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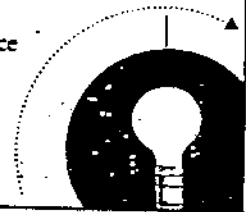
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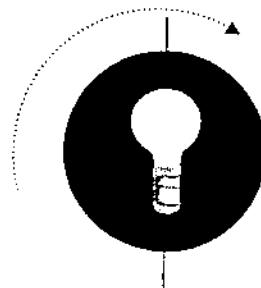




Innovation Model for the Real World

The connection between innovation and national wealth has long been a given, leading governments to attempt to facilitate the process. The current model of innovation is linear, emphasizing basic research as its foundation. However, there are indications that innovation is a more complex process, having design and development as its core. Recognition of a more holistic innovation system would perhaps allow governments and business to allocate scarce resources for greater return.

Darius Mahdjoubi, P.Eng.



Problems With the Model

If equating the process of R&D with innovation were true, understanding innovation would be far simpler than it truly is, and the real problems would be far simpler and less interesting than they truly are. Increasingly, however, it is becoming apparent that this model does not reflect the way in which innovation is practically linked to the market. For example, the model suggests that the sequence from research through development to production is a one-way path, concentrating on R&D and beginning with basic research. However, according to recent Industry Canada Science and Technology Statistics (1991), only 3566 Canadian businesses performed R&D, or only about 0.4% of total Canadian businesses. Of the total business expenditure on R&D in 1991, in fact, almost half was conducted by 25 firms. An Industry Canada discussion paper of September 1990 indicates only 3% of manufacturing firms had any R&D capability.

A more recent example comes from a 1994 survey of small- and medium-sized enterprises in Etobicoke, Ontario. This survey revealed that the technology resource most used by over 70% of respondents in developing their products was development/adaptation, rather than R&D. About 40% of the businesses surveyed indicated that, as suppliers or subcontractors, their technology development process is based on manufacturing well defined products, rather than on commercializing new knowledge they have derived. Some companies surveyed both developed their own products and manufactured products for others on sub-contract.

Indeed, Statistics Canada's Advisory

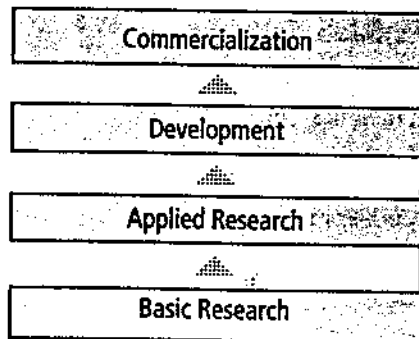
It is accepted wisdom that innovation plays the key role in economic growth. However, over the past five decades governments, economists, engineers and academics have thought of the innovation system as a series of steps leading directly from basic research to industrial commercialization. The starting point in this linear model of innovation (see Figure 1) is basic research, which has been primarily the purview of universities, government research institutes and the central laboratories of some very large firms. In this model, industry does not usually enter the picture until the applied research stage. Development is the last stage in this model, leading directly to commercialization.

Development has further been classified into "product development" and "process development." However, there may be no clear distinction between them. In fact, the same technical advance may be viewed as a product development by its producers, and a process development by those using it. The vast majority of product developments in the service sector, in particular, are process innovations for the manufacturing sectors. The linear model provides most policy thinking and making about technology development and economic growth.

Consistent with this model of innovation, science and technology policies have evolved that have long focused primarily, perhaps exclusively, on government-funded research and development (R&D). Combined with the economic rationale of market failure and Keynesian economic policies, government grants for R&D remain a popular policy.

Figure 1.

Linear Model of Innovation





Committee on Science and Technology Statistics concluded last year that R&D expenditures are not adequate to describe the dynamic system of knowledge creation, development, acquisition and application that determine the inventiveness of the system. Better data on the nature of innovation, its relationship to technological capabilities and the nature of diffusion are required.

