University Grant Program Research Report

CASE STUDIES OF INDUSTRIAL INNOVATION IN CANADA

by

M.E. Charles and D. Mackay

Chemical Engineering Research
Consultants Limited.
Toronto

May. 1975

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The views and opinions expressed in this report are those of the authors and are not necessarily endorsed by the Department of Industry, Trade and Commerce.

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M.E. Charles and D. Mackay

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PREFACE

In 1973 the Office of Science and Technology, Department of Industry, Trade and Commerce, awarded a grant to the C.E.R.C.L. Foundation to undertake case studies of the innovative process in Canadian industry. This report presents the findings of these studies, discusses the many factors which influenced the innovations and makes recommendations for the betterment of the innovative process in Canada.

This study differs significantly from previous attempts to examine the innovative process in that those involved in carrying out the study have acted as advisors to the particular companies over periods of several years. They have thus had the unique opportunity of viewing both successful and unsuccessful innovations from the inside. They have become familiar with the technologies, markets, corporate structures and individuals. Most previous studies have used interviews only as a means of eliciting information. Although such approaches are useful, and even necessary, it is recognized that an interviewee can give a somewhat biased account of past events. He may present his company in a favourable light, emphasize success rather than failure, fail to mention personality clashes, and generally ascribe more logic and foresight to the innovative process than probably occurred.

The background material was prepared by the thirteen advisors, two of whom have authored this final report. The views expressed are those of the authors and are not necessarily those of the companies, the C.E.R.C.L. Foundation, or the Office of Science and Technology. Along with many achievements, we have encountered several instances of company actions which in retrospect were wrong. Further, we have seen several personality clashes, and a number of innovative programs which failed. We believe that much can be learned from such unfortunate events.

Eighteen companies have been included in this study; all are based in Ontario, most are located close to Toronto. They are predominately small industrial enterprises, often privately owned and usually lacking large, long established research and development groups. Many have sought to create research and development groups with Government assistance through, for example, the National Research Council Industrial Research Assistance Program (IRAP) or the Department of Industry, Trade and Commerce Program for the Advancement of Industrial Technology (PAIT), or the Industrial Research and Development Incentives Act (IRDIA). The companies may not be typical of Canadian industry but they must represent a substantial fraction.

It is hoped that this analysis of their experiences will be of benefit to other companies seeking to improve their innovative capability and to Government in seeking to promote innovation in Canada.

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It is a pleasure to acknowledge the invaluable contributions of the following companies. The consultants associated with each company are given in parentheses.

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Aerofall Mills Ltd. (D. Basmadjian)
Canada Cycle & Motor Co. Ltd. (CCM) (H.L. Williams)
Canada Glazed Papers Ltd. (J.W. Smith, H.L. Williams, R.E. Jervis)
Consumers Glass Co. Ltd. (D. Barham)
Fiberglas Canada Ltd. (M.R. Piggott, M.E. Charles)
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M & T Products of Canada Ltd. (S. Sandler, R.W. Missen)
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Milltronics Ltd. (M.E. Charles)
Nachurs Plant Food Co. Ltd. (J.W. Smith)
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R-B Filters Ltd. (M. Wayman)
Surpass Chemicals Ltd. (O. Trass, C.E. Chaffey)
Toronto Coppersmithing Co. Ltd. (D. Mackay, O. Trass)
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THE C.E.R.C.L. FOUNDATION

This non-profit foundation has among its objectives to engage in research and to conduct studies relating to industrial, scientific, and economic and related problems encountered by government or industry.

Its members are principally from the staff of the Department of Chemical Engineering and Applied Chemistry at the University of Toronto, who are also consultants and directors of Chemical Engineering Research Consultants Limited (CERCL), a consulting engineering company incorporated in Ontario in 1963. The current President of the C.E.R.C.L. Foundation is Professor W. Howard Rapson, F.R.S.C.

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Introduction

It is first prudent to define the term "innovation" since it is clear that the term is open to different interpretations. We have generally followed Myers and Marquis (1969) in defining innovation broadly as the introduction in the market by a company of a new or improved product, process or service. The components which comprise the innovative process are several; there can be basic research, development, market survey, design, financing production, and marketing. The innovative process is only as strong as its weakest component. Any weakness in one of the components can jeopardize the entire innovative process. We have found it convenient to qualify an innovation as "successful" if it is fully commercialized and profitable, and "unsuccessful" if it is technically or (more usually) commercially wanting. The term "invention" we have used as meaning the initial conceptualization of the idea upon which the subsequent innovation is based.

Many studies of innovation have tended to concentrate on major innovations, such as xerography, penicillin, the jet engine, the electron microscope or the transistor. The oft-quoted OECD Reports (see for example Bourgault (1972) p. 38) show that Canada's performance rates very poorly in the context of such innovations. In this report we are not concerned with this type of major innovation; the innovations we have encountered are much less outstanding and profitable. Nevertheless, they often represent significant financial benefits to the companies. They may not lead to multi-million dollar, multi-national industries such as xerography, but they often represent the difference between financial success and failure for a small Canadian company. Indeed we are inclined to believe that there should be more emphasis on promoting the less spectacular marginal innovations which ensure the continued health of existing Canadian industry and less emphasis on diagnosing why Canadian industry has failed to foster major innovations.

It is not our purpose here to review the general state of the innovative process in Canadian industry and analyse the many factors which influence that process. There have been many excellent reviews in recent years including, for example, the Science Council of Canada Reports, "Innovation in a Cold Climate: The Dilemma of Canadian Manufacturing" (1971), "Innovation and the Structure of Canadian Industry" by P.L. Bourgault, (1972) and "Background to Invention" by A.H. Wilson (1970), and "A Science Policy for Canada" Volume 1 (1970), Volume 2 (1972) and Volume 3 (1973) prepared by the Senate Special Committee on Science Policy under the chairmanship of The Honourable Maurice Lamontagne, and the review "Entrepreneurship in High Technology" by J.W. Hodgins (1972), and numerous articles in business, trade and professional journals.

A good review of retrospective studies of technological innovations has been provided recently by Utterback (1974). He considered the market factors which influence innovation, the effect of company size, the source of the innovation, i.e. inside or outside the company, the time lag in achieving the innovation, the role of basic research, the characteristics of the innovative individuals, the source of the ideas for innovation, the role of consultants and patents, the presence of the few individuals termed "technical gatekeepers" who have extensive contact outside the firm and who influence strongly the flow of technical information to the company, the barriers to communication between departments in a firm, its organizational structure, the diffusion of innovations in the market, the cost and risk of the innovation, the characteristics of spin-off ventures, the proximity of a large thriving university and the role of Government support.

Utterback concludes that the innovative process is more complex than is generally appreciated and that it is not amenable to facile analysis. As he points out, many of the characteristics of innovations which have failed commercially appear to be similar to those which proved successful! There seems to be no easy recipe for identifying the environment which promotes innovation. Utterback suggests that traditional strategies such as incentives to increase research spending and improve information retrieval may be less important in stimulating innovation than governmental action to create new markets, assist market entry, provide venture capital and provide mobility and informal contact among members of the technical community.

Scherer (1970) discusses innovation as a response to opportunities to increase profits. The incentive to innovate comes from an expectation that the present discounted value of the expected stream of profits from the invention will be greater than the costs of the necessary research and development. A firm's effort and expenditures on research will therefore be related to its rate of discount, its expectation of the market success of an innovation, the possible gains from successful innovation, and other economic factors.

The expected gains from an invention may be increased by securing a patent, which provides a monopoly over exploitation of the invention for a fixed period of time. Patent applications take time, however, and disclose some details of the invention to those who might circumvent the patent by similar ideas. Defending a patent lawsuit can be expensive, so the protection is not complete. As a result many good ideas may not be patented, even where this would be possible. If the process can be kept secret, or there are barriers to entry in the industry, the protection of a patent may even be redundant.

Schumpeter (1950) argued that large profits were necessary to provide the substantial amounts of money needed for successful invention and innovation. He therefore concluded that industries in which monopoly power or market power was present would have a higher rate of invention or innovation than perfectly competitive industries which provided meagre profits. The validity of this argument has been widely debated in the economic literature.

A first issue in the debate is whether large firms are more innovative and inventive than small firms. Galbraith (1956) argued that only firms of considerable size would have the resources to produce technological innovations in today's complex world. Large firms can pool risks among many research projects, they can achieve economies of scale in research, and they can exploit economies of scale in developing and marketing a product once an invention takes place.

On the other hand, in a small firm, decisions to pursue a project can be made by a manager who is familiar with the individual researcher, the capabilities of the firm, and markets for the product. There are fewer layers of personal bureaucracy to discourage pursuit of a worthwhile project. Truly imaginative innovations may thus be pursued in a small firm, where someone in a large bureaucracy would be likely to say "no". Furthermore the inherent rigidity of large corporations may discourage truly creative people who could flourish in a less structured environment of a small firm. It is not clear from the empirical evidence that large firms are any more innovative than small firms. It does appear that small firms spend less money on research and development than large ones in proportion to their revenues, but there is no apparent advantage in any particular size firm for producing successful innovations.

Another issue is whether a diversified company will be more inventive than one producing a limited range of products. It can be argued that invention and innovation are chance occurrences and that frequently what is discovered is not what was sought. A diversified firm may be able to use random discoveries more effectively than a firm with a narrow product line. Scherer however, reports mixed results in empirical tests of this hypothesis. Studies of the relationship between patents issued and diversity of product lines have not been able to demonstrate that diverse firms are more inventive than others.

Finally, there is the original question whether monopoly *per se* is an inducement to innovation. Schumpeter's theory that monopoly provides the profits to support innovation is opposed by the theory that competitive pressure provides the stick to induce technological progress. Once again the empirical evidence is mixed. There is no preponderance of the evidence to show that firms with a high degree of market power are more innovative than others. In fact market structure appears to have very little to do with innovation.

Scherer suggests a few prerequisites which appear to contribute to high rates of innovation. An important determinant is the opportunities which are presented by advances in science and engineering. Thus at any given time there will be some industries for which new technologies or methods of operation are employed. Here there is much more likelihood for new ideas and innovation than in industries where the methods and technology have been gradually developed over a long period of time. To use Scherer's example, an electronics firm is more likely to produce innovations than a brick-making company. A second important factor is the willingness of entrepreneurs to pursue scientific knowledge for industrial purposes. In fact it has been suggested that differences in entrepreneurial attitude among countries may be the most important factor determining rates of technological progress. Thus the expectations for finding quantitative evidence of determinants of innovation in this study must be rather modest.

Hodgins (1972) has analyzed the effectiveness of entrepreneurship in high technology Canadian industry and concludes that the proximity of a thriving intellectual and industrial environment is essential and that a major impediment to entrepreneurial innovation in Canada is lack of an economic policy to encourage innovation.

Litvak and Maule (1972) have provided an excellent review of the characteristics and problems of the Canadian technological entrepreneur and they conclude from an analysis of 47 small newly established ventures that there is a need to rationalize the many Canadian governmental incentive programs. There is a particular need to improve the managerial capability of technical entrepreneurs and to promote stronger ties among entrepreneurs, venture capital and management consultants. Company failure is attributed mainly to lack of general management expertise. The entrepreneur is often unwilling to give up control of his company and prefers to operate as an owner-manager. The marketing performance of a venture was often weak and most new product development was carried out and implemented before the market potential and costs of market penetration were properly assessed.

Langrish et al (1972) analyzed the innovations upon which 84 Queen's Awards were made in the United Kingdom in the period 1966-67. An important conclusion was that the transfer of technology is very much a people-oriented process. "People routes" were identified as the hiring of new employees, talking to personal contacts at home and abroad and at conferences, consulting arrangements, collaborating with suppliers and customers, and acquiring knowledge through training or experience. It was concluded that technology transfer is accomplished much more effectively by the movement of individuals than by trying to move ideas through communication networks.

It often appears that the Canadian economic and political climate discriminates against the Canadian entrepreneur. This has been discussed by Gilpin (1971), Atherton (1973) and responded to by Kirby (1973). An interesting study by Schad (1973) of Husky Manufacturing and Tool Works Ltd. showed that the cost of locating an industrial enterprise in Canada is significantly greater than in the United States as a result of higher costs, duties and taxes. Such a situation reduces the likelihood that Canadian firms can export to the U.S. market at competitive prices, thus limiting many firms to the much smaller Canadian market.

Although the factors which influence innovation may be only poorly understood in a quantitative sense it is generally believed that Canadian performance is less than satisfactory. The reasons for this are complex and include factors such as the relatively small population and market in Canada, particularly when the country is compared to the United States, high transportation costs associated with the long distances between population centres which limit many markets to regions rather than the nation, the need to import many components, an excessive conservatism in providing capital to new ventures, the taxation and tariff structure, and finally an unfortunate tendency for Canadians to believe that imported technology is inherently superior to the indigenous variety.

In the case studies considered here we have attempted to identify the major factors which controlled the innovative process. From a discussion of these factors we make recommendations for changes in the innovative environment which we hope will improve the innovative capability of Canadian industry. This improvement is necessary not only to ensure the continued health of Canadian industry but also to provide further challenging and worthwhile opportunities for Canada's highly educated and competent youth.

In his study of innovation and the structure of the Canadian industry for the Science Council, Pierre Bourgault concludes that Canada may have many weaknesses but it has two great strengths which it can exploit: a young dynamic and highly educated population and rich physical resources. It is our hope in this report to identify some of the means by which this exploitation can be achieved.

DESCRIPTION OF COMPANIES AND INNOVATIONS

We believe the present study to be unique in that the thirteen individuals who participated in the study on behalf of the C.E.R.C.L. Foundation had had (or had during the course of the study) professional relationships as advisors with one or more of the participating companies. These individuals, with the cooperation of representatives of the companies prepared source material from which this final report has been assembled. In this section a brief description is given of the salient features of each of the eighteen companies and their innovations.

In total, some 60 attempted innovations were selected as examples. Some are quite substantial and represent almost the entire production of the company concerned, for example the Aerofall mill or the Eldema system. Others are more marginal in their effect on a company's operations and involve, for example, improvements to an operation or the substitution of a new material in a product component. In several cases the product or process was developed with technical success only to become a market failure, at least at present. It is debatable whether or not such cases should be considered as innovations; however, several are included here since they represent a considerable innovative effort by the company, they may yet prove to be market successes, and they often have had unexpected effects on other company operations.

Unfortunately, the confidential nature of the information prevents full details being given of all innovations; some are still under development; some are being held dormant until an appropriate change occurs in the market. However, it is hoped that the material presented here will nevertheless provide an insight into the wide variations of the innovative process.

ABREX Specialty Coatings Ltd.

ABREX Specialty Coatings Ltd. is located in Oakville, Ontario and was formed in 1959 by G.R. Bailey. It is a private, Canadian owned company with a wholly owned subsidiary in the United States. The company specializes in coatings and finishes but is expanding into other related high technology products. The number of employees has grown from the initial 5 to 17 at the present time, exclusive of part-time personnel and employees of the U.S. subsidiary. Research and development activities have formed the foundation for company growth during the last ten years during which time sales have more than quintupled.

The subsidiary company was established to provide production facilities in the United States so that unfavourable tariffs on exports from Canada could be avoided.

Abrex's innovations have led to positive spin-off effects in local industry.

