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ENGINEERING HISTORY PAPER #77

"Engineering History with an Economic Twist"

by Andrew H. Wilson

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WORKING PAPER 1/1992

ENGINEERING HISTORY WITH AN ECONOMIC TWIST

by

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April 1992

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Abstract

The full economic impact of engineering as an activity over the longer-term is a subject that has received little public exposure. A lot of information does, of course, exist on the first costs of products that have been engineered, although this is not often discussed in public unless something untoward - like a significant over-run - has taken place. Operation and maintenance costs may also be in the public domain. Techniques - such as life-cycle costing and benefit/cost analyses - have been developed to deal with the longer-term. And textbooks have been written on the economics of engineering in the context of first and life-cycle costs and benefit/cost ratios. But the fact remains that these measures are too narrow and do not fully describe the economic impact of an engineered product. Much more needs to be taken into account. To further complicate the situation, not all of this impact can be pinned down exactly in the money terms on which economic analyses normally depend, nor is it always seen in a positive light. This means that different people may assess the net impact of a particular engineered product differently in historical terms. The main purpose of this paper is to explore this situation. The discussion is largely descriptive, however, and no stunning conclusions are offered.

About the Author

Andrew H. Wilson is a graduate mechanical engineer with training in economics. Currently a consultant in research policy and management, he served for almost 30 years in the federal public service of Canada. Some parts of this paper have been presented before - for example, at the CSME Forum in Toronto in June 1990 and in lectures to several CSME groups across Canada.

About the Working Paper Series

In June 1991, the Board of Directors of the CSME agreed that its History Committee should be responsible for the production of a series of Working Papers on topics related to the history of engineering generally and to the mechanical discipline in particular. These papers may or may not be authored by members of the Committee or the Society. They will have a limited initial distribution, but CSME Headquarters will maintain a small supply of copies for distribution on request. These Working Papers may subsequently be published, in whole or in part, in other vehicles.

INTRODUCTION

Many years ago, an engineering colleague said to me that, since he graduated, he seemed to have done little other than tell his employers and their clients how much the engineered products they wanted to make would cost. In fact, costing has always been a large part of the practice of engineering, and many engineers have considerable expertise in it. Some have even written text books on the subject, including sections on the techniques of life-cycle costing and benefit/cost analyses which 'take care' of the longer-term. But the problem is that, over the longer haul, the economic impact of whatever was engineered is not limited to the product alone. This includes not only the pre-manufacturing, pre-processing or pre-construction impact on designers and materials suppliers, for example, but also the post-manufacturing, post-processing and post-construction impact the product has had on its users and on the physical and social environments in which it has operated during a particular period of time. In the case of a bridge, this period could be longer than 50 years, and the calculation of all of the aspects of the impact an enormously complex task. In the case of an automobile engine, the period will be shorter, and dealing with the impact complexities may be a lot easier.

The product we call 'history' comes to us in written, spoken, and a variety of graphic forms, based on a variety of sources, as shown in Figure 1. These sources may be primary - mostly documents and artefacts - or secondary, such as books, articles, and magazines. Reminiscence may also be a useful, though not always reliable, source of history. The usual content of history is strongly political, with social and economic overtones. It seldom deals directly with engineering, technology or science, although the political, social and economic outcomes of the activities associated with them are often recognized.

The product we call 'economics' can be seen in several contexts - for example, as a textbook written by a professional which attempts to explain the subject matter, as articles in newspapers and magazines by 'economic' journalists, or as government papers and reports. Economics measures things in money terms but its conclusions can be disputed depending upon the disputants' points of view. In the last couple of decades or so, the scope of economics, and especially theory and prediction, has been expanded enormously through the application of the computer. It may also be a practical art, as practiced by the business person, or a theoretical one, as practiced by the university professor. Like history, economics tries to explain the past and the present, and it also tries to predict the future. But, as the late John Deutsch used to say, it is essentially a 'rearview mirror' type of analysis since, like history, its predictions are heavily based on the past. This is what makes it difficult for economics to deal with engineering, technology and science since they are sometimes