Holistic Model of Innovation

Recent studies demonstrate that the creation of new technologies often begins not with the discovery of some new piece of basic knowledge, but with design, using existing knowledge, to meet a recognized need. The process of innovation moves back and forth between market needs, design, development, applied research and, at times, basic research. Consequently, any model of a real-world innovation system cannot limit itself to R&D as the basis of innovation. Instead, it must depict a dynamic process, involving the application of knowledge, together with other inputs, leading to design, development, creation and marketing of tangible, as well as intangible, products. In such a model, the core activity is a discrete stage that we can call "design and development and consulting/engineering services" (D&D).

In this model, the term design is used to denote a study of new combinations of existing products and components, rearrangement of processes, and planning of new products within the existing state of the art. Design is not invention in the usual sense; however, it is insufficiently appreciated that successful innovation, even in high technology industries, is often not so much a matter of invention (as a patent examiner might define invention) as it is a matter of design, in the sense of trying to devise a product or process that will achieve a desirable cluster of performance characteristics subject to certain cost constraints. Designing is not a lower level or routine activity and a design in some form is essential to initiating technical innovation. Redesigns are essential to ultimate success.

By adding an independent stage for design/development and consulting/engineering services to the linear model of innovation and explicitly defining the process of information/knowledge transformation between them, we create a network between market, production, D&D, R&D and basic research (see Figure 2). This approach depicts technology

development not as a one-way linear process, but rather as a continuous, dynamic process in which innovation can move forward from research to design to production to market, in reverse from the market to production to design to research, or in a cyclic manner inside any stage.

Moreover, the D&D stage can be made to apply widely to such activities as an enterprise's product design, process design, equipment design, plant design and operation management. This configuration is presented in Figure 3. In addition, it should be noted that product design/development is in practice often further subdivided, into design/development that applies to a product's function/application, form/aesthetic, or ergonomic features, although it is not necessary to incorporate this subdivision into the overall innovation model here.

In practice, there are many ways that companies acquire or perform their design/development. In general, these activities can be classified into two categories: make (or technology development) and buy (or technology transfer). Each procedure for acquiring technology—either transfer/buy or develop/make—may

be further organized into a hierarchy, according to the cooperative edge of knowledge acquired and competitive advantage of economic value (see Figure 4).

By combining figures 2-4, we create a more holistic model of innovation (Figure 5), which shows a dynamic process that is more consistent with reality than the linear model of innovation. This holistic model of innovation shows clearly that innovation can occur throughout a company's operations, triggered in some cases by new knowledge, but in other cases by an opportunity to fulfil a market need.

Reverse engineering involves trying to manufacture legally a product similar or superior to one already available on the world market, but without direct foreign investment or the transfer of blueprints for product and process design. Almost forgotten in the linear model, reverse engineering requires understanding of the basic mechanism behind products and the skills to copy, imitate, adapt and assimilate technologies. Studies of Japan's and Korea's technology development are not complete without addressing the crucial role of reverse engineering in innovation. After the Second World War when Japa-

Figure 2.