The most common approach to innovation is visualization of a new product, preliminary laboratory tests to prove feasibility and the sale of pilot quantities for end-use testing in a customer's plant and on his products. The company's own research and development laboratory is well equipped for the formulation and testing of new coating materials.

Products are not advertized or promoted in the usual way since the customers for a particular product are normally few in number. Rather, co-operative programmes are sought with the major potential customers. The company is sufficiently small for new ideas to be considered by the owner and General Manager and rapid action taken.

As an example of this Company's innovative effort we have selected the continuous electrocoating process for the application of paint. The company did not, of course, invent electrocoating. Rather, it recognized the market need for an electrocoating process for continuous metal strip.

The changes needed in the existing technology formed the basis for innovations upon which the company's penetration into the market and reputation were built. The ideas were generated internally and by professorial advisors to the company management and research team. Without Federal Government support through the Industrial Research Assistance Program (IRAP) these innovations would not have been possible because the company could not have otherwise afforded the outlay on the research program.

Not only was inventiveness required in process design with respect, for example, to the cooling of the paint solution because of the heat generated by the passage of the electric current and to the removal of ions which tend to build up and adversely affect the coating process, but it was also required in the manufacture of the coating resins themselves. Although resins constitute the main product line of the company, there was a need, for example, to improve the hardness of the cured resin, to reduce the curing time, increase the pot-life and increase the coating efficiency. This work was largely experimental and new products were tested on a simple laboratory device called a "Depletor" which was designed and manufactured by the company. The "Depletor" was so useful that it itself became a company product and between 40 and 50 units were manufactured and sold throughout the world, even to large companies.

The innovations in the formulation of the resins and demand that resulted required improved and enlarged production facilities with better quality control. Again a university professor was able to offer substantial advice in this area.

It would appear that in the overall sense the innovations could be classified as resulting from both a technological push and market pull.

The company searched the literature extensively and made use of facilities at National Research Council, Ontario Research Foundation and the University of Toronto.

An interesting aspect of this innovation is that for each new application a specifically designed plant was required; no product or plant could be simply adapted. For example, the equipment required for the continuous line coupled with the heat treatment process differs from that used for normal coatings, and differs again from that used to coat only one side, to coat aluminum coil, to coat galvanized iron or to coat discrete objects.

Of the total research and development costs, about one-half have been covered by the IRAP grant which terminated in 1973. Growth of the research budget is expected as sales volume increases; typically the company has been spending about 20% of sales on research and development, a figure consistent with the pharmaceutical and specialty chemical industries.

Although patents have been applied for, the technical and commercial exploitation of the ideas preceded the issuance of the patents. Exploitation of know-how is bringing revenue from the U.S.A. and Germany.

Success has been largely dependent on the presence of the "prime mover" who was originally the owner, G.R. Bailey. Subsequently, F.R. Crowne was appointed General Manager and has similar drive. The creative, "go-go" atmosphere permeates the whole organization.

Innovation has resulted in a quintupling of sales and a tripling of staff during the period 1965-73. The major reward perhaps has been the establishment of a reputation as a small, reliable firm which can handle successfully difficult tasks in the specialty coating field.

AEROFALL MILLS LTD.

Aerofall Mills Ltd. is now located in Clarkson, Ontario and was founded in 1946 by D. Weston following his leadership in the development of the Aerofall mill concept of grinding when employed by Consolidated Mining and Smelting Co. from whom the patent rights were acquired. In 1954 D. Weston formed the sister company Milltronics Ltd. (which also participated in this study) for the specific purpose of developing control systems for Aerofall mills. In 1965 control of Aerofall Mills (and Milltronics) was acquired by Canadian Corporate Management, Toronto, a wholly Canadian owned holding company. D. Weston remained a minority shareholder and Director, and R. Meaders, the former General Manager became President. In 1974 R. Meaders was appointed Chairman of the Board and A. Clarke assumed the Presidency of the Company. A formal R & D program was initiated in 1967, and in 1968 the company moved from downtown Toronto to its present location. During its lifetime the company has designed some 100 milling installations and presently has a staff of approximately 30 persons.

In 1967 the company initiated a formal research and development program with the support of IRAP. In part, this was in response to the need to increase sales volume. While the research activity was generally successful in that new and improved auxiliary equipment and design methods were developed for the Aerofall mill, a decrease in company sales led to a suspension of research activity in 1969-70. The company's versatility was increased by providing services for the design and analysis of ball mill systems. Subsequently sales substantially improved and the research effort was reactivated. Perhaps the most significant innovation by the research group is the development of a new vortex classifier which is attached to the exit of the Aerofall mill and greatly reduces the proportion of oversize material in the mill effluent. It is estimated that the new classifier reduces the classification costs by 20%. The design evolved during the course of extensive flow studies in model classifiers of various geometries under the direction of two doctoral engineers. The device is a good example of innovation by combining scientific methods with sound engineering judgement.

The innovation on which the company was built was the Aerofall mill. The motivation for the invention of the Aerofall mill was a reduction in the power requirements and large equipment costs of conventional milling operations. This was achieved through relatively simple but ingenious structural and operational modifications of conventional rotary mills. The principal innovative features are:

(a) Use of internal wedges on the ends of the mill and impact bars along the shell of the mill. The wedges have the highly desirable effect of preventing particle segregation and, together with the impact bars, apply strong compressive forces to the mill charge. The scientific basis of this action does not appear to be fully understood, and the inventor must be credited with extraordinary engineering ingenuity in developing the concept.

(b) Use of uncommonly large diameters (up to 34' compared with up to 17' for the largest ball mills). This has the effect of increased impact crushing of the solids on their return to the bottom of the mill, and an increase in compressive, gravitational and centrifugal forces. Since the wedge action requires close proximity of the two faces of the mill, the design resulted in uncommonly high diameter to length ratios of about 5:1, compared to 1:3 for conventional mills.

The large diameter design also required the company to develop uncommonly large and rugged bearings. Their expertise in this field became a major factor later on in their successful design of the world's largest ball mill. This is a prime example of unexpected spin-off from the original innovation.

(c) A third innovative feature was the removal of primary ground material by sweeping the mill with a continuous air stream. This process is inefficient in mills of conventional length and becomes effective and economical only for the large diameter to length ratios of the Aerofall mill.

(d) A ball charge is required only for tough applications, and then to a much lesser extent than in conventional mills.

The Aerofall mill thus achieves in a single economical step the crushing of materials by natural impact and compressive forces, grinding through self-abrasion and partial classification through removal of product by air. Further classification and dust removal takes place in conventional cyclones, scrubbers and bag filters. The combined effect of these features was to bring about a 20-50% reduction in equipment, power and installation costs.

CANADA CYCLE AND MOTOR CO. LTD. (CCM)

This company is located in Toronto and is very well known for the manufacture of bicycles and sports equipment, particularly hockey equipment. It is a public company, a division of Seaway-Multicorp. A plant is also operated in the Montreal area. The company exports to the United States, Europe and Australia.

The annual sales are about $40,000,000 per year and the company has 1,600 employees. It has had a research group for the last eight years which has been working mainly in the area of improving the company's products and particularly in substituting new materials for the conventional materials, for example the introduction of plastic components on bicycles and exercise machines and the development of plastic hockey sticks and moulded athletic footware. The research programme has been supported by PAIT grants and there has been an annual expenditure of about $75,000 total per year on research.

Two innovations are considered in this case; the use of adhesives to join components of bicycle frames and the development of a plastic hockey stick. These innovations are all substitutions of new materials (usually plastic) for traditional materials such as wood, metal or rubber. They are all presently underway and none has yet reached successful commercial exploitation.

In the first innovation, a PAIT grant was received to support the study of adhesive joints in bicycle frames. The general approach was to try various adhesives, preparing samples for aging and testing. An accelerated aging test was devised which consisted essentially of exposing test pieces in an autoclave to an atmosphere of air and moisture at various temperatures. This innovation is a technological push, there being a recognition of a need to improve the process of making the frames of bicycles without substantially changing the production method. The major information inputs were trade literature and attendances at conferences on high performance adhesive. Some use has been made of technology already developed for aircraft assembly.

The second innovation is the replacement of the traditional wooden hockey stick by a plastic version. The incentives are the growing scarcity and cost of white ash and hickory, the variability in wood quality and the inadequate performance of hockey sticks during "slap shots" in which the puck may be struck at speeds in excess of 100 m.p.h. The strength requirements placed on the present day hockey stick are sufficient to demand a more advanced technology in new materials and processes. The hockey stick has to be lightweight, tough, strong and stiff with material density and balance being critical. This project has been supported by a PAIT grant and would not have been possible otherwise.

Various modes of construction and materials are being considered and if the project is successful it should place the company in a competitive position as a leader in supplying high performance hockey sticks.

This company has several other interesting innovative ventures about which it is not appropriate to give details here.

CANADA GLAZED PAPERS LTD.

Canada Glazed Papers Ltd. located in Scarborough, Ontario has constituted the Coated Paper Division of Rolland Paper Co., Montreal since 1966. As such, it is a Canadian owned public company and employs about 200 persons. The major product is coated paper prepared from a base stock of bleached sulphate pulp paper and clay pigments and minerals bonded with latex, casein or other proprietary agents. Annual sales of coated papers are of the order of $1 million.

In 1966, a research group was established with the support of the Research Assistance Program. The activities of this group emphasized studies of Canadian clays and their use in coated papers, studies of the properties of, and synthesis of, polymeric adhesives, and studies of mechanisms inherent in the coating and drying of paper. The group was successful in acquiring expertise and equipment to measure a number of parameters important to coated paper which are available in only a very small number of Canadian laboratories. Significant progress was also made in the use of Canadian raw materials. Few innovations were, however, carried through to the production stage and after a period of about six years the research group was disbanded. Nevertheless, there is no doubt that the group did play a significant technical service function during its existence.

CONSUMERS' GLASS CO. LTD.

Consumers' Glass Co. Ltd. was founded in 1917 with the acquisition of the property and plant of the Premier Glass Co. Ltd. of Ville St. Pierre, Quebec. Growth of the company accelerated with the construction in 1954 of the Toronto glass container plant. The executive offices were moved from Montreal to the Toronto plant in 1961. The acquisition of another glass plant in 1967 gave Consumers' Glass the major share of glass production in eastern Canada. Increased demand led to the opening of another plant at Lavington, British Columbia in 1969. Four distribution centres have recently been opened across Canada in Vancouver, Calgary, Milton(Ont.) and Moncton(N.B.).

The major products of these plants are glass containers for the food, beverage, drug, chemical and cosmetic industries. The company did, however, in recognition of trends in packaging, diversify its holdings in the late 1960's to include plastic products.

The glass products division employs a total of some 2700 persons and the plastic molding and packaging divisions some 730 persons.

The glass and plastics packaging division are 80% Canadian owned, while the plastic molding plant is 50% Canadian owned.

Sales of the glass division were $63 million in 1972.

A separate research group was established in 1968 at the Toronto glass plant. Previous to this time a technical service group and the production staff team were responsible for both research and development, with emphasis on development. This work continues and consists largely of statistical experimentation using the plant production facilities.

The research group consisting of four professional staff and three technicians was established with the financial support of IRAP. The work was undertaken mainly in a well equipped laboratory, although plant facilities were also made available.

The company has a marketing group also located in Toronto. This group is responsible for evaluating the market potential for new products and actively seeks new opportunities. Members of this group also act as coordinators between customer, sales and production staff when a new item is produced. Ideas are accepted from any employee.

Major innovations occur relatively infrequently in the container glass industry. Examples of these are the production of lightweight non-returnable bottles and tempered lightweight bottles. The research group at Consumers' Glass was involved in the development of one new product - chemically treated glassware - in response to a market pull. This glassware for medicinal and other purposes is produced on line by treating the interior surface of containers with sulphur dioxide and sulphur trioxide gas in order to remove sodium ions from the surface as a soluble sodium sulphate. In addition, the research group under the leadership of Dr. L. Gevaert, was also highly successful in applying analytical techniques not normally encountered in the industry in order to solve customer problems. In this sort of situation the intangible benefits of increased customer satisfaction and confidence are hard to judge.

It should be noted that this group was recently disbanded on the advice of a management consultant group. Most of the personnel (2 professional and 3 technicians) were absorbed within the company indicating that management obviously saw the worth of continuing to employ these people.

FIBERGLAS CANADA LTD.

Fiberglas Canada Ltd. was established in Oshawa in 1941 in order to produce continuous filament glass. Subsequently in 1945-46 the production of fine glass fibre insulation material was initiated. This private company has expanded considerably and now has manufacturing plants in Sarnia, Montreal and Edmonton for the production of thermal and acoustical insulation materials, and in Guelph for the production of textile fibre and reinforcing fibre. The company head office is located in Toronto. In 1967 the company purchased, as a wholly owned subsidiary, Vermiculite Industries Ltd. which produces expanded vermiculite products for the construction industry. Fiberglas Canada Ltd. has recently entered the polyester resin field and a manufacturing plant is under construction in Elmira, Ontario. As a consequence of its diversification, the company is formally organized into three divisions: Textile, Reinforcements and Chemicals; Insulation Products; and Corporate Services which includes R & D. It employs a total of about 1500 persons. Total sales in 1973 amounted to about $75 million and it is expected that sales will reach $100 million in 1975.

The company established a formal R & D group in 1965 under Mr. K.P. Gladney with the financial support of the Industrial Research Assistance Program. A major new laboratory facility was completed in 1967 in Sarnia alongside the company plant. The R & D group has evolved and grown steadily and now consists of some 56 persons, including 15 professionals of which 6 have doctoral degrees. Part of the group is located in Guelph, Ontario and is concerned with textile and reinforcing products. Overall, about 3/4 of the group is development oriented and about 1/4 research oriented. The laboratories are very well equipped with instruments for chemical analysis, as well as for physical testing.

The main innovative efforts have been devoted to the development of improved and new insulation and reinforced composite materials, and the development of improved and new production methods. For example, the resin used to bond the glass fibres in the conventional insulation product was improved by the reduction of the phenol content and hence the phenolic effluent during the manufacturing process. Attempts were made to find a competitive inorganic insulation material that would withstand temperatures substantially higher than those allowable for the conventional resin bonded glass. More recently, major efforts have been devoted to the use of low-cost, high aspect ratio mica flakes as a reinforcing agent in plastics and to the development of a new continuous process for making conventional resin-bonded glass pipe insulation.

The idea of using mica, instead of glass, in polymers as a reinforcing agent arose outside the company. Professor R.T. Woodhams, Department of Chemical Engineering, University of Toronto, realized that high aspect ratio mica flakes could provide a low cost reinforcing agent and patented the concept. Fiberglas, with Dr. Woodhams as consultant, further developed the idea and determined, for example, that optimum mechanical properties were obtained by combining both mica and glass fibres with a polymer matrix. Government support for this program was obtained from the Defense Research Board.

A major process innovation which is expected to have far reaching consequences relates to the production of resin bonded glass fibre insulation products. For many years products have been manufactured by a labour intensive method in which glass fibre mat impregnated with uncured resin is batch cured into the appropriate shapes. The method is slow and costly because of the high manual component. The new process is based on a continuous processing concept which is being patented and which, it is felt, has the potential to revolutionize the production of insulation products on a world-wide basis. The idea originated in the Company's engineering group mainly as a response to a market pull for a similar but cheaper product.

The costs involved here are estimated to total $300,000, of which a rough breakdown would be $140,000 for R & D pilot development, $150,000 for product and engineering design and prototype construction, and the remaining $10,000 for patent costs. The project was financed entirely by company funds.