THE HISTORY CONNECTIONS

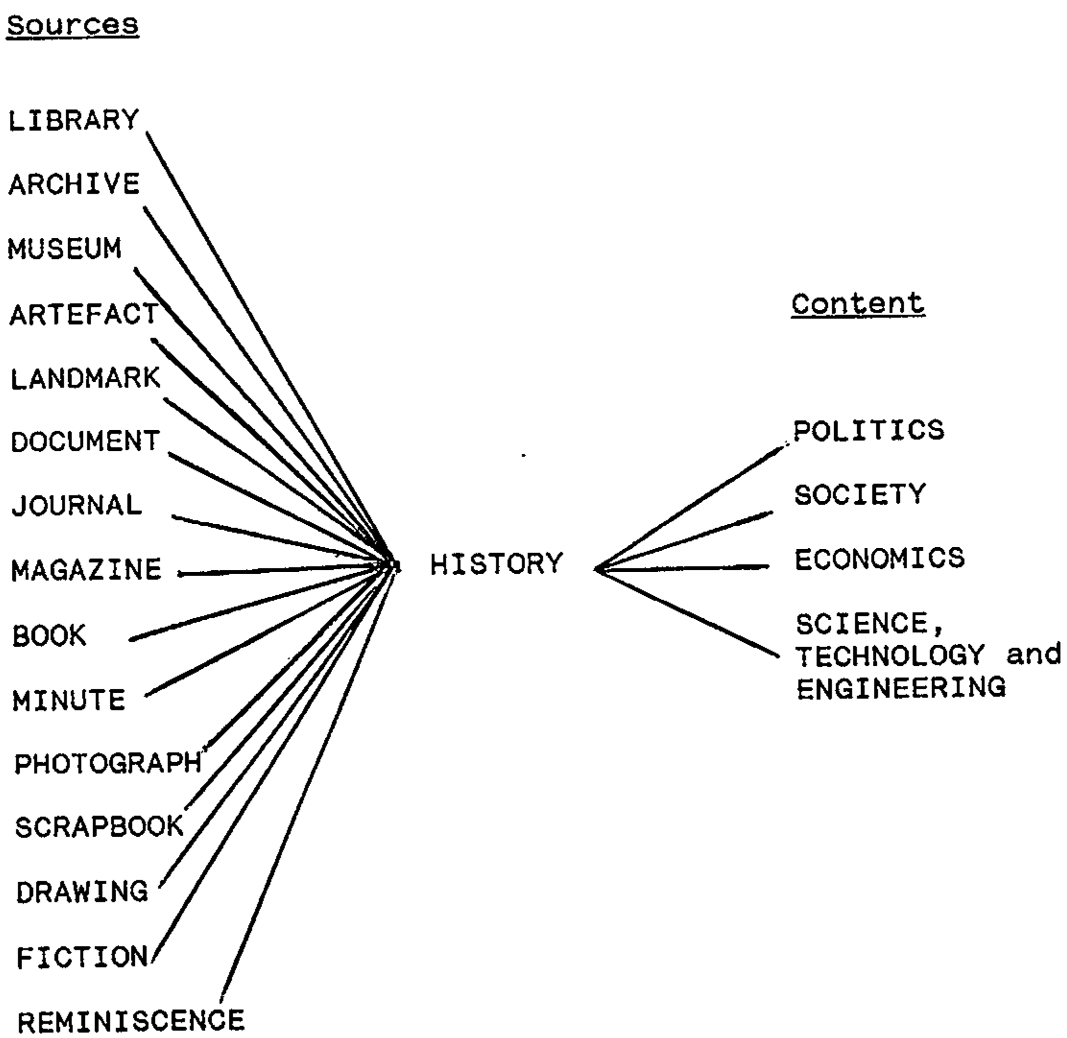

Figure 1

subject to rapid change, especially in a future-oriented context. I once sat in an economics class where the professor spent a great deal of time trying - in my view, unsuccessfully - to prove that economics was a science. That was many years ago, and the application of the computer to it during the intervening years has not changed my view.