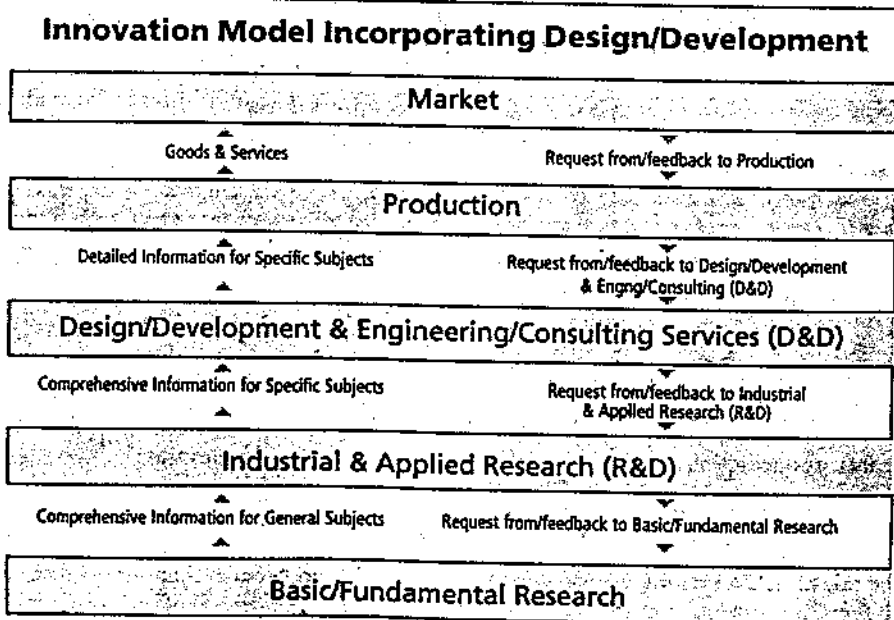


Figure 3. Categorization of Design/Development (D&D)

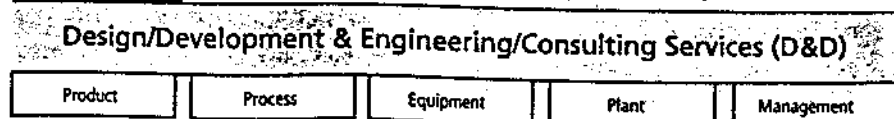


Figure 4. Design/Development Procedures

Buy/Technology Transfer				
Design/Development & Engineering/Consulting Services (D&D)				
Product	Process	Equipment	Plant	Management
Supply/Licence	Buy Engng Services	Buy Design Engng	Turn-key Plant	
Buy Know-how	Buy Know-how	Buy Know-how	Feasibility Study	Technical Assistance
Buy Patent	Buy Patent	Buy Patent	Installation	

Make/Technology Development				
Design/Development & Engineering/Consulting Services (D&D)				
Product	Process	Equipment	Plant	Management
Copy	Copy	Copy	Commission	Operation Management
Imitate	Imitate	Imitate	Detail Engng	Maintenance Management
Adapt	Adapt	Adapt	Basic Engng	Production Management
Invent/Innovate	Invent/Innovate	Invent/Innovate	Project Management	Plant Management

nese industry was vastly devastated, its method of copying, imitating, assimilating and improving upon imported technology was consistent with reverse engineering. Often originally developed through reverse engineering, the Japanese approach to product and process design created a new type of innovation management. We should therefore recognize that innovation, comprising both forward and reverse engineering, will affect our national innovation system and technology strategies deeply, as well as the management of technology in business.

It is also worth mentioning that the holistic model of innovation holds additional sections related to the internal structure of other stages (market, production, R&D and basic research), as well as the role of human resource development systems (education, training), information centres and technology transfer mechanisms, social/cultural and natural environments and appraisal of intellectual capital. However, discussion of these is beyond the scope of this article.

Where To From Here?

For engineers, acceptance by policy mak-

ers, managers and academe of a more holistic model of innovation is important because such a model recognizes explicitly the range of activities in which they are most involved. Where in the linear model engineering services is a missing link, in the holistic model, engineers' place in the innovation system is recognized. This model can be used to justify a more proactive role for design and engineering services in companies' investment and strategic decisions. On the other hand, as a taxonomy and hierarchy, the model can guide managers and policy makers in technology planning and provide support for creativity and innovation.

At the enterprise level, looking at the process of innovation differently would allow companies to develop technology plans that are broader than simply defining the technical aspects of their products, R&D projects, or management of engineering sections. Technology plans premised on a more holistic model of innovation are better able to describe the main patterns and potential changes in the technology strategies of an entire business, and therefore better able to be integrated with conventional business planning. In

today's fast-changing industries, where the lifecycles of specific technologies can be shorter than the lifecycles of specific projects, technology planning must go hand-in-hand with financial planning, to create an action plan for a given business.