The Vice-President, Manufacturing acted as the prime mover in this case and as a consequence of his interest the innovation proceeded very rapidly.

The reward will be an economic advantage with the possibility of breaking into other markets which were unaccessible before.

FLUID POWER LTD.

This company is located in Rexdale, Ontario, having about 60 employees and annual sales of about 2 million dollars per year. It is a subsidiary of Garlock Inc. a large American company well known for the manufacture of seals and gaskets. The principal products are hydraulic and pneumatic cylinders, fluid power systems and presses. It has a small R & D group and laboratory which was initiated with IRAP support. The R & D group is in very close contact with production, engineering and marketing departments and there has been very beneficial direct participation by the research group in marketing. The principal thrust of the research program has been to improve the existing products by substituting reinforced plastics for metals in cylinder components and by devising new components for use in fluid power systems. A major accomplishment of the research group has been the development of more sophisticated design procedures for cylinders and cushions. This has been of substantial benefit to the company by placing it in a very favourable bidding position, particularly on large diameter and heavy duty cylinders for use in dams or lock gates. The former research manager, Mr. A. Van Eyken, was recently appointed Manager of Engineering and Research.

The research group has pursued a number of innovative programs in recent years with varying degrees of success. Two of the successful innovations are discussed here.

The first innovation was the use of glass fibre reinforced plastic (GFRP) as a replacement for metal in the manufacture of air cylinders. The background to this innovation was the serious copper shortage in 1969 when large diameter brass tubing which the company customarily used for air cylinders became almost unobtainable. A research program had been in progress on the substitution of plastic materials for metal in various cylinder components. It became apparent that the company could benefit considerably by immediately applying this expertise to the problems of substituting GFRP tubing for metal tubing in cylinder barrels of the 10 to 16 inch diameter range. This proved very successful and enabled the company to fill orders which otherwise could not have been completed. An interesting byproduct was that the self-lubricating properties of the molybdenum disulphide impregnated cylinder liner gave improved performance.

The substitution was not as simple as might appear. There were considerable difficulties in design and manufacture. The production department was not familiar with the properties of GFRP, machining this material was new to them, and there are certain design difficulties in the construction of these cylinders which are not encountered in metals which require careful analysis. These cylinders are now available in the standard line of air cylinders offered by the company.

The innovation was clearly a response to a market pull; however, it was made possible by the background which had already been built up in the R & D group by Dr. Davison who was convinced that there was a future in the substitution of plastic for metal components in such systems. Without IRAP support for the research group and without the championship of Dr. Davison the innovation would not have taken place. The key to success was the availability of a technically competent group who recognized a market opportunity and moved rapidly to exploit it.

The second innovation was the development of a custom designing service for hydraulic cushions, used in very demanding duties such as dams, lock gates and, in general, moving very heavy pieces of equipment.

The research group which at this time was under the direction of Mr. Van Eyken had been attempting to develop new cushioning devices and systems based on fluidic components. As they gained expertise in cushioning it was natural that they should be consulted on the existing company design procedures for cushions. Mr. Van Eyken was dissatisfied with the existing design methods and undertook a lengthy mathematical and experimental analysis of the process of cushioning a cylinder with a taper ram. As his analysis became more accurate and detailed, he became aware that he was now in a position to develop a computer program to custom design taper ram cushions in order to meet any particular load requirement. Most of his work was done on a computer terminal installed at Fluid Power Ltd.; however, some of the initial calculations were done on the computer at the University of Toronto.

The company happened to have purchased recently a numerically controlled lathe and Mr. Van Eyken recognized that it was possible to extend the cushion computer design to generate a computer punched tape which would manufacture the ram to the exact specifications. The principal success of this innovation is that it has placed the company in a position to bid confidently on a number of hydraulic cylinders for dams and lock gates where the cylinder is moving a mass of very high inertia often at high velocities and in which cushioning is a very critical part of the operation. There is no doubt that the Company would not now be in a position to bid on these jobs had this work not been done. It is difficult to place a dollar figure on the benefit which has accrued from this work. However, the company management is adamant that their new technical sophistication has placed them in an enviable position in obtaining new work involving cushioning.

This innovation is more a technology push than a market pull and illustrates the desirability of a company improving the technical understanding of its products and processes, even without seeing clearly in advance the benefits which will be derived. The innovation was not planned in advance nor were markets surveyed. It depended on Mr. Van Eyken's conviction that the company should have a better technical understanding of the cushioning process.

Fortunately this conviction was shared by the management and a substantial fraction of the IRAP funds was devoted to this topic.

M & T PRODUCTS OF CANADA LTD.

This company is a wholly-owned subsidiary of M & T Chemicals Inc., of Rahway, New Jersey, U.S.A. which is, in turn, a subsidiary of the American Can Co. M & T Chemicals Inc. (the official name of the parent company since 1960) was founded in 1908 as the Metal and Thermit Corporation to carry out detinning operations on tin plate scrap. Since that time it has become one of the foremost producers of inorganic tin chemicals (for the electroplating, ceramic and other industries), of organotin compounds, and a pioneer in developing uses for these compounds. M & T in the U.S.A. employs a research staff of about 200 people in several locations.

The Canadian operation, which started in Toronto in 1946 as United Chromium of Canada, became Metal and Thermit-United Chromium of Canada Ltd. in 1955 and M & T Products of Canada Ltd. in 1960.

Up to 1956, most of the products handled by the company were imported from the United States, although some compounding was done in the Toronto plant. In 1956 the company moved to a plant in Rexdale, Ontario and began manufacturing a wide range of chemical compounds for the electroplating industry. The manufacture of vinyl plastic protective coating compounds was also started at this time. In 1961, the company moved to a new plant in Hamilton which was equipped to carry out Canada's first recovery of tin from tin plate scrap arising from can manufacturing operations. Facilities were also installed to produce tin chemicals, particularly sodium and potassium stannates. Subsequently it doubled the size of its plant and built a research laboratory in a $500,000 expansion completed at the end of 1965.

Today, the company, with annual sales of about $7,000,000, employs about 75 persons including 6 professional, 14 technically trained, 23 hourly paid, and 32 sales and office personnel. Its operations may be considered under four major headings:

1. Detining or metals recovery.

2. Production of plating chemicals, as well as cleaning and buffing compounds for metals finishing processes.

3. Production of organotins and inorganic tin chemicals.

4. Compounding of vinyl-based coatings, organosols and plastisols.

There are no clear divisions in the company under these headings, although a separate sales force is used for the platings operation. Any market research needed is performed by the sales group.

As already indicated, the expansion completed in 1965 included a research laboratory. At that time the new laboratory was designed to provide facilities for both a research and development group operating under a grant from IRAP and the quality control and technical service group. However, it should be noted that the company does not presently have a separate research group. Innovative work is now being performed by two technicians. One of these, a prime mover and innovative person, spends about half of his time on development work and directs the activities of a technician from the previous research group. About 80% of the old laboratory is now being used for quality control and technical service work while 20% (about 200 square feet) is devoted to the development program. The laboratory is well-equipped for wet-chemical work but also includes two atomic absorption spectrophotometers, one previously acquired for the original research group and a new one subsequently purchased to satisfy the demand generated by the demonstrated usefulness of the first.

The company is actively involved with the local East Hamilton community in programs to keep effluent disposal under control. In addition, it plays an important role in the highly experimental and innovative (though difficulty-plagued) East Hamilton Solid Waste Reduction Unit (SWARU) by virtue of its unique expertise in the detinning of scrap metal. Thus, metal salvaged from the garbage processed in this unit, is sent to the company for detinning. With a world shortage of steel scrap and tin prices at high levels and increasing, this recycling is both ecologically and economically sound. Additional facilities for handling this scrap have now been installed but, because of SWARU's mechanical problems, the feed has been on a discontinuous basis and no economic evaluation of its impact on the company can yet be made.

M & T Products submitted several innovations of which we describe three by way of example.

One of the successful innovations resulted from the identification of a market problem and the application of some ingenuity on the part of the coatings formulators. The problem was to develop an orange coating for use on highway marker cones, made of PVC rather than metal, which would have high visibility, high impact strength at low temperatures and yet would not sag or soften at high temperatures. Moulds were heated and then dipped into a PVC resin and plasticizer bath. No patent position was taken, because the idea for the application of a plastisol came from the background of coatings experience available, as well as that developed by the U.S. research group. The innovation required only minor modifications to the existing plant and minor costs for start-up which were relatively difficult to isolate from normal operating costs of the coatings group in the plant. No government grant or other funding was received or solicited. Nevertheless, the new process has resulted in new sales of about $17,000 per year and may therefore be considered successful. It should perhaps be noted that technological success here was indicated by customer satisfaction with the product.

Examples of two technically successful but, so far, commercially unsuccessful innovations related to the recovery of tin tetrachloride follow. Each of these resulted in the issuance of a Canadian patent to the company. The inventors in each case were the research directors (Dr. Philip Rosenblum, Patent No. 916394 issued Dec. 12, 1972 on "Production of Tin Tetrachloride", and Dr. Peter D. Goulden, Patent No. 916892, issued Dec. 19, 1972 on "Production of Anhydrous Stannic Chloride from Aqueous Solution"). Dr. Goulden followed Dr. Rosenblum as director in 1967. The company received financial support for this research from the Industrial Research Assistance Program.

The convenience and desirability of recovering tin in the form of easily volatilized tin tetrachloride can readily be documented. However, the tin tetrachloride must be in the anhydrous form to be useful. The developments of the IRAP research group led to two different solutions to this problem.

In the first, stannic chloride was reacted in solution with potassium chloride to form potassium hexachlorostannate which was recovered as dry crystals by evaporation and crystallization. Subsequent pyrolysis of these crystals to form liquid anhydrous tin tetrachloride completed the process. In the second, aqueous solutions of tetravalent tin and chloride ion were mixed with oleum or sulphur trioxide with the water in the system. The lower phase consisted of anhydrous stannic chloride, which could be separated from the upper phase and readily recovered in the pure, completely anhydrous form.

Both of these innovations resulted from the scientific studies of the research group coupled with literature research and process development using the pilot plant facilities of the parent company. As evidenced by the issuance of the patents a high degree of inventiveness was exhibited and each depended upon the active involvement of the research director. Each process went through a pilot plant stage in Rahway, New Jersey. A very rough estimate of the cost of these innovations would be about $25,000 for the research stage and perhaps another $25,000 for the development of the processes. The awarding of an IRAP grant to the company was an essential element in this technological success. Unfortunately, commercial exploitation of these discoveries has yet to be achieved. The lack of success, so far, of these technical innovations has been attributed, for the Canadian market, to both poor overall economic considerations and insufficiency of the Canadian demand.

In the U.S.A. a market was available but these processes were not previously economically competitive with the direct chlorination method. Presently, however, the situation is being reviewed.

MADISON PROPERTIES LIMITED

This is a Canadian-owned, federally-incorporated corporation carrying on business in Mississauga, Ontario. The Madison Chemical Industries Division was formed in November 1973 to perfect and market a line of urethane solids, elastomers and foams. Originally it was anticipated that Madison would licence a formulation developed by the Ontario Research Foundation but it was decided instead to develop the company's own product line. Madison management thereupon embarked on an intensive program of research and development coupled with a number of preliminary marketing surveys. The market studies revealed that with the exception of some limited blending facilities producing rigid urethane foam, virtually no companies presently blend two-part thermosetting urethane systems in Canada and that there was a need for such a facility. Management believed that such a facility should be flexible enough to permit manufacture of a complete line of related products. The program of research and development led to the perfecting of a series of formulations which are both unique and inexpensive.

The innovation in this case is a series of modified polyurethane products custom designed for heavy duty uses, including rigid and flexible protective coatings, mouldings, groutings, encapsulants, and insulants. Each of Madison's various systems are supplied as an A and B liquid which are mixed in equal parts by volume. Depending on the formulation chosen, the two components interreact in a few seconds or minutes to form either a rigid solid (similar in appearance and hardness to the steering wheel of an automobile) or a flexible or elastomeric solid (i.e. a somewhat rubbery coating) or the combined ingredients expand and form a rigid foam (i.e. a lightweight cellular solid). Madison has conducted considerable research into the development of various cheap additives and fillers and has been successful in locating several materials which, in the course of the thermosetting reaction between the A & B components, actually become an integral part of the finished product. Madison is able to adjust formulations so as to provide end users with a wide choice of viscosities and setting times of the liquid components and a broad range of physical properties such as elasticity, hardness and strength in the finished products.

Because Madison was privately funded and because of the almost prohibitive expense of the research program described above, it was apparent to management that Madison must be selective in its marketing approach. Out of a score of potential applications which were considered, the one with the most immediately-exploitable market potential appeared to be the development of a sprayable rigid coating which could be applied over wood and metal. Such a product was finalized in mid-1974 and was immediately marketed to the trucking industry as a coating for the interior of transport trailers. This application, now known as Diamonite Sealcote, has been extremely successful and has been approved by the Department of Agriculture for food-carrying vehicles.

All of these systems are unique in that they can be formulated so as to ensure reliable curing under adverse moisture and temperature conditions.

In addition to the specialty products mentioned above, Madison is also now marketing a standard urethane insulating foam-in-place system. Early marketing efforts have been very successful.

All of Madison's systems can be applied using readily available two-component spray guns.

Madison has submitted to Underwriter's Laboratories an elastomeric material designed for use as a tank coating or tank lining and for any structure where it is sought to protect metal from corrosion. Early results indicate that the requisite tests will be successfully completed by April 1975. Madison's elastomeric materials are 20% cheaper than, and cure much more quickly than, coal tar epoxy which is the only other approved coating material for such purposes.

One of Madison's rigid solids has just been approved by Bell Canada as an encapsulant for cable splices and for cable plugging. Madison foams have been used successfully by Bell Canada as a protective shield around underground telephone cables. Madison's rigid solids are being successfully used by Slater Steel of Canada as a rock pole mount grouting.

In addition to the foregoing applications, all of which are being commercially exploited to the extent that working capital is available, Madison has also implemented or has plans to implement the following products: materials for making patterns and molds, industrial grouting compounds, undercoatings, waterproofings, synthetic truck floor boards, panels for the trucking industry, synthetic utility poles, marine coatings, pipe coatings and pipeline insulation.

The company has relied on selectivity in marketing to bring about its present profitable position but future growth will to some extent be limited by the lack of development and research funds and because of heavy demands for capital equipment.

Madison's management team consists of a lawyer as its full time chief executive officer, a Ph.D. in polymer chemistry as its head of research, an experienced sales manager and two fully-qualified technical representatives under whom work a team of applicators and sales agents. This closely-knit and highly competent group possesses a thorough knowledge of markets and products and has the management skills to further expand on the company's recent successes.

The company has considered applying for government assistance on several proposed projects but management hesitates to bear the expense of visits to Ottawa that it feels will be entailed and the time-consuming exercise of completing the necessary forms. The management is genuinely concerned that a small company, such as Madison, is at a disadvantage with respect to well-financed, large corporations which can afford the time and money required to prepare and negotiate proposals for support of R & D.

METEOROLOGICAL & ENVIRONMENTAL ENGINEERING CONSULTANTS (the MEP Co.)

