality improvement initiatives by local manufacturers.

The Centre should improve response time by:

1. offering quick, quality prototyping capabilities,
2. offering facilitation services, and by
3. offering industrial design capabilities.

The majority of the respondents felt that the Centre should be a private enterprise and be financed by private enterprise. One respondent suggested that the initial infrastructure needs should be heavily supported by federal and provincial governments and operating costs initially should be cost shared by governments and clients. Subsequent financing needs should be paid for by clients or beneficiaries, and at some point the Centre's activities should be privatized. All respondents thought that the idea of a steering committee with representation from industry, government agencies, post-secondary institutions and other interested parties was a good idea. All respondents thought that the Centre, if established, should be located in St. John's.

The majority of the respondents had grave concerns about the implementation of such a Centre. Respondents felt that the local market that would be serviced by a Prototyping Centre was not large enough. Existing services currently available at other centres and at private enterprises would be underutilized. Assisting local companies and local entrepreneurs to form alliances in the international marketplace was considered to be a better investment in the long term.

# CHAPTER FIVE

## Conclusions and Recommendations

### Summary of Study

The focus of this Delphi study was to assess the needs for a Provincial Centre capable of delivering manufacturable prototypes of high quality and simultaneously reducing the time-to-market for Newfoundland innovations. This study also attempted to determine the specialized systems and resources that were necessary for the operation of such a Centre.

A modified Delphi technique that consisted of two rounds was utilized to obtain data for this study. For round one, a questionnaire was first electronically mailed and transmitted via the Internet to a Delphi panel of experts consisting of ten persons located across Canada, each with expertise in the areas of prototype and product development. For the purposes of this study, this panel was termed the National Delphi panel. The questionnaire asked only three broad questions to facilitate the dat collection. As well, the respondents were free to give open-ended responses to the questions posed. The collected data was qualitatively analyzed and categorized into sections by utilizing a Total Quality Management tool called affinity.

A second Delphi panel was formed with seven persons from Newfoundland and Labrador with expertise in the areas of the study to respond to a second questionnaire that was developed from the data gathered from the first Delphi round. This second panel was termed the Provincial Delphi panel. The questionnaire for this second round was also electronically mailed and transmitted via the Internet to the Provincial Delphi panel with the exception of two members who did not have access to the Internet. In these two cases, the questionnaire was transmitted by facsimile to the respondents. The collected data from Round 2 was also analyzed qualitatively.

## Conclusions

The data obtained from this Delphi study indicated that a Mission statement be developed for a Provincial Prototyping Centre that would produce manufacturable prototypes and products. The focus of this Mission statement would be to improve response time for the entry of new products to the marketplace, support engineering education and training, and ensure that customer satisfaction is valued.

The goals and objectives of a Provincial Prototyping Centre in Newfoundland and Labrador, should be:

1. to provide the technical support to inventors in developing a prototype,
2. to facilitate and guide inventors' product development efforts,
3. to link inventors with financial support agencies,
4. to encourage and facilitate inventors by linking them with other inventors who have been through the product development process,
5. to encourage inventors to develop a marketing plan,
6. to assist small business in developing production prototypes quickly and at an affordable price,
7. to facilitate the development of existing capabilities and businesses in the province, and
8. to develop prototypes based on its own market intelligence.

This Delphi study also determined that the following list of equipment would be necessary in a Provincial Prototyping Centre:

1. rapid prototyping system and the associated equipment

for this system,

2. special-purpose materials handling equipment,
3. 5 axis CNC milling machine and associated tooling,
4. 3 axis CNC milling machine and associated tooling,
5. small plastics processing machines,
6. hardware for the production of circuit boards,
7. articulated arm welding robot and associated equipment,
8. wire electronic discharge machining and associated equipment,
9. engineering workstations and associated software,
10. test equipment.