Financial institutions and the accounting profession have recently begun to take great interest in the integration of intellectual capital into the conventional framework of financial performance measures for business. Because the structure of the holistic model is based on the transformation of information/knowledge, it is able to act as a link with the appraisal of intellectual capital, activity-based costing and techno-economic analysis of projects. This method may further assist engineers to fill emerging positions in the new techno-economic paradigm.

In addition, if innovation is viewed differently, engineering education could well come to recognize excellence in execution (design and development, reverse engineering and production) as activities of at least equal stature to the pursuit of original knowledge. Certainly, universities must not abandon basic research (for the linear model may still apply to the start-up of new industries or the launch of breakthrough products), but by equating innovation with R&D through the system of research grants and publication of research results to achieve tenure, university engineering programs may not be preparing students as well as they might for these future engineers' role in the real world.

Engineers must come to appreciate that design is not an activity limited to engineering services, but is a broad phenomenon able to link them with many other disciplines. Certainly, the professional improvement of engineers will depend on their understanding of design, but it will also depend on their ability to express to society at large that design is the core of innovation, not an appendix to fashion. Fifteen years ago, the Organization for Economic Cooperation and Development's Frascati Manual made measuring innovation by expenditure on R&D standard practice. Roughly a decade later, the OECD admitted in the Oslo Manual that R&D data underestimate the amount of innovative activity in small firms, and that we are still far from understanding all the factors that shape the rate, direction and growth of innovation and technological change, at every level of the economy. Perhaps non-linear, holistic models of innovation can assist us to ex-

plore the innovation process more fully. Who knows, maybe the OECD's next manual on interpreting the innovation process will bear the name of a Canadian city!

Finally, on a national level, looking at innovation holistically would allow policy makers to develop more effective policies to facilitate the innovation system. Among G-7 countries, Canada has the highest ratio of government and university to business R&D expenditure and Canadian tax treatment of R&D is the most generous offered by any industrialized country. Yet Canada has a history of difficulty in translating good ideas into commercial success. Clearly, the assumption that scientific discovery leads automatically to new products and services, thereby enhancing national economic performance is false. Yet because it is the premise on which current Canadian public policy is based, too little support has gone to exploring the place of design/development and the dynamism of forward/reverse engineering in the network. If a more holistic model of innovation were recognized, scarce funds could be reallocated to where they could achieve more bang for the buck. ♦

Darius Mahdjoubi, P.Eng., is an industrial consultant specializing in technology strategy, planning and management. A mechanical engineer, he focuses his practice on plant design, facilities planning and industrial factory set-up. He recently completed a project on "community technology strategy," which regards community systems of innovation as building blocks of a national innovation strategy. His email address is: darius@artnet.net.