This private company was formed in 1970 by a group of engineers and meteorologists. The group recognized that there was a need for industry to undertake its own studies of air quality around plants by performing source sampling and atmospheric dispersion studies. The members of the group brought to the company experience in meteorology, consulting practice, air quality management and atmospheric instrumentation. It has only a small full time professional team. However, it makes full use of consultants and employees of clients. In essence, the company provides a service which has become necessary as a result of the recent growing concern about environment quality.

This company was founded by Mr. M.S. Hirt, a meteorologist, to provide services to government and industry. It has conducted studies around smelters in the Gaspe Bay Peninsula, in Northern Quebec, in the Dominican Republic and at Sudbury. It has worked on assessing particulates and sulphur dioxide concentrations within the air pollution envelope of Metropolitan Toronto. Source sampling studies have been done for various companies in Ontario.

The innovation in this case is the provision of a new service rather than a new product. The individuals who formed this enterprise were previously employed mostly by the Federal Government and they recognized the need for this service and accordingly left Government employ to form this spin-off company. In doing so they were able to make full use of the expertise which they had gained while in government service. This has been achieved without any conflict between the company and the Federal Government.

One of the principals was aware of a small radiosonde package unit developed by the Atmosphere Environment Service which is capable of producing reliable data and costs only about $6.00/package compared with the present $40-60. These can be used on a routine basis to assess atmospheric stability. The company hopes to manufacture and market these units making full use of the technology developed within the Federal agency but not exploited therein.

This is an example of the small group of Canadian professionals recognizing an opportunity and taking the necessary risks and initiative to form an independent company to exploit the opportunity. This type of enterprise merits support in that it provides Canadian expertise to solve Canadian problems and generates challenging employment opportunities for Canadian professionals. Had the company not existed there is little doubt that the services would have been provided by U.S. companies in this field. Thus the benefit of this innovation is not in providing a better or less expensive service, but the less tangible and harder to value consequence of Canadians rather than Americans providing the service. If experience here leads to future innovations, then further benefits may accrue to Canada.

MILLTRONICS LTD.

Milltronics Ltd. was established as a private company in 1954 by D. Weston for the purpose of designing control systems for the Aerofall mill. While it was initially located in Toronto, it was relocated to Peterborough, Ontario in 1956 and subsequently purchased by Union Carbide of Canada. In 1966 Milltronics Ltd. became the wholly owned subsidiary of Canadian Corporate Management Co. Ltd. The company's products have increased in number and include, for example, in addition to custom designed control systems, motion failure alarms, and ultrasonic bin level sensors. The number of employees increased from the original 3 or 4 to about 50 in 1967 and 75 in 1972 at which time the company was reorganized and systems engineering de-emphasized and a subsidiary company in Watertown, New York State, phased out. With a new emphasis on manufacturing, including a major contract for the production of pocket calculators, the number of employees quickly rose to over 100 in 1973.

In order to augment its longer term innovative capability the company established a research group and facilities in 1967. Financial support was obtained from IRAP. The main emphasis in the research program was the development of new sensing elements to be coupled to custom electronic equipment; in particular, a sensing element for the continuous determination of particle size in slurries received much emphasis and the approach to this problem will be subsequently described. The research group as a formal entity was disbanded in 1972 and key personnel attached to other sections. Innovative work continues to be carried out in the development group. The company could not afford to maintain a research group concentrating on longer term projects without significant government support.

At the present time, the major divisions of the company are sales, production, and engineering. Each of these divisions has a manager who reports in the first instance to the Manager of Operations who is in turn responsible to the General Manager, John Gemmell. The General Manager is responsible to Canadian Corporate Management.

The company does not have a formal market research group. In the first instance company personnel will attempt to forecast the market for a new product and if this appears promising then the company will retain a market research organization in order to produce an unbiased market assessment. There is really no formal mechanism for the consideration of new ideas within the company. The Manager of Development is responsible for assessing the technical viability of a new potential product. The Manager of Production and the Manager of Sales would also have a hand in assessing the cost of production of a product and the market potential.

John Gemmell emphasizes that in order to increase business volume it is necessary to: (1) sell more of the established products, either through direct sales or through representatives who are backed up by the company; (2) represent other companies and sell their products, for example, turbidity meters manufactured by Great Lakes Instruments Ltd., (3) acquire other companies or product lines; (4) develop new products; and (5) obtain contracts to manufacture items, such as the pocket calculators.

Market research is recognized to be a most critical aspect of innovation.

Two innovations which have been selected for study are the motion failure alarm and the on-stream continuous particle size analyzer.

It is clear that the source for the idea of the motion failure alarm was a customer who was anxious to have a remote reading alarm. The sensing element is an induction coil. The innovation can be classified as a combined technological push and a market pull. The initial product sold well and following an improvement the annual sales increased by a factor of approximately four. This development has taken place over 3 to 4 years. There have been no significant outside information inputs into this development program. The required technology appears to have existed within the company. As a consequence, no adaptation of present technology is really required and the impact on production methods has also been minor. The cost of the innovation was relatively small. No patents were involved in this innovation and no government funding was involved either. The rewards of the innovation are obviously increased sales; several new jobs have been created, including those in another company which manufactures the induction coils.

The on-stream particle size analyzer, as yet, is an unproven innovation. The source of the idea was customers who indicated that the availability of a continuous on-stream particle size analyzer would greatly help in process control. A research project in order to fulfill this apparent need was undertaken with the support of IRAP starting in 1967. After the research group looked at a large number of possibilities, a patented device was thought to provide a good chance of success and the rights to manufacture and sell this device were acquired for North and South America. It was understood by the licensor that Milltronics would undertake further substantial development work. The fact that there is a market demand for this device and that technology existed in the form of published papers and a patent suggests that this particular device or innovation if it is successful could be characterized as both a technological push and a market pull. Over a period of three or four years the company has conducted applied research and prototype development of this device again largely under its own auspices without substantial information input from outside other than from the license holder in the United Kingdom.

A fair degree of adaption of the company's previous technology has been required since the instrument utilizes beta-radiation in order to measure the concentration of a solid in a slurry. Since the flow characteristics of the slurry within the instrument are of paramount importance, a new area of expertise outside that of the electronics, namely fluid mechanics, became important. Furthermore, one of the major problems involved in the development of this instrument is the selection of materials such as Nylon and polypropylene. Not only is abrasive wear important here, but the chemical interaction between the flowing mixture and the polymer material has been important in that aging of the polymer material with time has led to a change in the absorptivity of beta-radiation with time. This resulted in an apparent drift in the particle size distribution.

There will be a significant impact on production methods because of this innovation. The cost of the R & D for this innovation has been relatively high and so far very few units have been sold. The present status of the project is such that prototype units are in the process of being installed in two other locations. However, the mood of the industry seems to be to wait and see how successful these installations are. A patent was involved in this case and the item is being manufactured and sold under a license agreement. Support from IRAP was available over a period of 5½ years. There is no doubt that this program could not have been sustained without this government financing; on the other hand, the company is not yet convinced that even the cost that it has carried during this program will be returned by sales of the developed product.

NACHURS PLANT FOOD COMPANY LTD.

The company was founded about 30 years ago by Mr. Ben Peterson of Marion, Ohio, and when he died in 1962, his estate sold the company to a consortium of former employees and others who had run the Canadian branch of the company in London, Ontario. Nachurs International Ltd. the parent company, was then incorporated as a private company in 1963 as McLachlan Associates London Ltd. In 1964 the parent's name was changed to Nachurs International Co. Ltd. and by supplementary letters patent dated 1967 various changes in the parent's capital structure were effected and the parent was converted into a public company. The parent's name was changed to its present form in 1967. The Head Office was located in London, Ontario, until 1972, but was moved to Marion, Ohio, because about 90% of its market is in the Mid-west United States. The parent company, Nachurs International, operates a nearly wholly owned subsidiary Nachurs Plant Food Co. in Marion, Ohio, but the company is at present controlled in Canada, and the majority of the shareholders are Canadian. At one time the company produced a moth proofing material called Berlou, but the major product lines at present are a liquid fertilizer and a cattle food supplement.

The company at present has sales of about $15,000,000 which have risen from a figure of about $1,700,000 in 1965. The President of the company is Mr. Allen Farrow, a Canadian who now resides permanently in Marion, Ohio. The company is essentially a marketing company employing many salesmen who sell direct to the farmer. The company provides a soil testing service and on the basis of the soil tests, recommendations as to the nutrients and supplementary trace materials required are made to the farmer. The company supplies equipment for the farmer to store the fertilizer. The manufacturing facilities are not extensive, and the manufacturing process is not complicated. The company has no research group although two chemists are responsible for quality control and for minor modifications to the formula when required. The company has no development group, nor does it have a market research group. Developments within the company are based on "grass roots" contacts between the salesmen, farmers and the management within the company. The mechanism within the company for consideration of new ideas is typical of a small company; if the President is attracted to an idea, he will exert every effort to have the idea developed and implemented in the field.

The successful technological innovation of the company is based on the one very superior grade of liquid fertilizer which is manufactured from orthophosphoric acid, caustic potash, urea, ammonia, water and miscellaneous trace elements as well as ammonium thiosulphate. This solution has a remarkably high solubility and a nearly neutral pH of 7. Its use in conjunction with dry mix fertilizers has resulted in significantly higher yields because it can be applied under conditions which are often inappropriate for the use of dry mix fertilizer and because it is readily available to the plant and can result in a rapid initial growth after which the plant is more able to utilize slower release dry mix fertilizers.

The solution was discovered by an employee with a Ph.D. in agricultural chemistry. The idea was exploited initially by Mr. Peterson who began to market the fertilizer solution in drug stores as a plant food for very small scale growers. The innovation can be classified as a science push, or possibly a technological push, since it was unexpected that such a high concentration fertilizer could be prepared in solution form. Subsequent increases in sales and a development of the material for general use took place during general growth within the industry. Nachurs seems to have been significantly more successful than other small liquid fertilizer companies, possibly because of unique marketing methods and their soil analysis service.

At times in the development of the program, various trace materials were added to the fertilizer solution. Such modifications served to make an impact on customers. It is important, however, to point out that many farmers have repeated their orders year after year, and these repeat orders can only be based on successful results. One of the early requirements in the production of the fertilizer was a system of quality control in order to overcome the considerable difficulties involved in manufacturing a solution in which the composition was critical. If the percentage of anyone of the ingredients is allowed to vary by more than a few tenths of 1%, crystallization occurs. The original production team did not have one university graduate in science or technology. The management, therefore, approached Chemical Engineering Research Consultants Ltd. for recommendations regarding techniques and methods which would ensure a consistent and reproducible crystal-free product.

Drs. Vanecek and Smith undertook a thorough study of the product, determined the narrow composite range of solubility of the eutectic being studied, and proposed a series of analytical procedures together with simplified tables which were used by the manufacturing group to produce crystal-free fertilizer. Vanecek and Smith showed the Canadian operation how to prepare trace elements solutions using chelating agents to prevent the formation of trace amounts of hydroxyapatites, which were rapidly eroding pipelines and stainless steel valves within the manufacturing plant. Drs. Smith and Vanecek also advised the company on soil testing and other methods of analysis. It is probable that this type of operation needs no more technical advice than that provided by consultants on a casual basis.

New product development has not been pursued by the company aggressively, but an aggressive program is being pursued to market the product as a cattle feed supplement. The cost of quality control procedures and manufacturing changes required to reach sales of $17,000,000 a year are minimal compared to the value of the product. The product was never patented and has been copied by competitors. No government funding was even applied for. The success of the fertilizer solution most certainly depended on entrepreneur promoters. Mr. McLachlan is a person of great enthusiasm and personal energy. He was responsible for the creation of the company as a large scale marketing force. Subsequently, Mr. Allen Farrow replaced Mr. McLachlin, and he has shown skill and good judgement in pursuing markets and minor technical developments which can be used to assist in selling the product.

The success of the company, in this case without a research group, seems to have depended on the entrepreneurial skills and energy of a very small number of people. The innovation yielded a product with highly marketable characteristics, that led to early growth of the company. However, since the product has been copied by several competitors, the continued success of the company must be attributed largely to non-technical factors such as entrepreneurial skill and energy. The beneficiaries of the innovation include the company, the competitors, and the farmers.

NASH AND HARRISON LTD./LEIGH CONTROLS LTD.

This company was established in Ottawa by Paul Nash, in 1958, to manufacture and sell a photo-electronic defect detecting machine designed by him. The number of possible applications of this type of machine has been steadily expanded since then, and sales now amount to nearly one million dollars per annum.

In 1971 the company was acquired by Leigh Instruments, another, much larger, all-Canadian company. (Total sales for Leigh Instruments were $25 million in 1972.) In 1973, Nash and Harrison, and Leigh Controls of Farmingdale, N.Y. which were both Leigh subsidiaries, and both engaged in web inspection, consolidated their research and development and production operations in Ottawa. At the same time, the company changed its name to Leigh Controls Ltd. The Ottawa plant now employs about 31 people.

The research group has a staff of six engineers and technicians, and receives support from the Industrial Research Assistance Program. The group is constantly seeking and evaluating possible new applications for its product. It also examines new flaw detection methods, with the aim of improving the speed and sensitivity of the machine, and its tolerance for severe operating conditions. The laboratories are equipped with a spectrophotometer, and electronics testing equipment, and have a machine shop for the building of prototypes.

Innovation is felt to play a major part in the survival of the company. The high sensitivity flaw detection machine (model 131) has undergone considerable development and improvement recently in response to market pressures, and because of a desire within the company to improve the technology involved. The developments only required minor changes in tooling, but considerable changes in production methods were needed. These developments were strongly supported by the company owner at the time but most of the changes were introduced by the initiative of the research director. IRAP support was instrumental in bringing about the changes. R & D and design costs came to about $150,000. Other costs were very small. The main reward was that the company was able to continue to operate.

Research and development has more recently been directed towards the production of new types of inspection equipment, and several new machines have just reached the marketing stage.

A new inspection system, using T.V., originated in the R & D section, as a result of seeing new possible detection methods advertised in the literature. R & D and design costs came to about $60,000 at the time of writing and were supported by IRAP.

A printed card inspection system originated from enquiries by a greetings card manufacturer. R & D and design costs again were about $60,000 and were supported by IRAP.

A relatively low sensitivity inspection system originated from competition in the market place, required relatively little research and development, so that the total cost of marketing development to the conceptual stage is estimated at $5,000. IRAP support was not important in this development.

In the cases cited above the costs quoted do not include those necessary to bring the product to production which include costs for drawings, tooling, methods, inventory, etc.

The company is finding that good management is one of the most important prerequisites for successful innovation in a company of this size. Ideas generated by research have to be critically examined for profitability in the market place, and the time expended by the research staff has to be carefully allocated so that little time is spent in unprofitable areas. Each member of the research staff has to operate very efficiently, because in a small operation, the amount of financial support available for research and development is very limited.

R-B FILTERS LTD./JOHNS-MANVILLE CO. LTD.

R-B Filters Ltd. was founded in 1970 for the purpose of manufacturing synthetic polymeric membrane filters in Canada. The founders had previously been employed in the production of membrane filters in the U.S.A. but they believed that they could form their own company to make a unique contribution in this area. These filters are primarily used for filtration of water samples, the removal of microorganisms for public health analysis, and as electrodialysis membranes for separating blood components and their identification in hospital diagnostic procedures. They can also be used in the separation of particulate matter from air. The company offers a wide variety of such filters. The major financing came from a venture capital company.
The company obtained a PAIT grant in 1971 and later an IRAP grant which enabled it to manufacture and market these membranes successfully. However, due to a number of technical difficulties the cash flow to the company was not sufficient to satisfy the venture capital company and R-B Filters was forced into receivership. It was sold to Johns-Manville Ltd. The operations have now been reorganized and this enterprise is now part of the Johns-Manville Corporation of the U.S. The innovation planned by the two founders has thus been entirely successful in that their product is being marketed although the corporate structure is not quite what they had intended.