This study also determined that a Provincial Prototyping Centre should include the following personnel:

1. a director with considerable technical expertise in the fields of prototyping and product development,
2. One or two Professional Engineers with 5 to 10 years of experience in the applicable fields,
3. One or two mechanical electronic technologists with experience in machine design and the development of prototypes,

4. A journeyman machinist with 5 to 10 years of experience in precision machining, welding applications, and CNC mill lathe operation,
5. A person skilled in marketing technical services,
6. Designers and project liaison officers may be required, and
7. clerical assistance would be an asset.

## Recommendations

Based on the analysis of the data gathered during this study, the following recommendations are made by the researcher.

A. That a steering committee representing the interests of government, industry, entrepreneurs, the university, post-secondary institutions, and other interested parties should be formed to further investigate the feasibility of a Provincial Prototyping Centre.

B. If a Provincial Prototyping Centre was to be implemented, it should be governed by a board of directors comprised of representatives from local manufacturing companies, prototypers, and inventors who have been through the product development cycle.

C. If a Provincial Prototyping Centre was to be implemented, it should utilize existing resources co-operatively that are currently located in St. John's.

D. A Provincial Prototyping Centre should be allied with an existing post-secondary technical institution in order to facilitate specialized training leading to a three year technology diploma in mechanical engineering technology.

E. That further study be undertaken to explore potential clients' opinions regarding the need for a Provincial Prototyping Centre.

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# APPENDIX A

## Round One Delphi Questionnaire

MEMORIAL UNIVERSITY OF NEWFOUNDLAND

FACULTY OF EDUCATION

Welcome to round one of the Delphi study. It has been devised to ascertain the elements that are viewed as necessary for a Centre that can be useful to individuals who are attempting to develop manufacturable products.

The Delphi technique is a research method used to achieve a level of consensus from a panel of experts. It can also provide evidence that is useful in setting priorities in planning. It is normally completed in successive rounds that initially collect ideas and consensus and refine each idea.

The preliminary round or ROUND-ONE, which is this form, is essentially an opportunity to brainstorm on the questions provided. As there have been few Delphi studies utilizing both e-mail and the Internet, you will be involved in unique research.

There are three questions designated for ROUND-ONE. Please reflect on each and send back your opinions and answers.

ROUND ONE

1. What issues should be addressed regarding the implementation of a prototyping centre?

2. What resources are required in implementing a prototyping centre?

3. What specialized systems are needed for the operation of a prototyping centre?

Thank you for the comments on these questions.

Please provide me with your comments on these questions in either point form or narrative form as soon as possible utilizing e-mail techniques via the Internet.

My e-mail address is: SBOLAN@FAC.CABOT.NF.CA

Yours Sincerely,

Stephen Bolan, B.Voc.Ed., A.Sc.T.

# APPENDIX B

## Round One Closure Letter

Memorial University Delphi Study

Round One Completion

The information included with this transmission is the combined results of the previous Delphi ROUND-ONE. The information has been collected from all responding Delphi panel members and categorized into various topics according to a Total Quality Management process. This process was subsequently screened by experts in the utilization of this approach.

In order to provide closure to this round, please study the information gathered and the categorization of this information and provide notification via e-mail if you concur with the categorization and whether or not you specifically concur with the necessity of all provided information. If you are not in agreement with the necessity of a particular item please provide a response within that specific section of the ROUND-ONE questionnaire. Thank you for you efforts on behalf of this study.

Yours Sincerely,

Stephen J. Bolan

# APPENDIX C

## Round Two Delphi Questionnaire

MEMORIAL UNIVERSITY OF NEWFOUNDLAND

FACULTY OF EDUCATION

Welcome to this round of the Delphi study. It has been devised to ascertain the elements that are viewed as necessary for a Centre that can be useful to individuals who are attempting to develop manufacturable products.

The Delphi technique is a research method used to achieve a level of consensus from a panel of experts. It can also provide evidence that is useful in setting priorities in planning. It is normally completed in successive rounds that initially collect ideas and consensus and refine each idea.

The preliminary round or ROUND-ONE, involved a panel of national experts in the fields of rapid prototyping and product development. Information collected from these experts is the basis of this round or ROUND-TWO, which is this questionnaire.