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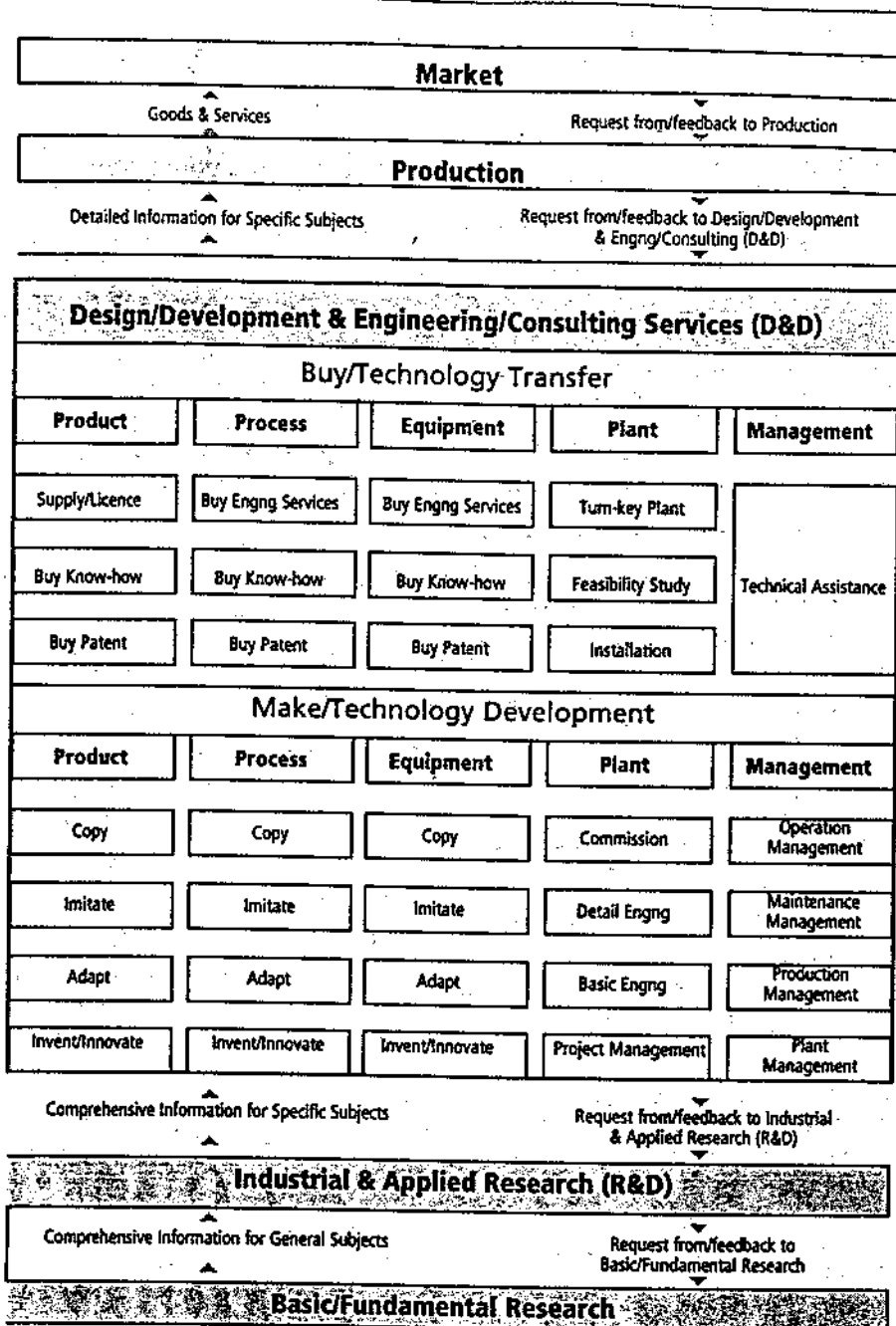
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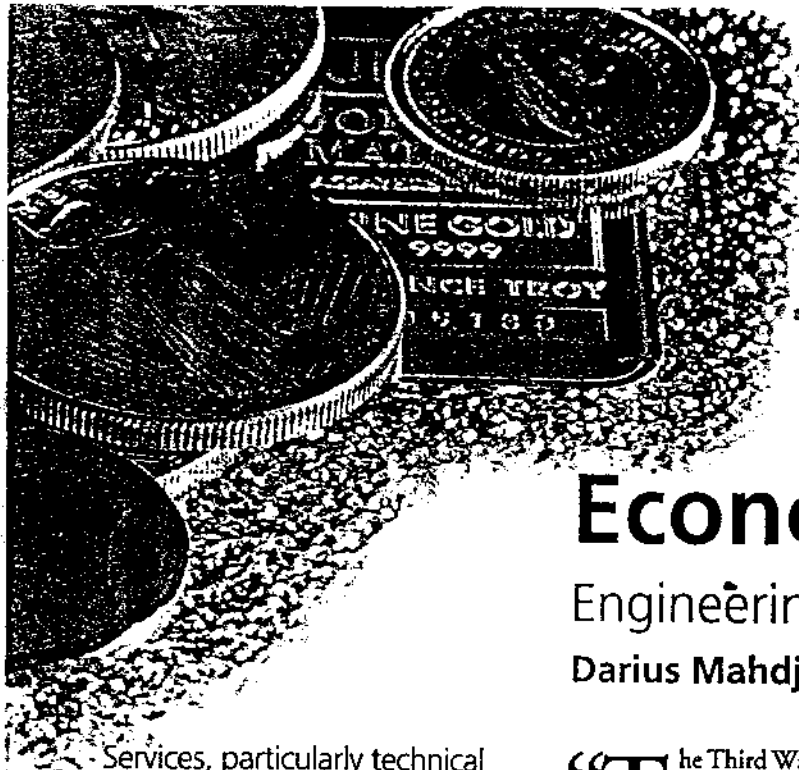
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Figure 5. Holistic Model of Innovation