This innovation consists of a variety of membrane filters and auxiliary equipment. These filters have pore sizes in the range of 0.1 to 5 microns. They are based on cellulosics (cellulose acetate or cellulose nitrate).

The success of the venture depended entirely on the drive of the founders. It took the separate contributions of all three founders, F.G. Rott, C.T. Badenhop, and F.E. Coombs to achieve the gestation and birth of the company. Each played a critical role at a critical time. The personalities of those involved played a very significant role in providing impetus, technical know-how, understanding of the market, and in making the company function.

The enterprise at one stage was very close to failure. This is now attributed to the nature of the arrangement between R-B Filters and a venture capital company. The venture company had both equity and loans which gave it an unusual measure of control. Essentially, it was providing working capital. The venture capital company was apparently oriented towards a quick return on investment, and its attitude to the day-to-day losses being experienced in the early years was very unhealthy, stifling to the people on the job and had a general negative effect on the morale of the entire operation. The action calling their loan was a reflection of the desire for a quick return on their investment and it put R-B Filters out of business.

What was required in this situation was a source of funds which was prepared to wait a longer period of time. This is probably possible only with the association of a very large corporation for whom this level of investment represents a minor item. This is of course the current situation with Johns-Manville who purchased the company and who now control it.

It is perhaps unfortunate that ownership of the company has been transferred from Canada to the United States; however, the company still functions in Canada. There was a distinct possibility that it might have been removed from the country. This raises questions about whether the regulations regarding PAIT and IRAP grants have enough clout to prevent such removal, or alternatively to recover the funds from the foreign purchaser of the technology developed with their type of support.

SURPASS CHEMICALS LTD.

The company was founded in 1954 as Surpass Petrochemicals and reorganized into its present form in 1962. It is a Canadian public company with shares listed on the Toronto Stock Exchange. It manufactures and sells lubricants and lubricant additives which are mostly used in internal combustion engine oils for sludge dispersal, rust prevention and oxidation inhibition. Sales are primarily to large oil companies which use these additives to formulate their lubricant additive packages. The product thus requires a highly technically oriented sales effort. The company is located in West Hill and Scarborough, Ontario, has about 55 employees and sales of about $2.5 million annually. Its research group and laboratory have received IRAP support. Manufacturing facilities consist essentially of a number of multi-purpose batch processing units which allow flexible operation with a variety of products. The research group has a pilot plant where larger scale experiments can be conducted and has facilities for organic synthesis, analysis, and testing of additives for lubricant formulations.

Seven innovations were identified as having emerged from the research group in this company, most of these being substantial process improvements or new manufacturing processes which in some cases also involved new product compositions. Rather than to go into the chemical and physical details of each innovation, the characteristics of all seven are reviewed in total.

The specialty products, complex organometallic compounds, are synthesized and dispersed in oils, there being careful control over all operations. The physical chemistry of these processes is often complex and the introduction of a new process or product presents a considerable technical, scientific, and marketing challenge.

The source of the innovative idea varied considerably, arising from customer, research group activities, direct applications of company knowledge and experience, patent literature and the recognition that a cheaper raw material could be used or superior performance obtained.

The incentive for the ideas was almost equally a science or technology push based on an improved understanding and utilization of the underlying chemistry and physics, and a market pull or defensive response to a market situation arising from a shift of customer interest from existing to other, preferred products. The scientific, trade and patent literature was of significant value in the generation of these innovations; however, the presence of the research and development group in the company has been the single most important factor in consummating these innovations.

Patents have not played a very important role although some patent applications are being pursued.

Government funding through the Industrial Research Assistance Program has been invaluable.

One innovation, a process improvement for over-based calcium sulphonate production, has contributed in a major way to the commercial success of the company in the last few years when prices were low and competition intense by permitting more efficient and reliable production of this most important additive. Two other innovations, both involving new processes, are in commercial use and contribute increasingly to current sales. There is little doubt that to survive this company needs to keep abreast of modern lubricant additive technology. The presence of the research and development group is critical to the company's success. It is encouraging that this is recognized by the management.

Several of the innovations have not achieved commercial exploitation and are essentially in abeyance at present. It is expected that conditions may change to provide a climate suitable for their exploitation. Other different applications for some products may be possible, but there exists no mechanism within the company for finding such uses and the markets for them.

TORONTO COPPERSMITHING CO. LTD.

The company was founded in 1929 with its main activity the fabrication of corrosion-resistant equipment in copper for the process industries. It expanded later to fabricate in nickel, stainless steel, titanium, tantalum, monel and even zirconium. The company is privately owned and has a staff of about 60 consisting of about 30 in the workshop, 4 secretarial staff, and 25 technical staff of whom 6 are professional engineers or equivalent. The annual sales are in the region of $2,000,000. It is located in Scarborough, Ontario. Being relatively small the company has no rigid departmental organization although there are production, marketing and design groups. The company is also divided according to product divisions of blending, agitation, filtration, thermal processing, general manufacturing and contract engineering. This latter division (Torco Engineering) is recent and offers contract engineering services making the skills of Toronto Coppersmithing personnel available to those who do not necessarily wish to purchase equipment. Each division has one or more technical people responsible for promoting sales in that division.

An R & D group was established with IRAP support. The group has continued after support ended although the individuals now have duties involving other aspects of company business. For example, Dr. Ho, the Research Manager, is responsible for the sale of heat exchangers, another engineer for blending equipment and another for filtration. The laboratories are equipped for conventional chemical engineering studies and also for demonstration and processing of customer samples. This has greatly assisted sales. An outgrowth of the research effort has been the computerizing of design, costing and other company activities, it having recently obtained its own computer, the first of its type to be installed in Canada.

Prior to the start-up of a research group supported by an NRC IRAP grant in 1966 the company was essentially a fabricating organization which would take a customer's drawing and produce from it the final article. The company did comparatively little design. In recent years it has changed in emphasis from fabrication to design and engineering. The creation of the Torco Division heralds an even greater move in this direction through the provision of not only design and engineering services associated with process equipment, but through the provision of these services in areas unrelated to the process equipment. Essentially, the company will now serve the customer who has a problem rather than the customer with a drawing. The presence of the research group played an important role in this change.

In many industrial innovation studies it is possible to identify a discrete product or service which orginated in a research group, was developed, and eventually marketed. The Toronto Coppersmithing experience is not of this type, since the company does not normally supply standard items of equipment on an off-the-shelf basis. Rather, the company supplies process equipment on a custom basis for specific industrial needs. Each piece of equipment ordered is one component of a plant and it must be custom designed to meet the conditions of that plant. This situation makes market surveys extremely difficult, if not impossible. Much of the research effort has thus been devoted to improving design procedures and developing a more detailed understanding of the performance of the equipment.

It is interesting to examine one research group project, the development of a continuous solids blender. This innovation started with an idea from the former research director, Dr. Scholtz, who believed that there was an opportunity to sell equipment of this type which was not then available on the market. This was developed, patented and named the "Conblend".

Most solids blending is done on a batch basis. The ingredients are added to a blender and then mixed for a time sufficient to achieve the required degree of homogeneity. Dr. Scholtz believed that it may be preferable to blend continuously by feeding solids streams into a device which would discharge a product of the required degree of homogeneity. There are significant savings in labour costs by operating such equipment continuously. Little market research was done prior to the research program, indeed it is doubtful if market research in such an area is meaningful. The system was successfully demonstrated in the laboratory but to date it has not been sold as a commercial item. The major difficulty appears to lie in finding the first industrial customer for such an item.

The research on continuous blending was not wasted since it gave the company considerable expertise in this area and it helped enormously with sales of related blending equipment such as ribbon blenders and double cone blenders. The presence of a research group which can talk authoritatively about the performance of such equipment is a great asset to sales. By taking steps to involve the research people directly in product sales a very healthy and profitable working environment has been achieved at Toronto Coppersmithing.

WIX CORPORATION LTD.

This Toronto company was incorporated in 1942, is public and listed on the Toronto Stock Exchange, 40% of the stock being held by Wix Corporation, Gastonia, North Carolina. The company has four major divisions: automotive filter manufacturing; automotive filter sales; aviation and industrial manufacturing;and sales and the R & D department. Annual sales are about $7,000,000 and there are about 430 employees. The early research group consisted of about 6 individuals and has a well equipped laboratory. It has received IRAP support. The research group has provided general assistance to the company in improving products, substituting new materials and in developing rapid cyclic filtration systems and rapid cyclic immiscible phase coalescence and separation systems. These cyclic systems were pioneered in the Chemical Engineering Department at the University of Toronto.

Three innovations were identified in this company: (i) rapid cyclic immiscible phase coalescence and separation, (ii) rapid cyclic filtration and (iii) materials substitutions.

The first two ideas arose from studies at the University of Toronto on rapid cyclic ion exchange systems. The idea provided a technological push which was coupled to a market pull in the form of knowledge available in the company on the need for coalescing and separating equipment for treating liquid mixtures and on the need for filtration equipment. In combination, these provided the driving force for the innovations.

Both efforts required considerable inventiveness by the R & D staff, since the equipment for such operations did not previously exist and the theoretical aspects of the situation were only poorly understood. In both cases, government funding was essential. Patents have been applied for. The success of both ventures has depended on a very capable technical group who could make and test the various items of equipment.

A major contribution of the R & D group has been in the third area, the substitution of new materials in the manufacturing of existing products. These include adhesives, surface treatment of gasoline filters and the introduction of various plastic components. It is difficult to quantify the financial rewards; however, it is clear that these innovations have contributed to the retention of full production and employment in times of a poor market and tough competition, probably increased sales, the addition of new facilities and employees, and an enhanced reputation in the general field of air and oil filters.

Another very important contribution of the research group has been in providing general engineering assistance to the company. Often the engineering or production staff present their problems to the research group. A solution is often forthcoming. The general atmosphere of the company encourages the adoption of improved procedures thus facilitating trials and early adoption of improvements. The availability of a viable research group and consultants has enabled a multitude of small day-to-day engineering problems to be tackled, some of which have resulted in dramatic improvements to production processes.

The company's president has taken an active interest in the group and has encouraged it to take objective views of the manufacturing operations as well as of the fundamental mechanisms governing operation of actual and proposed products. Much of the success of the group is due to his and the management's encouragement.

The research manager is a dynamic, forceful individual, but with a warm sympathy for his colleagues. He began with the group as a fresh Ph.D. from the Department of Chemical Engineering at the University of Toronto, and has succeeded in making himself a most valued member of the management team.

WORTHINGTON (CANADA) LTD.

Worthington (Canada) Ltd. was founded in 1955. Later the parent company Worthington Corporation purchased Montreal Locomotive Works and, as part of the transaction, Worthington (Canada) became a subsidiary of MLW. Worthington (Canada) Ltd. manufactures and resells valves, compressors and centrifugal pumps. Pumps for the handling of sewage, paper stock, and abrasive slurries, as well as more conventional systems, constitute the main fraction of sales. The company is also part of the Worthington Pump International group which is owned by Studebaker-Worthington Corporation, U.S.A.

The annual sales of Worthington (Canada) Ltd. are about $11 million and the company employs about 220 persons. The head office is located in Toronto and the general offices and plant in Brantford, Ontario.

Traditionally, the development group has been responsible for the introduction of new products. For example, the paper stock and slurry pumps were largely piloted by this group during the period 1964-1972. Projects such as these were undertaken after comprehensive market analysis showed that there was a significant demand for the ultimate products.

In 1965 a research program was initiated with IRAP support and emphasis was placed on studies of inducers for centrifugal pumps, hydraulic transport of particulate solids and materials for pump construction.

The inducer studies were technically interesting and the results have been applied to the design of small chemical process pumps. It is anticipated that modifications will also be made to larger pumps for applications in which suction capability is a problem.

The hydraulic transport and materials studies were undertaken largely to resolve uncertainties that existed in the technology relating to the design, construction and application of the new slurry pumps. In this way much of the research effort contributed indirectly to the success of the new product or could lead to improvements in the product.

The slurry pump was developed during the period 1968-72 in response to a market demand and followed the successful introduction of paper stock pumps in 1968, and a modification in 1971 both of which were very successful. Financial support was available from PAIT for the slurry pump project.

The main sources of information for the development of the slurry pump were the scientific and trade literature, prior related experience, and knowledge gained from prototype testing. Two types were developed - metal lined and rubber lined. The linings are abrasion resistant in order to reduce or eliminate wear by the slurries.

Slurry pumps have been available for many years from other manufacturers. Worthington's analysis of the market suggested that there was room for another manufacturer, especially one that had built up a good reputation for heavy duty pumps for related applications.

Substantial changes were required in production methods for pump components. Whereas machining of metal components was possible for all previous pumps, neither the hard metal nor rubber components could be machined in the manufacture of the slurry pumps. Casting and molding operations replaced machining operations. In short, new production techniques were required by the materials selected.

The company's confidence was justified in that sales of slurry pumps amounting to almost $1 million were made in the first year of production.

It is clear that without the developments leading to new products over the past decade the company's activities would otherwise have been severely curtailed by the corporate strategy of transferring the manufacture and marketing of valves to another Canadian company in the group. This is a good example of a company where present sales are based largely on products specifically developed over the last ten years.

DISCUSSION

1. General Comments

At the start of this study it had been hoped that quantitative data would be obtained on matters such as company expenditure on research and development, production, start-up and marketing for the various innovations. This proved to be impossible for two reasons. First, in most cases the companies themselves did not have the cost data available and second, where such data were available, the companies were naturally reluctant to divulge data which could be of advantage to a competitor.

It was also exceedingly difficult to obtain data on the profitability of the innovations. It would be very satisfying to be able to state that a given investment in research and development yielded a particular return in profits, extra production and new jobs. The situation, however, is usually very much more complex. During the period of the study, Canadian industry underwent a severe recession. Some of the companies regarded themselves as being fortunate in surviving during this period and attributed their survival in part to the innovations. In many cases, benefits accrued to the company which are difficult to quantify. For example, the hydraulic cushioning research program at Fluid Power Ltd. undoubtedly contributed to the company obtaining contracts to manufacture large hydraulic cylinders, but it is impossible to determine the proportion of sales attributable to the research and hence the financial return. Often the expertise which is gained in the company through attempting an unsuccessful innovation is of substantial benefit to the company in improving its existing products and in providing a technically competent group to back up the sales personnel and convince a prospective buyer that he is indeed purchasing a service or component from a technically able and reliable source. Notable examples were found in Consumers Glass, Fluid Power, Toronto Coppersmithing and Wix.

We have extracted and presented as much quantitative data as possible from the case studies. As indicated in the introduction, however, we do not expect that precise quantitative relationships among these data can be used to explain a large portion of the variation in successful innovation. Innovation is not like a production process where outcome can be predicted with great accuracy from knowledge of the input. There is clearly a large random element to innovation depending upon a conjunction of forces which are only dimly understood.