As there have been few Delphi studies utilizing both e-mail and the Internet, you will be involved in unique research.

Please reflect on the questions for ROUND -TWO and send back your opinions and answers.

**MEMORIAL UNIVERSITY OF NEWFOUNDLAND**

**DELPHI QUESTIONNAIRE**

The following questionnaire is separated into two parts. Part One, which contains one set of questions is concerned with the current activities that your company utilizes in the development of new products. Part two, which contains three sets of questions, is concerned with issues involving the establishment of a Provincial Prototyping Centre.

**Part One**

Question Set One

Current Product Development/Prototyping Activity

1. What products or prototypes are being developed by your company at the present time?

2. Where is the activity involved in the development of these products or prototypes carried on?

   In-house ( )

   In the Province ( )

   Elsewhere ( )

3. How much of the product or prototype do you fabricate in your plant?

0-25% ( )

25-50% ( )

50-75% ( )

75-100% ( )

4. To what extent do you use mathematical modelling for your product or prototype development process?

not at all ( )

very little ( )

a moderate amount ( )

a great deal ( )

5. What strategy do you utilize in the development of new products?

6. How long does it take for you to introduce a new product to market?

| | |
|---|---|
| Less than 6 months | ( ) |
| 6 to 12 months | ( ) |
| 1 to 2 years | ( ) |
| Longer than 2 years | ( ) |

7. What strategy do you utilize to assure that a quality product is being developed?

8. How do you measure the quality of the products you produce?

9. What strategy do you use to assure that customer input is incorporated into the products that you develop and produce?

10. What are the deficiencies that currently inhibit the timely entry of new products to market in the Province?

## Part Two

### Question Set One

### Mission, Role and Governance Questions

1. What should the goals and/or objectives of the Centre be?

2. What should the role of such a Centre be with respect to your organization?

3. What services should be offered by the Centre?

4. How should the Centre be governed?

5. What organizational structure should such a Centre have?

6. How should this Centre integrate with other research centres in the Province?

7. How should intellectual property issues be addressed by this Centre?

8. How should client confidentiality issues be addressed by this Centre?

9. Please elaborate on how this Centre could support education and training.

10. What role should this Centre play in the improvement of the quality of products manufactured in Newfoundland and Labrador?

11. What role should this Centre play in the improvement of response time for the introduction of new products for industry?

12. Should this Centre be established as part of an existing post-secondary institution?

13. Should this Centre be established as a private enterprise?

14. Should a steering committee with representation from industry, government agencies, and the post-secondary institutions be formed to address all issues involving the concept of a prototyping Centre?

## Part Two

### Question Set Two

### Business Plan, Location and Implementation Issues

1. What type of market should this Centre service?

2. How should this Centre be financed?

3. In what area(s) of the Province should this Centre be located?

4. Should this Centre target new and emerging technologies only?

## Part Two

### Question Set Three

### Computer Integrated Manufacturing Technology Questions

1. To what extent are each of the following technologies needed for a Prototyping Centre?
(1 = not at all, 2 = occasionally, 3 = moderately, 4 = extensively):

A. Manufacturing resource planning ( )

B. Computer-aided design ( )

C. Numerical control ( )

D. Computer numerical control ( )

E. Direct numerical control ( )

F. Flexible manufacturing systems ( )

G. Robotics ( )

H. Automated materials handling ( )

I. Computer-aided test/inspection ( )

J. Computer-aided process planning ( )

K. Rapid prototyping ( )

L. Other ( )

2. What other concerns and comments do you have with respect to the idea of a Provincial Prototyping Centre?

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Thank you for the comments on these questions.

Please provide me with your comments on these questions in either point form or narrative form as soon as possible utilizing e-mail techniques via the Internet.

My e-mail address is: SBOLAN@FAC.CABOT.NF.CA

Yours Sincerely,

Stephen Bolan, B.Voc.Ed., A.Sc.T.