Economic Renewal

Engineering Holds the Key

Darius Mahdjoubi

Services, particularly technical services, are playing an ever greater role in Canada's increasingly information-based economy. Yet the relationships between technical services and technology development, and between technology development and economic growth are not well understood by government policy makers. Perhaps it's time for new economic policies that account for technology's place in wealth creation and technical professionals' role in technology development.

The Third Wave." "Information Revolution." "Economic Restructuring." "The Great Reckoning." Whatever you call it, our economic future can no longer be regarded as a linear continuation of the past. A new era has begun that will drastically change every aspect of our lives.

What's new about this new economy is that it's based on knowledge, rather than on conventional materials, involving manipulation of information at a very small scale, rather than mass processing of raw material. Activities that generate, process, store and transmit information—services all—are or soon will become the most valuable parts of every business.

Role of Services Growing

The growing importance of services in Canada's economy can be observed in Table 1, which compares the performances of its goods and services sectors in recent years. The goods producing sector includes: agriculture, resource extraction and processing, manufacturing and construction. The service sector includes all other economic activities, such as: transportation, distribution, communications, trade, finance, personal and business. Table 1 shows how service industries have comprised an increasing share of Canada's real Gross Domestic Production (GDP) in recent decades. While the relative importance of goods production has continuously declined, services have increased in value.¹

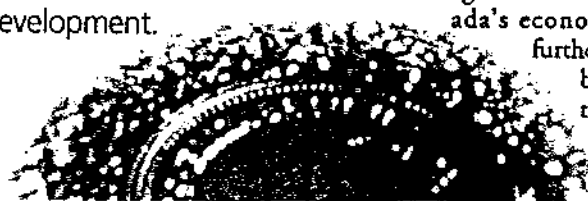
The increasing role of services in Canada's economy can be further examined by breaking the service

sector into consumer, government and producer services. Consumer services include accommodation and food services, distribution, private health care and entertainment. Government services include public education and national security. Producer services comprise:

- ◆ accounting;
- ◆ marketing;
- ◆ law;
- ◆ security;
- ◆ consulting engineering;
- ◆ engineering design;
- ◆ industrial design;
- ◆ management consulting;
- ◆ maintenance and repair;
- ◆ computers;
- ◆ architecture, and
- ◆ science.

Table 2 shows that over the past 30 years, the share of government services in Canada's GDP has declined, while the share of consumer services has remained constant and the share of producer services has increased. In fact, service sector growth since the Second World War has been fueled almost exclusively by business demands for new and improved producer services. Indeed, during the last 25 years, the value of producer services in real (1981 dollar) GDP has risen by 20%.¹

The service sector currently accounts for 71% of total employment in Canada. During the 1980s, almost 1.9 million new jobs were created in Canada, entirely due to new service sector jobs. Service sector employment is the largest and fastest growing part of the Canadian economy. Indeed, employment in Canada's service industries grew at an average annual rate of 3.1% between 1971 and 1990, leading all other sectors in employ-



ment growth. Canada is second, after the United States, among Organization for Economic Cooperation and Development countries in the contribution services make to the GDP.¹