This is not to say however, that we are completely ignorant about determinants of success in the innovative process. We can identify a number of factors which seem to be present in cases of successful innovation. These factors are therefore influential in innovation, even if they are not determinant in a precise sense. In short we are not looking for factors which will ensure that a particular invention takes place. Rather we are attempting to determine what factors contribute to a climate in which the probability of successful innovation is higher than would otherwise be the case.

We find that innovation is a product of people, their ambitions and their environment which defies quantification in terms of dollars or man-hours. Insight is a more appropriate analytical tool than statistics.

2. The Companies

Of the 18 companies, three, viz. Fiberglas, Consumers Glass and CCM, can be classified as reasonably large operations with annual sales in the range 40 to 75 million dollars, with the remaining fifteen being either small or representing an identifiable subsidiary of a large company. The "small" companies averaged 47 employees and had average annual sales of 3 to 4 million dollars.

The average research and development group consisted of 4 to 5 people, usually 2 scientists or engineers and some technicians. The person in charge of the R & D group usually had a Master's or Doctor's degree or industrial research experience elsewhere. Most smaller companies had the advantage of close personal communication between the R & D personnel and the management. Formal meetings were often arranged at about monthly intervals to discuss progress and to terminate and initiate projects. Consultants were often present at these meetings. Where management tended to remain more distant from the R & D group and showed little interest or concern a real need was felt for better communication. Each side should feel the need for the other to be aware of and sympathetic to its perspective. The happiest and most productive environment occurred when management frequently confirmed its belief that the R & D effort was valuable and was contributing to the welfare of the company and where the R & D group showed willingness to change its program to meet company objectives and assist in other company functions, such as sales or technical service. Such environments were found in about two thirds of the companies. Although it is difficult to provide quantitative verification we suspect that a high research management capability in a company is reflected in faster and more effective innovation.

Several of the companies were entrepreneurial in nature, the founder being the president and principal shareholder. He took a very direct personal interest in the R & D activities and normally spent considerable time in the laboratory.

There was usually no formal mechanism for processing new ideas or suggestions, nor was there any detailed formal accounting kept of time spent on various projects. Overall expenditures were very closely scrutinized, although at times it was difficult to ascertain how much was being devoted to a specific project, especially when there were several projects and the R & D group also engaged in other activities such as technical service or visits to customers.

It was clear that in a larger company, the R & D group is more likely to be isolated from the commercial or marketing activity than in a small company. The danger here is that the approaches followed to meet established objectives are likely to be longer term, more esoteric, and more difficult to implement. While a very large company can possibly afford an "ivory tower" with individuals working in intellectual isolation, this is certainly not possible in companies of the type studied here.

Only five of the companies had specialists in market analysis on their staff; most relied on assessments by the senior executive, the sales manager, and a market consultant.

3. The Innovations

A total of 60 innovations or potential innovations were identified within the 18 companies. In most instances, a company described typical innovations only and did not even attempt to list all innovations within its experience. Other companies, however, more completely identified their innovations. Of these innovations, half (29) were described as having been profitable to the company and the remainder had been unsuccessful, or were being held in abeyance for some change in market conditions, or were still in some further stage of development.

The feeling was that there was no shortage of ideas for innovation, rather the problem was to identify at an early stage those ideas which would prove to be profitable. This is in accord with the findings of recent studies of the characteristics of those scientists who are generally regarded as being very creative and successful. Their principal characteristic was not necessarily the generation of new ideas but rather the ability to separate the good ideas from the bad and pursue the good ideas to completion.

Some 70% of the ideas were generated within the company, usually by an individual such as the research manager or owner, who was familiar with the company technology and capabilities, and the needs of the market. Fifteen percent of the ideas came from customers, 10% from university professors or consultants, and 5% from government sources, patent literature or material suppliers. These figures should be regarded with some scepticism since the individual who had the original idea may often have been influenced by information from others.

Estimates have been made by the U.S. Department of Commerce Panel on Innovation and Invention which have been quoted, for example, by Myers and Marquis (1969) and which suggest that the R & D process may represent 5-10%, of the cost of innovation, engineering and designing the product 10-20%, tooling and manufacturing engineering 40-60%, manufacturing start-up 5-15%, and marketing 10-25%. Although we are unable to provide similar data for the innovations considered here, it is clear that the distribution of costs is substantially different. Most of the successful innovations involved an improvement to an existing product, process, or service, and there was relatively little tooling, manufacturing, or start-up expense. In comparison, the above data are presumably more typical of the proportions of costs associated with introducing new products. Since most of the companies considered here are relatively small, they could not afford the expense of launching a major new product and their innovations thus tended to be modifications of existing products which could be sold in the same market place. Consequently, the research and development costs amounted to a significantly greater fraction of the total cost than the 5-10% quoted above, possibly 50%.

It is useful to categorize the innovations and their approximate frequency of occurrence as follows:

new or substantially improved products	40%
new or substantially improved processes	30%
substitution of new materials	20%
provision of new services	10%

The production of innovations based on new materials may be untypically high. This may to some extent reflect the expertise of the group which undertook this study, but more likely represents a developing trend as materials costs rise and substitute materials must be found.

It does seem that as technology becomes more complex and the fruits of technology more difficult to harvest, there will be a reduction in the proportion of innovations attributable to new products and processes. Developments of new synthetic high performance materials and the rising cost of some traditional materials may increase the importance of this particular category. Likewise new services may be increasingly important. This view has been expressed by J.E. Goldman of Xerox Corporation (1972)

"-the impact of technology on the economy in the next decade will not come primarily from technology's function of entering manufacturing productivity. Rather, I believe technology will be directed toward the improvement of services, or, more broadly expressed, improving the quality of life. Perhaps this is an even more demanding area for application of technology."

The major information inputs into the innovative process came from company activities, mainly in the form of results obtained in a research program. This accounted for an estimated 60% of the total information input. Trade and scientific literature was the second most significant information input accounting for possibly 20%. It is notable that trade literature, particularly descriptions of activities of competitors and companies in other countries, appeared to play a more important role than did the pure scientific research journals, which are largely academic in content. The third most important information input, amounting to possibly 10%, was obtained from consultants. The remaining 10% was shared among patent literature, government reports, research foundation reports, customers, suppliers, conference presentations, and expositions. Again these figures must be treated with some caution since documents such as textbooks, tabulations of physical and chemical property data, correlations of physical and rate process data, tabulations of properties of materials and available components play a very critical role in the innovative process and often tend to be taken for granted.

The high proportion of information input from company activities suggests that in order to innovate it is necessary for the company to undertake experimental work in its own laboratory facilities with suitable staff. Almost all of the innovations involved the production of a material, or component, or system, and testing it. In few cases was it possible for the innovation to be processed on the drawing board or to be contracted out. About half of the innovations were described as having originated from a science or technology push, in that it was realized that some new process or product was possible as a result of increased knowledge of the current technology. The other half were described as having a market pull origin in that there was usually recognition that there was a need for a particular item, or that in order to maintain sales in the light of a changing market or changing raw materials supplies, it would be necessary to alter current methods of production.

Most studies have found that 60 to 90% of innovations arise from market, mission or production needs with 10 to 40% coming from technical opportunities. Our data lie outside the usual range possibly as a result of the high proportion of small companies in this study. Many of these were specifically formed to exploit a technical opportunity, examples being Nachurs, Aerofall Mills, Milltronics, Abrex, Madison and Nash and Harrison. Often it is difficult to classify an innovation in these two categories.

There was no significant difference in the success-failure ratio for the two categories, although there were some notable failures in the technology-push category in which a better appreciation of the market during the innovative process would possibly have reduced the amount of effort wasted on the innovation. It is unwise to regard these two categories rigidly and separately because, for an innovation to be successful, there must be an element of both push and pull present. Furthermore, it is likely that for every innovation considered here, several others have been considered as possible innovations but had been rejected at an early stage either because the item would not sell, or (less often) because its production would prove technically very difficult. The only worthwhile conclusion that can be drawn is that it is very desirable at an early stage in the innovative process to carry out as completely as possible an assessment of the technical and marketing feasibility as well as the feasibility of production and financing. This should include investigation of potential applications, total sales at various prices, and probable market share to be taken by competitors. This diagnosis of the likely success or failure of the innovation should be carried out as impartially as possible but often this is very difficult because there is a prime mover or product champion who is convinced that his idea will lead without doubt to a successful innovation.

In most of the successful innovations there was indeed an individual who played the role of product champion and who had often considerable difficulty convincing his colleagues that his course of action was wise. Success was much easier to achieve when he gained the support of the company president or if he was the company president. There are many classic examples of groups or individuals who have rejected innovations at an early stage as not being feasible only to be proved wrong by the determined inventor. The telephone is a very good example. In such cases the inventor is subsequently warmly applauded for persevering. On the other hand, when an inventor proves to be wrong, this determination is conveniently dismissed as blind obstinacy. Apparently the successful innovator's two most important characteristics are the ability to be right, and to resist the Jeremiahs around him.

The most immediately successful innovations were those in which a change in the market was perceived and this resulted in a technical development to meet that change. A simplistic view of this process would be that the sales personnel recognized the need for a modified product and transmitted this to the research and development group, who then produced the necessary innovation. In practice the process seems to be very much more complex than this. Sales personnel often fail to recognize the importance of technical improvement and in the few cases where they do transmit a suggestion, it appears that it is often rebuffed by the research and development group, who regard themselves as being more properly involved in more fundamental technical matters. The obvious recipe for improving this communication gap is to involve the research and development personnel directly in sales and have them actually participate in such activities as visits to customers' plant, in sales negotiations, in installation, and the after-sales service. We found cases in half the companies where this improved communication resulted in significant suggestions for improvements in company products. Often the research and development personnel recognized that they were working on the wrong problem and that the solution was simpler than had been first expected. This improved communication is more readily achieved in a small company where all personnel are located in close proximity and are not rigidly compartmentalized by departmental boundaries.

There was a suggestion in some companies that since they received financial support for their research and development group, through the Industrial Research Assistance Program administered by the National Research Council, it was improper for the group to become involved in marketing or technical services efforts. While pressure in this direction may have been exerted in the early days of the program by N.R.C. officials, it is clear that they now consider it desirable for the research and development personnel to become involved in marketing. Indeed, we suggest it may be desirable to formalize this to the extent of requesting or requiring that, where government support is forthcoming for the salaries of research and development personnel, some fraction of their time be spent in sales or technical service activities, in order that they become more aware of the commercial implications of their work.

4. The People in Innovation

One factor which has been frequently neglected in studies of innovation is the character of the people involved in the innovation process. We have had the pleasure of being associated with several very striking personalities in this study and it is remarkable how important their personalities have been in promoting the innovations. Those who have acted as entrepreneurs are often individuals with much enthusiasm, considerable drive and technical competence. They have undoubtedly made a very significant contribution through their individual efforts.

The characteristics of persons largely responsible for innovation have been considered recently by Brown (1973) who described them as being intellectually curious, very receptive to new information and ideas, able to recognize and define problems and needs, mentally restless and tense, strongly motivated, goal oriented rather than method oriented, and impatient with things that get in their way. Brown also suggests (and to this point we will return later) that they probably showed many of these characteristics early in life.

We saw all these characteristics in individuals associated with these companies. The key qualities appear to be an entrepreneurial drive and willingness to take personal risks, coupled with technical and managerial competence. The technical and managerial qualities can probably be taught to some extent; however, the entrepreneurial approach and the willingness to take risks are probably inherent in the individual. We have no doubt that the personality of the key person plays a very significant role. In many cases the owner or founder of the company was the key person, and he had set up the company on his own initiative as an entrepreneur. He was often the main source of ideas. In other companies the research and development director or the group as a whole was responsible for the drive behind the innovation.

Almost all of the key persons had a degree in applied science or engineering with a few having degrees in pure science or in commerce. Since most innovations involved a fairly high level of technical sophistication, the would-be-innovator who lacks a formal training in applied mathematics, applied chemistry and applied physics is at a considerable disadvantage. The present day potential innovator must have some appreciation of the vast body of scientific information which has been accumulated in this century, and particularly since the Second World War. This can only be achieved through formal advanced study at a University. However, this training by no means guarantees an innovative capability. Indeed, it is probable that only a relatively small fraction of the community is capable of significant innovation.

We found that the success of the research and development group depended to a very large extent on the personality of its manager, particularly his ability to get on well with upper management, keep them satisfied with his efforts, yet not give in too often to their short term demands. Obviously his skill at managing subordinates is of critical importance. We found cases where the manager, being technically very competent, was less competent in personnel management and motivation. Some assistance in this area would be welcome especially as creative individuals are usually more difficult to manage, with conventional production management techniques being inappropriate. This suggests that such individuals should be selected very carefully with attention being paid to their ability to cooperate with their colleagues, as well as other personality traits such as enthusiasm, positive thinking, self-confidence, and courage.

The research manager should have the capacity to cooperate readily with people of very different backgrounds. In particular he should excell in communicating and setting up harmonious relations with management, sales, production and government personnel. Some individuals have the fortunate ability to communicate well but in others this ability is notably lacking. In both small and large companies it is vital that the research manager communicate effectively with the rest of the company and he must show a real interest in, and empathy for, his colleagues. Furthermore, it cannot be too strongly emphasized that in selecting research personnel for small companies, personal compatibility is as important as technical ability.

The individuals who were the source of most of the innovations tended to be intensely interested in technical developments in their field of endeavour and they would seize every opportunity to become more familiar with the activities and advances of other companies, universities, research institutes, in Canada and abroad. Consciously or unconsciously, they were acting as information retrieval systems assimilating every scrap of information which became available. The value of these individuals to a company cannot be too highly estimated and it would seem desirable to encourage their inherent curiosity by providing them with reasonable opportunities to read as much technical literature as possible, attend conferences, visit expositions in Canada and abroad so as to achieve a high level of awareness of developments in their own technology. In almost all of the companies studied such individuals were provided with such opportunities.

While it is not difficult to define the personal qualities characteristic of the successful entrepreneur/innovator, it should be recognized that some of these very characteristics, such as perseverence despite enormous difficulty, can make it difficult to live and work with such an individual. In 20% of the companies, we encountered very strong personalities who pursued their objectives very single-mindedly and who were not particularly receptive to criticism. Such persons can probably survive and be successful in very small companies. However, as a company grows their attitude has to adjust or major difficulties arise.

The entrepreneurs whom we encountered were by definition successful since their companies were operating satisfactorily. Either by foresight or luck they had promoted good ideas to a successful conclusion. Unfortunately, many or most others failed.

5. The Benefits of Innovation

In the discussions with the company representatives an attempt was made to assess the benefits that the companies had obtained from innovation. Ideally the benefits should be expressed in dollar terms; however, this usually proved to be impossible. There were many very successful innovations, e.g. the sonic sensing system and motion failure alarm of Milltronics, the slurry pump of Worthington, the liquid fertilizer of Nachurs, all of which had very marked effects on the fortunes of the companies involved in terms of sales, profits and jobs. About 12 companies were in this category. These benefits are obvious and substantial. They led to products which constitute a major proportion of the company's sales.

In addition, however, it was very striking that many unexpected benefits accrued to the companies from both the successful and unsuccessful innovations. One company expressed the belief that the process improvements which it had made had resulted in greater efficiency and more reliable operation. Production costs were reduced significantly although the exact amount was not known. One result of better reliability and lower cost was greater stability for the company in the bad market situation which existed during the recent recession which may well have been an important factor in the company's survival. In seven of the companies we found unexpected benefits of this type.

Many of the innovations arose from high cost or unavailability difficulties with raw materials. In such cases the innovations often allowed the company to continue production of a modified product, in the absence of which the company would have ceased operation. Again it was impossible to quantify the benefit.

In one third of the companies there were spin-off activities within the company which had proved to be very profitable. For example, in Fluid Power, the work on hydraulic cushioning led to an improved ability to design cushions and improve production methods using a numerically controlled lathe. The obvious technical competence of the company in this area greatly assisted sales and impressed prospective buyers. The Aerofall Mills expertise in stress analysis of mill components was made possible only through extensive use of the computer facility. Its purchase, however, could not be justified without the existence of a research and development program. It resulted in the company becoming a leading North American expert in analyzing structural failures in existing mill installations, and as a result the company reaped the benefit of replacement orders for various failed mill components. The experitse in the design of large, robust and precise mill bearings, which was in Aerofall Mills could be exploited when General Electric produced its wrap-around motors which eliminated the need for a gear drive, but required precisely the type of bearing developed by the company.

In Toronto Coppersmithing, the computer-aided design which was initiated by the research group eventually led to the creation of a new division within the company to provide engineering design services. There are many other examples in which the character of the company has been changed significantly by the presence of highly qualified individuals, often hired initially into a research and development group, partially supported by Federal Government funds. These changes cannot be quantified in dollars and cents. Usually it was the newly hired individual who first suggested the change to a sympathetic management who already had the desire to effect changes.

The presence of an R & D group has often proved to be of immense value to the company in allowing it to meet new opportunities rapidly and flexibly. Such a group often plays an internal consulting role for the entire company and to some extent acts as technical service consultants for customers. In the case of Consumers Glass it was noted that one of the most significant contributions of the group was in increasing customer satisfaction. A customer is undoubtedly impressed when his supplier is able to solve a problem, demonstrating that he has in his organization a highly competent technical group which can assist the customer in times of difficulty. We often heard comments of the type "the customer was impressed and delighted by the assistance that he received from our research and development people and this undoubtedly influenced him in purchasing from us again."

In many cases where design procedures were used by the company the research group had been able to improve the design methods with considerable saving of time and materials. Often the design methods were computerized and this provided the incentive for the installation of a time-sharing computer terminal in the company offices. When such a terminal is installed it becomes advantageous to computerize other company operations with a concomitant improvement in speed and technique.

6. The Market

It is frequently concluded that too many innovations are attempted without the proper advance market surveys. Our observations lend some support to this belief and suggest that some companies (possibly five) were remiss at one time in failing to obtain as much information as possible about the market. The opinion was expressed that the PAIT scheme was very good in that it forced the company to undertake a detailed market survey and that this may demonstrate to the company that it is not in a position to market the proposed product or indeed that the production costs involved would be beyond its capabilities. The opposite view was also expressed that market surveys are of very doubtful value and that innovations by their very nature preclude accurate prediction of sales. Instances were cited where market studies have been shown to be very expensive and very wrong.

The situation seems to vary greatly from industry to industry. A company such as Toronto Coppersmithing or Aerofall Mills manufactures a custom piece of equipment for installation in a production line and the market is restricted to a small number of companies. The existence of a market depends entirely on whether or not these companies are installing new equipment or replacing old equipment. A market survey to determine a precise number of sales is almost impossible in such cases. When the product is truly new it is extremely difficult to predict its degree of acceptance, particularly if a rival product appears on the market at the same time. The general conclusion appeared to be that where a market survey could be done it was worth doing, but one should be cautious in interpreting the results. The real answer is not obtained until the company tries to sell its new product or service. The marketing manager or salesman keeping his ear to the ground and remaining totally familiar with his customers and the market in his product area is indispensable.

There is clearly a need for considerable flexibility on the part of government departments concerning the nature of required surveys in support of applications for funds, since the situation differs considerably from case to case.

7. The Role of Government

(i) Comment on Current Programs

Thirteen of the companies received direct financial support from the Industrial Research Assistance Program, four received support from the Program for the Advancement of Industrial Technology and one received support from the Defence Research Board. Some also received assistance from provincial government sources such as the Ontario Development Corporation and from provincially assisted research foundations. Three had received no government support. Where government support had been obtained it was obviously appreciated and the funds seemed to have been spent wisely.

The IRAP approach was generally preferred to that of PAIT by the smaller companies because it gave them more flexibility and the application procedure was easier and less costly. The amount of information which the company has to provide for a PAIT application is substantially greater and this was felt to be beyond the resources of some small companies. It was suggested by one company official that it would cost about $5000 to prepare a PAIT application. Inevitably, there were comments about the amount of government bureaucracy which had to be handled. However, it appears to be impossible to disburse funds such as these without some measure of bureaucracy if adequate control is to be maintained over their disbursement and their proper distribution.

Larger companies generally tended to prefer the PAIT program, possibly because there are larger amounts of money involved and because the applicant has at his disposal sufficient accountants and other staff to undertake the necessary paper work associated with the application.

One of the interesting features of the government support, particularly through IRAP, was that the benefits which had accrued to a company as a result of undertaking research often proved not to be the benefits which were envisaged when the application was originally made. In at least three cases there was a major change in research direction. This is not surprising because of the nature of research and was particularly obvious in the case of companies which had no prior research and development experience. This casts some doubt on the desirability of providing government support on a project basis. Where a research and development group already exists in a fairly large company there is presumably a good knowledge of whether or not a project is worth undertaking. In a smaller company with no previous research and development experience it is unlikely that this knowledge or experience exists. It is then desirable to provide support, not on the basis of a project, but rather on the basis of funding individuals to undertake research work in the general area of the company's products. After a few years of preliminary research it is likely that the company will be in a position to suggest and probably define a number of viable projects. This approach of supporting individuals and research teams, rather than projects, was the original emphasis of the IRAP, and this has proved immensely beneficial in many cases.

It is clear, therefore, that while there is a need for a government support scheme of the PAIT type which is oriented towards well defined projects with prior market surveys, there is also a need for government support to foster research and development in companies which have no previous experience and in which potential projects are only very loosely defined.

A significant responsibility of a new R & D group is to review the company's practices and define meaningful projects. Research into the company's existing products, processes and services with a view to becoming more technically and scientifically knowledgeable about these activites will lead to an improvement in the company's operations and the definition of meaningful projects. The changing nature of markets must also be continuously followed.

A major benefit of government support programs was the claim that it enabled the company to hire and retain technically competent individuals (often the Manager of the R & D group) who could act as internal consultants. They provide invaluable service to the company in solving a multitude of small problems in production and in making very valuable suggestions for changes in established procedures. For example in Toronto Coppersmithing the R & D manager promoted the installation of a time sharing computer which could be used for design purposes, costing, and ultimately accounting purposes. The design capability in bearings in Aerofall Mills was built up and became a valuable service offered by that company. In many small Canadian companies there is a lack of input from young, technically competent engineers and scientists. Any government program which encourages the flow of such individuals into Canadian industry must improve the general level of technical competence and bring substantial benefits.

(ii) New Programs for Government

Several aspects of the innovative process should be approached more directly by government. These relate to such matters as unfavourable tariffs at the U.S. border, the supply of venture capital, the inherent difficulty in making the first sales of a new product or process, and the importance of expertise other than that relevant to R & D. These matters are raised and discussed in the paragraphs below.

More attention on the part of government is needed in the area of tariffs and trade with the U.S.A. This is a large and complex question; however, it does appear that the tariff situation is generally unfavourable to many of the companies considered here. For example, Abrex set up a production facility in the United States in order to avoid the tariff which would otherwise be levied on exports to that country. Similar products being imported in Canada from the United States are subject to much lower tariffs. There were numerous complaints of this type and documentation has appeared elsewhere (Atherton, 1973). It is of course true, however, that Canadian industry enjoys a high degree of tariff protection, leading to higher consumer prices and in some cases higher prices for production inputs than would otherwise be the case.

Possibly as important as unfavourable tariffs was the frequently expressed concern that imported materials and components sometimes became unobtainable. The bulk of these are obtained from the United States and the feeling was expressed that the Canadian market, being about 10% of the U.S. market, was regarded in the U.S. as being a location to dump excess production, often at relatively low cost (thus weakening the position of the Canadian supplier) and also as a market which would be the first to be closed in the event of shortages. In several cases it has been necessary for companies to cease production or use alternative materials at greater cost. The irony of this situation is that Canada is, of course, a major producer of many raw materials and the general long term answer to this problem must be an increase in domestic processing of these raw materials both to generate a healthy secondary industry and to guarantee the supply of manufactured items at reasonable cost to Canadian companies. It seems possible that the industrial world is entering upon a period in which raw material costs will increase significantly and supplies will be guaranteed to Canadian secondary industry in times of shortages only by political agreement, the development of domestic sources, or payment of higher prices.

Another area in which government assistance would be welcome is in the supply of venture capital, with the government acting as a direct supplier of the capital, or in supplying or backing small business loans. This question has been considered in detail elsewhere and the small entrepreneur would clearly benefit from some form of government assistance which will provide him with cash on a reasonably long-term basis and make him less vulnerable to the often precipitate actions of the few venture capital companies which presently exist. Whether the returns to the Canadian economy of subsidies to venture capital would exceed the costs, however, is quite dubious; there is no compelling proof that this is so.

A further major finding in this area is that some assistance is urgently needed by many companies in the area of promoting the first sales of a new product in order that the market can be penetrated and successful utilization of the product demonstrated. In several cases where the innovations had not yet been successful, it was believed that if such assistance could be provided, the item would be sold and the innovation would become successful. There appears to be an inherent reluctance on the part of Canadian industry and government to purchase untried Canadian technology. There is a myth that imported untried technology is more reliable. Several companies expressed the need for such a program. This would generate a cash flow, lead to acceptance of the innovation in the market place, lead to improvement of the innovation as a result of customer use and would boost the morale of the company. There are examples of real bitterness expressed over a company's inability to sell what was regarded as a superior product on the Canadian market in comparison to imported items. Distrust of a new Canadian product or purchasing inertia were the usually quoted reasons for failure to sell.

The funding of such a program would have to be very flexible. In many cases the government can act as a purchaser and absorb the risk. In other cases, for example process equipment, it would be necessary for the government to promote the sale of the first item by underwriting the start-up cost and to some extent the possibility of a loss through failure of the innovation. In return, the government could be guaranteed a share of the proceeds from any successful innovations. We suggest that a program of this type, in which a Canadian innovation is subsidized by government sources and the buyer protected to some extent against the risk of being the first buyer, be examined. It seems illogical for the Federal Government to support the R & D components of the innovative process and prototype manufacture, and not support the final stage of market promotion.

A need was also expressed for more general government assistance with the innovative process in areas other than the early technical stages of innovation. Many companies were delighted with the assistance which they had received from government scientists and engineers in, for example, the National Research Council laboratories, provincial research organizations and the Technical Information Service of the National Research Council. However, there is a real lack of government assistance in other components in the innovative process. Although there is a measure of government assistance with market statistics, often the information required by the company is so detailed and specific that it does not exist within government files in the normal course of events. Information is also needed on production techniques.

It was suggested that a system could be devised in which a company would have available to it a group of specialists or consultants either in government, or in private practice subsidized to some extent by government, which could assist the company with whichever is the weakest component in the innovative process. This assistance could be in the areas of technology, engineering design, production, financing, marketing or management methods.

This proposal is in many ways analogous to the situation which exists when an individual feels in need for medical help. He can obtain general medical help from his family physician but more specific help can be obtained by a referral to a specialist. It was suggested that government should provide or support specialist consultants for all the components of the innovative process - not just the R & D stage and that this would greatly enhance the innovative performance of the small Canadian companies. Some companies expressed the belief that they did not know where their own weaknesses lay. This is possibly particularly the case in entrepreneurial companies where the capabilities of the company are reflected by the capabilities of the owner-entrepreneur. Often an impartial assessment of the company's operations would be very valuable. A similar conclusion was reached by Litvak and Maule (1972) who recommended the design of special management-education programs for entrepreneurs.

The success of the Technical Information Service of the National Research Council seems to indicate that a broader service of this type would be of immense benefit to Canadian industry. This service will be difficult to implement since it will be necessary for the consultant to spend considerable amounts of time actually in the company in close contact with the people performing the operations in order that he can identify accurately the situations which need improvement. The view was also expressed that merely identifying needs is not sufficient. It will be necessary for changes to be implemented in order that the company operate differently.

It was generally felt that the emphasis of government programs supporting the development of new knowledge and new research capabilities in in Canadian industry may be somewhat misplaced. It is probable that a marked improvement can be obtained simply by using presently available technology and methodology. Many of the companies have felt the benefit of having available technically competent individuals who can apply techniques which are new to the company, but which have been used by other companies elsewhere. Such improvements can hardly be classified as significant innovations, but this does represent an area in which substantial improvement in operating performance can be obtained without necessarily introducing the risks and cost of research programs. The key is to encourage the employment of innovative individuals who can generally update the company technology.

While the Federal Government's "Make or Buy" policy under which research is contracted through the Department of Supply and Services to the industrial and university sectors is welcomed, we are concerned that published statistics reveal that a relatively small proportion of the funds (or contracts), i.e. about 25% is awarded to primary and secondary industry. The largest proportion is awarded to tertiary industry, i.e. consulting organizations and universities. We feel that a real effort should be exerted to place more funds in the primary and secondary sectors so that the important spin offs can more readily take place. Finally, with the substantial strengthening of Canadian industry in the ways described, thought must be given to the trend by which sucessful Canadian companies are bought out by U.S. interests. Indeed, two of the companies described in this report changed ownership from Canadian to American hands during the course of this study. This question is one which has received recent government attention and, for example, the National Research Council has introduced stipulations into IRAP which considerably tightens the guarantee that the innovative results will be used for the benefit of Canada. We believe that such action is generally welcomed.

The advantages and disadvantages arising from the purchase of a Canadian company by a U.S. organization is a complex issue beyond the scope of this report. There may be many short term advantages, especially to the seller, and there may even be improved employment and production.

The disadvantages are less tangible. They concern the extent to which Canadians are willing to allow control of their industrial community to fall into foreign hands. The issue is ultimately one of national sovereignty.

8. The Role of Universities

Most reviews of innovation include in their conclusions or recommendations a statement that universities should improve the innovative capabilities of their graduates, should provide more services to assist entrepreneurs, and generally assist in improving innovative capability of Canadian industry. There is certainly no reluctance to do so. Regrettably, however, little has been accomplished. One reason is that no one has yet discovered how to teach innovation. The mechanism by which academic staff interact with entrepreneurs, or even become entrepreneurs, is an issue bordering on the contentious. As a result of our twelve years of experience as members of CERCL we feel that we are in a position to make some comments and suggestions on the improvement of the interface between universities and industry. These views cannot be regarded as impartial; nevertheless, they are based on first hand knowledge.

It is easy to devise ineffective methods of improving the liaison. One common approach is to have casual visits by industrialists to University departments and casual visits by professors to industrial organizations. However, relatively little that is truly constructive is, in our opinion, achieved in this way.

A second method which we do not favour is the creation of university-based industrial research organizations which often operate in competition with private technical laboratories and provincial research organizations. It is doubtful if these university-based organizations can remain viable without considerable government subsidy, and it is questionnable if this type of operation is consistent with the role of the university in society. On the contrary, we are convinced that industrial research should be done in industry and by industry. If the University professor is to participate, it must be in the industrial environment rather than in the university. None of the very beneficial spin-offs within the companies described earlier occurs if the research is contracted out to other agencies.