Within the service sector, consumer and producer services, often referred to collectively as commercial or business services, experienced the fastest growth in the period 1967-1988, with average annual employment gains of 7.3%. This group includes such jobs as scientific and engineering services and management consulting. The proportion of business services in Canada's international trade in services is also increasing. Although Canada currently runs an overall service trade deficit, the percentage of business service exports has increased substantially in relation to total services exported. At the same time, business service imports as a share of total service imports have declined.²

Engineering Services

How much of this increase in Canada's trade in services can we attribute to engineering? Although statistical information in this area is limited, there are strong indications that engineering and technical services (as opposed to such administrative services as accounting, marketing, law and security) are increasing their role in Canada's economy.

For example, Canada generally records trade surpluses in computer, consulting and professional services, while consulting and engineering services recorded earnings of over \$590 million on projects in foreign countries in 1989. In 1987, export of consulting and engineering services accounted for almost 12% of Canada's total industrial revenue. At the same time, Canada's total foreign revenue increased by 39% between 1986-1987, while total revenues rose only 17%. This shows that during that period, exports were growing at a much faster rate than domestic trade and that a healthy share of those exports was related to engineering services.²

Engineering and Technology Development

Why have the role and value of engineering services increased in Canada's econo-

my? Simply, it is because they relate fundamentally to the process of developing and enriching information. And in as much as every economic activity relies to some extent on technology and technology is created by people generating, manipulating and applying information, an economy based on information must become integrated with technology.

Further, as technology develops, the value of the equipment, information and human resources comprising it increases. If the economy then captures this added

value, the next generation of technology development can be nurtured. The effect, ultimately, is to elevate the entire economy, which can then further develop its underlying technology base, leading to another cycle of value added activity. However, as an economy's technology base develops, it takes ever increasing levels of value added to elevate it further.

Engineering services are the medium through which value is added, because they take information generated and processed through basic research and

TABLE 1
SERVICES AS A SHARE OF
GROSS DOMESTIC PRODUCT, 1970-1990

Year	Total Production	Goods	Services
1970	\$B 252	40%	60%
1980	\$B 382	37%	63%
1990	\$B 509	34%	66%

Source: *Canada's Service Economy: Facts and Figures, 1991*

TABLE 2
PRODUCER SERVICES AS A
SHARE OF TOTAL SERVICES, 1961-1990

Year	Government Services	Consumer Services	Producer Services	Value of Producer Services in Billions
1961	33.0%	30.6%	36.4%	
1970	34.9%	27.6%	37.5%	\$ 56.7
1980	32.6%	28.3%	39.1%	\$ 94.1
1990	28.9%	29.1%	41.3%	\$136.7