Universities are essentially reservoirs of knowledge, scholarship, and experience which maintain their vitality by undertaking research programs. In Canada a high proportion of Ph.D. graduates is in university employment. Mechanisms should be created to enable these trained scientists and engineers to participate in the innovative process in Canadian industry. To ignore them deprives Canadian industry of a vast reservoir of knowledge, which has been built up at immense public expense, and decreases greatly the manpower participating in innovation. We have become convinced that it is only through frequent and intense contact between the university professor and industry that the academic can obtain a real understanding of industrial problems and reach a position to make a contribution. The liaison must be on a reasonable financial basis, otherwise neither side will take the exercise seriously. Undoubtedly some academics are reluctant to participate in such a manner, but many are, and these should be encouraged.

Many academics can make a technical contribution to the innovative program by providing general information on the topic and keeping the industrial group up-to-date as a result of their personal study of books and papers, attendance at conferences and knowledge of who is doing what, where. The academic can also provide information on new instruments, devices, materials and techniques. In several cases in this study the professor assisted in obtaining the use of computer and instrumental facilities for the company in the days before the company obtained its own. He can also assist in obtaining research staff and in providing summer students. In the experience of the University of Toronto chemical engineering group, 25 Ph.D. students have been placed in R & D positions in Canadian industry over the last ten years through contact between staff and industry. Professors usually get to know their students quite closely and can identify, we believe, the features which will make a student a satisfactory member of a creative team. This provides an easy and efficient method of directing the more enterprising students into a suitable industrial environment where their abilities can be fully utilized.

One unexpected benefit of the presence of an outside advisor has been that he is frequently able to take some of the heat out of disputes over research activities which are both technical and personal in nature. Often he substantially improves communication between the research group and management by talking individually to each side and explaining some of the difficulties of one side to another. Often management expects too much, too fast, from a research group and this may lead to friction. The research group may become too preoccupied with its own technical research problems and neglect its more general role in the company. A few tactful words in the right place can greatly improve morale in such situations.

Direct contact of this kind between the university and industry is reflected in the university by the content of courses and the emphasis in curricula and help the professor to keep his research activities relevant. This is particularly desirable in the applied sciences and engineering. For example, a significant research effort has evolved at the University of Toronto as a result of the group's association with Abrex, Fiberglas, MEP, Milltronics and Wix.

There was criticism by some companies that recent Ph.D.'s lack managerial ability and marketing experience. This is understandable since the typical university graduate program seldom brings training or experience in company operations, management or marketing. It seems desirable that those students who believe that they are going into research and development groups in industry, particularly in small companies, should undertake some studies of management or marketing during their graduate program. Since few students know where they are going to be employed until completion of their programs, it would appear desirable to encourage all those in applied doctoral graduate programs (with the exception of those who are determined to seek a career in pure scientific research) to undertake some studies in industrial organization, economics, marketing, or management. We do not suggest that the Ph.D. graduate in applied science or engineering should undertake a concurrent M.B.A. program, but at least he should have some familiarity with the jargon, terminology, and techniques in order that he is more aware of his own shortcomings and can begin filling gaps in his training. Possibly this lack of knowledge can be remedied by taking appropriate courses immediately after graduation with the Doctor's degree. Such professional development courses in business management and related topics are becoming increasingly available both on and off campus.

In order to further develop innovative skills in young potential entrepreneurs we suggest a program based on the premise that university professors can tentatively identify those students who have the qualities which will make them entrepreneurs. In our experience in the Department of Chemical Engineering and Applied Chemistry at the University of Toronto we have become convinced that the set of qualities which contribute to the character of an entrepreneur are identifiable as early as the second year of a four year undergraduate program. This is in accordance with Brown (1973) who claims that many of the creative characteristics of the entrepreneur or innovator appear early in life.

We suggest that in a class of say 50 engineers a group of 3 to 5 be selected who are judged by the staff, and in their own estimation, to be of the type who would be willing at some stage to form their own enterprise. These individuals should not only have technical competence but also the vital entrepreneurial drive. They would be interviewed and told that in the opinion of the staff they have entrepreneurial abilities and that the staff is willing to assist them to develop these abilities. We believe that the moral-boosting features of this approach is very important. These students would then be told that their elective courses should include elements of business management, economics, finance, or marketing, and possibly arrangements could be made for them to take courses in a Business School which are not normally available to such students. In many university curricula there is sufficient elective content that this can be readily accomplished.

We suggest here that the emphasis on selection be from among students in engineering and science programs, since experience shows that these are the ones most likely to be the technical innovators of the future.

The second stage would be to offer the students summer employment in an entrepreneurial atmosphere in which they will have direct contact with an entrepreneur. They will then have the opportunity to appreciate how he lives and works, the difficulties which he experiences, and the satisfaction which he obtains from his enterprise. Hopefully, this will convey to them what kind of future lies ahead if they do decide to embark on the entrepreneurial journey. Most of the entrepreneurial companies with which we have been associated are eager to give young engineers an opportunity to work during the summer in reasonably challenging positions. It is essential that these students hold competitively awarded, government supported scholarships during their summer employment. This financial support would contribute to both the students' education and to the entrepreneurial company. It would be unfair to expect the company to pay since it is unlikely that it would prove to be profitable and the program would then degenerate into yet another "give a student a summer job" appeal.

Many of these students will choose to take a graduate degree. We suggest that again it is appropriate that they take a course of study which includes topics such as management, marketing, or financing and examination of entrepreneurial experiences. Where necessary, rules governing graduate programs should be modified to allow this to occur. These individuals should receive special scholarships, analogous to a National Research Council Postgraduate Scholarship. They will have little difficulty finding employment on graduation, even with larger companies, and we hope that at some stage they would leave their employers to start their own enterprises.

In essence, the program combines selection of young men or women with entrepreneurial traits and technical competence, informing them that they have these traits, and providing them with the necessary tools to start their own enterprises. This should pay dividends for a relatively small expenditure of money or effort. We suggest that a pilot program of this type be initiated. Although the full results will not be known for many years, indications of success should be apparent reasonably quickly. We understand that a similar program is under consideration in Sweden and an attempt should be made to follow progress there.

We also suggest that a parallel study would be useful in which an attempt is made to identify the characteristics of the successful Canadian entrepreneur and determine if and how he could have been identified at an early age.

The program suggested above may have its faults, but it is, to our knowledge, the only one of its type proposed for Canada by which universities can make a real contribution in the innovative sphere by educating young people in entrepreneurship.

In summary, it is clear that the participation of professors in industrial innovation as consultants and co-directors of research should be encouraged. In addition to the direct contribution, the association in this way with industry will lead to a favourable impact on university-based research programs and the education of both undergraduate and graduate students. Furthermore, the proposed scheme for the identification and development of young entrepreneurs will itself be more successful if the professors involved have had, or have such professional relationships with industry.

CONCLUSIONS AND RECOMMENDATIONS

As a result of studying the innovative attempts of eighteen companies we believe that we have gained some insight into the difficulties facing the Canadian innovator and into possible means of improving the innovative environment. We summarize our findings below, noting again that they apply particularly to smaller Canadian companies.

The Innovations

It is extremely difficult to obtain meaningful numerical data on the innovative process. The wide variations in companies, the subjective nature of the data and the intangible benefits suggest that experience and insight are of more value than statistics in studying and seeking to improve the innovative process.

There is no shortage of innovative ideas. Most ideas are generated in the company by individuals familiar with the company's technology and market and receptive to information from outside on new technology. Such individuals play an invaluable role in translating new knowledge into production. It is usually necessary to have a R & D group with laboratory facilities to achieve an innovation. Any mechanism which improves communication between the R & D group and other company groups, particularly sales, will reap benefits in generating new ideas, in improving the relevance of research, and in servicing the customer.

We see increased need for innovation in the areas of services and materials substitution with possibly less future emphasis on products and processes, because we believe that raw material costs will rise rather than fall in the near future.

There is evidence that the market may not always be surveyed as effectively as is possible. Such surveys are difficult and the results often suspect. Knowledge of the market is, however, of critical importance in deciding whether or not to attempt an innovation and all available means to forecast the marketability of a product should be exploited.

The Benefits of Innovation

We found many benefits from attempted innovations apart from the obvious ones of increased or new production. All benefits were difficult to quantify. An attempt to innovate, whether successful or not, may bring advantages in areas such as improved process stability and reliability; decreased dependence on a scarce or costly raw material;

improved customer satisfaction; better after sales service; spin-off within the company to improve design, costing or production techniques; better materials and component selection; faster company response to a changing market. All of these benefits should be reflected in larger profits or more rapid corporate growth than would otherwise have occurred. Setting up an innovative group may bring to the company highly competent and creative individuals who may have a significant personal impact on the company.

The People in Innovation

People and their personalities play a very important role in the innovative process. A successful innovation usually has a champion who has the determination and drive to overcome the many obstacles which are encountered in research, production, financing and marketing. Canadian industry owes a considerable debt to these people. In selecting individuals for R & D groups more attention should be paid to ability to communicate and establish satisfactory working relationships with other company personnel.

The basic innovative requirements remain a sound knowledge of applied science and a receptiveness to new science and technology.

Government

Governments have done much to promote innovation. However, more support is needed to create a better environment for innovation in Canada. The support provided by existing programs has been used effectively and undoubtedly has resulted in improved industrial performance. We see a need for a package of government programs in support of innovation as outlined below. Flexibility and minimal bureaucracy are essential features of such programs.

First, support is needed for a new R & D group in a company with little or no previous research experience. The objective of the group should be to develop a deeper understanding of the company's products and processes with only light emphasis on specific projects. The size and objectives of the program should be tailored carefully to the company's capabilities and no fundamental work, or projects which will take longer than about 3 years to reach completion, should be attempted. Our experience suggests that the research results may not be clearly demonstrable in advance or even in retrospect as profitable but we are convinced that the general increase in technical competence leads to greater productivity. This type of support which is similar to the Industrial Research Assistance Program of the National Research Council should involve academics and others as advisors to the company. The R & D personnel should be required to keep in close contact with other company departments, by, for example, regular involvement in management and sales activities.

Second, support is needed for specific research or innovative projects similar to the present Program for the Advancement of Industrial Technology of the Department of Industry, Trade and Commerce. The company must already have an established and competent group. Before undertaking the project there should be a clear understanding of the time required, the market and tariff situation, required production facilities, financing needs and other requirements to complete the innovation. Any weaknesses in a component of the innovative process should be strengthened. The project should not normally require more than 3 years. University faculty and other consultants should be used as required for assistance with scientific, technical, production, marketing and other matters.

Third, a program is needed to promote the first sales of Canadian innovations. Government should act as purchaser where preliminary tests indicate a high probability of commercial success. When this is not appropriate, government should offer significant incentive to a company to be among the initial group of purchasers of a promising new product, process or service. This program will greatly improve market penetration, bring a cash flow to the company, provide customer experience, assist further sales and improve morale.

The above three programs should be augmented to a greater extent by the "Make or Buy" policy administered by the Department of Supply and Services in which an existing industry group undertakes research for government. At present only about one quarter of this contracted research reaches primary or secondary industry. Strenuous efforts should be made to increase this fraction in the expectation that this flow of cash and knowledge will lead to greater industrial productivity and more stable industrial R & D groups. Important spin-offs in the industrial sector will inevitably occur.

Guidelines are often quoted for the extent to which an industry should invest in research, an example being 2% of sales. For a small company with annual sales of $1 million this represents $20,000 which is totally inadequate. A group consisting of only one professional and one technician will cost at least $50,000 annually. The result is that many of the smaller innovative companies invest a very high proportion of their sales income in research. They thus become very vulnerable in times of poor markets. Several of the companies in this study went through a very difficult period and there was a temptation to abandon research in the struggle for survival. Their smallness, however, imparted to the companies a remarkable flexibility and ability to react quickly to a new market or technical opportunity. These companies thus operate in a different manner and environment from the larger, well established companies with high sales volumes. We conclude therefore that these small businesses must be treated differently in government research incentive programs. They need, we believe, more support, less bureaucracy, more technical, scientific and market assistance and recognition that they are more vulnerable and often closer to bankruptcy. It should be possible to devise a program which will buffer the high technology, entrepreneurial company which is judged to have a sound product against the vagaries of an uncertain market.

Finally, the important effect of tariff regulations, control of venture capital, control of foreign take-overs, information retrieval and transfer on the innovation process must continue to be recognized.

It is further recommended that the Ministry of State for Science and Technology establish an office to provide information and advice on all current and future support programs. In addition to those identified above, other programs, such as that administered by the Defence Research Board, are available. We are convinced that an independent agency could serve a very useful coordinating role and central source of information.

Universities

The reservoir of knowledge and experience in universities should be more effectively tapped in support of innovation. Only by increasing university-industry contact will academic programs change to improve the innovative performance of graduates. We favour increased involvement of University faculty in industrial research but this research must be located in industry and with satisfactory financial arrangements. We do not favour university based industrial research institutes since they do not have the same potential for spin-off benefits in industry and they may actually reduce the incentive for industry to set up its own R & D facilities.

Professors can make contributions to industrial innovation in the areas of scientific and technical knowledge, finding personnel and in improving R & D - Management communication. Faculty members should attempt to improve innovative performance by changes in courses and research and by fostering entrepreneurship in the young. Ph.D. students who plan to enter industry should be encouraged to take business courses as part of their graduate program.

We propose that a program be initiated on a pilot basis for identifying and encouraging young Canadian entrepreneurs among students in university applied science and engineering courses. The details of such a program have been presented earlier. Close contact should be maintained with Swedish experience in this area.

Hopefully, a greater involvement of academics in industrial innovation and encouragement of young entrepreneurs will create greater awareness within universities of the innovative process and appropriate changes will be forthcoming in their scholarly programs at both the undergraduate and graduate levels.

In summary, most reviews of the innovative process in Canada commence with the premise that Canadian innovative performance is poor. Our opportunity to examine the diverse activities of these eighteen companies has convinced us that the innovative performance in Canadian industry is probably better than is generally appreciated. We have certainly encountered a large number of extremely competent, hard-working and dedicated individuals. Their accomplishments are rarely momentous new products or processes. Rather they are usually unobrusive changes in products or processes which in total must represent a very significant improvement in the state of health of Canadian secondary industry. If these individuals are typical, then we have no doubt that the intellectual capability exists to improve greatly the innovative performance in Canada. The Canadian innovator finds himself working in an environment fraught with many difficulties and frustrations. Governments, universities and industry itself can do much to improve the innovative environment in Canada.

The innovative process has been more than adequately studied and analysed. We believe that little benefit can be obtained from further analysis. Indeed, there is a danger that the old adage that excessive analysis leads to paralysis will apply to government policy in support of innovation. Rather, what is now needed is selected changes in the support programs and new experimental or pilot programs with analysis of the response of Canadian industry to these new stimuli. Government itself must show a willingness and ability to innovate mechanisms to encourage industry to innovate. The time has come to act decisively to encourage more innovation in Canadian industry.

We are encouraged by the observation that present government support programs can be expanded, modified and combined to form a support package which will contain the necessary components to encourage new and continuing innovative ventures in Canadian industry. The personnel, material and financial resources are available. All that is needed is the will and confidence to succeed.

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