Source: *Canada's Service Economy: Facts and Figures, 1991*

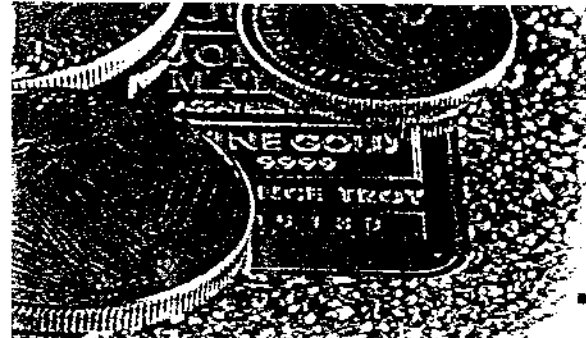
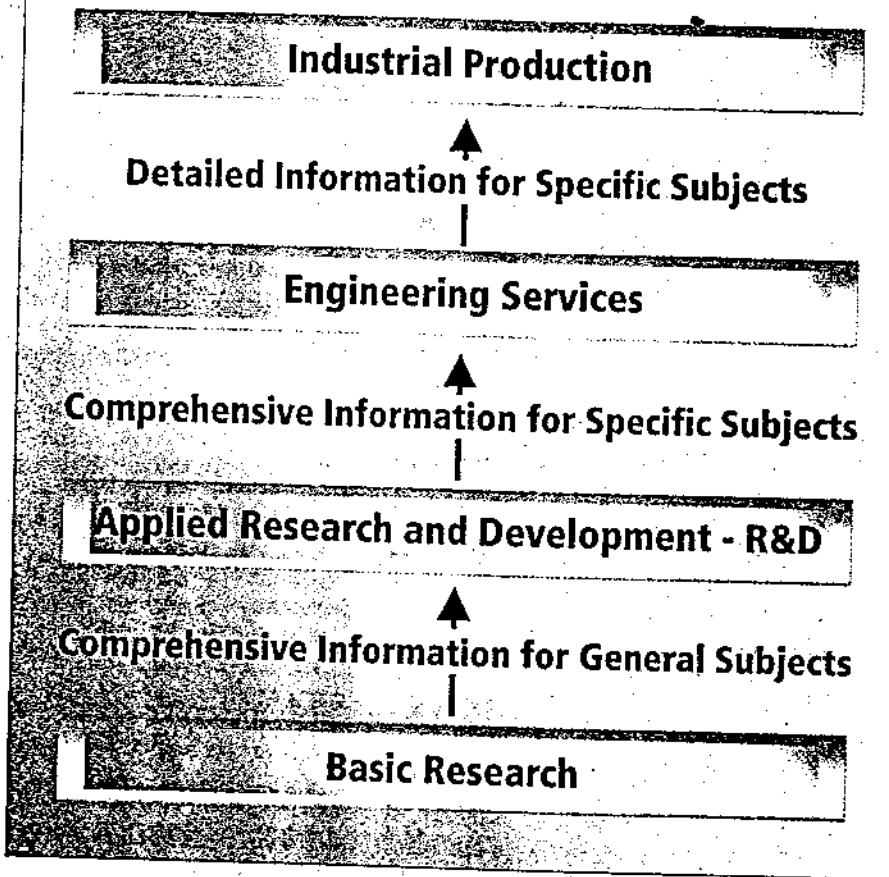


FIGURE 1

ENGINEERING'S ROLE IN PRODUCTION



R & D and focus it to solve specific production problems (see Figure 1). This process is called innovation. It is through innovation that technology is enhanced and the economy's technology base is elevated. In addition, engineering services link investors, entrepreneurs, technology holders, manufacturers of machines and construction firms, which all play a part in enhancing an economy's technology base.

Government Policy

What does this mean for government economic policy? First, that governments must begin to rethink their traditional economic assumptions, which cannot ac-

count for the relationship between technology development and economic growth, because they do not recognize its existence. Demonstrated by the increasing role of engineering services in Canada's economy, this relationship is central to economic development, yet traditional economic development policies have until very recently largely ignored it. Even so-called science and technology policies have largely targeted development of scientific and technical research, rather than recognizing engineering and technical services as the source of innovation.

Until governments at all levels begin to recognize a dynamic economic model in which the economy and technology in-

teract in a development cycle that adds value through innovation, our efforts to kickstart Canada's economy can be only partially successful. Canada needs a comprehensive national technology strategy that recognizes technology as the foundation on which our entire economy is built. Our national technology strategy should also be able to integrate a wide range of scientific, environmental, financial and economic development programs and policies.

Members of the engineering team, who transform basic information from research into value-added technology through innovation, have a major role in defining and implementing what our country's technology strategy should be. So far, however, this role has been little understood or appreciated. In the wake of the federal government's recent announcement on "Building a Federal Science and Technology Strategy" and the Ontario Premier's Council's Project on Innovation and Entrepreneurship (see sidebar), it's time for technical professionals to speak up so that their key role in economic restructuring can become part of any national technology strategy. ♦

Darius Mahdjoubi is an industrial consultant specializing in technology strategy and planning. He holds BS and MS degrees in mechanical engineering and has worked in plant design, facilities planning and establishing industrial factories. He is currently part of a team working to develop a municipal technology development strategy for Etobicoke.

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