Engineering is a professional activity. So are history and economics - or so their practitioners would have us believe, and they do have a point. And just as engineers may not be enthusiastic about historians and economists pontificating on engineering, so the historians and economists may look askance at an engineer who claims to be 'doing' history or economics. On the other hand, an interloper from one profession may well have a freer hand to suggest what might be called 'heresies' by the other professionals. So I will make no claim to be 'doing' history or economics, but will reserve the right to be a heretic - and this may be a good place to start.

FIVE HERESIES

These are relatively gentle, not at all earthshaking, but they may help explain the overall thrust of this paper.

The first may be called 'lifetimes and generations'.

Nowadays, the majority of people survive for around seven decades, but only a few may live for a full century. Nobody has experienced a millenium, although some buildings have! When you add this to the fact that most of what we might call the 'history of engineering' has happened in the last two hundred years, it becomes necessary to use some less conventional measures for the passage of time. I would suggest that, in addition to the decade, two others should be used: the lifetime and the generation. An average lifetime nowadays is around 75 years, and an average generation - at least until the 'boomers' came on the scene - has been around 25 years. So 2 1/2 decades make a generation, and 3 generations, conveniently, make 1 lifetime.

Using these new measures, James Watt was perfecting the steam engine in 1775, or roughly 3 lifetimes ago. Around 1840, or 2 lifetimes ago, Joseph Whitworth proposed the introduction of standard screw threads. In 1917, 1 lifetime - or 3 generations - ago, the Quebec Bridge and the Trans-Siberian Railroad were completed. In 1942, 2 generations ago, Fermi and his colleagues produced the first controlled nuclear chain reaction. And 1 generation ago, in 1967, the year of Canada's EXPO, the US Surveyor III spaceprobe made a soft landing on the moon.

It is, of course, always possible to extend this system of measurement 'backwards' beyond Watt and the Industrial Revolution - an economic period that itself lasted about a lifetime, and in which he played an important role. This puts the Seven Wonders of the World, for example, at between 30 and 40 lifetimes ago. The waterwheel was invented around 400 BC, or 32 lifetimes ago, and windmills 800 years later, or 21 lifetimes ago. Leonardo da Vinci lived only 7 lifetimes ago.

This system can also be applied to the history and development of Canada, as shown in Figure 2. From it we see that it was only 5 lifetimes ago that Champlain and Hudson were exploring the St Lawrence and the vast northern bay. Kelsey first saw the Prairies 4 lifetimes ago. The Peace of Paris, which ended the fighting between France and Britain over North America, was made just 3 lifetimes ago. The Act of Union between Upper and Lower Canada was passed just 2 lifetimes ago.

So if the decade is includes, this system establishes a practical, three-period scale for the study of engineering and its economic impact in a historical context.

The second heresy may be called 'contemporaneous events'.

History normally takes contemporary events into account when making political, social and economic analyses and judgements, so this second one is not terribly heretical in its scheme of things. What history often does is to ignore or downplay the influence of the engineering as an independent variable in its original analysis. But the problem seems to be more difficult in relation to economics, which tends to treat engineering as a more or less invisible 'given'. Like Mount Everest, as Leigh-Mallory said of his motivation for climbing it, engineering is taken for granted 'because it's there!'. But this problem actually serves to reinforce the need, when dealing with the economic impact of engineering in a historical context, to take economic, political and social factors into account. For example, the supply of personal computers over the past decade may well have been influenced as strongly by social as by economic pressures. The supply of paved roads in the remoter regions of the country may have been the result of political pressures, and the supply of military aircraft a result of political as well as economic pressures.

I have called the third heresy 'post invention/innovation'.

Not only does economic analysis tend to ignore engineering, when it considers science or technology at all it seems to give pride of place in this analysis to research and development which, it wrongly believes, is the only real well-spring of invention and

GENERATIONS & LIFETIMES

CANADA

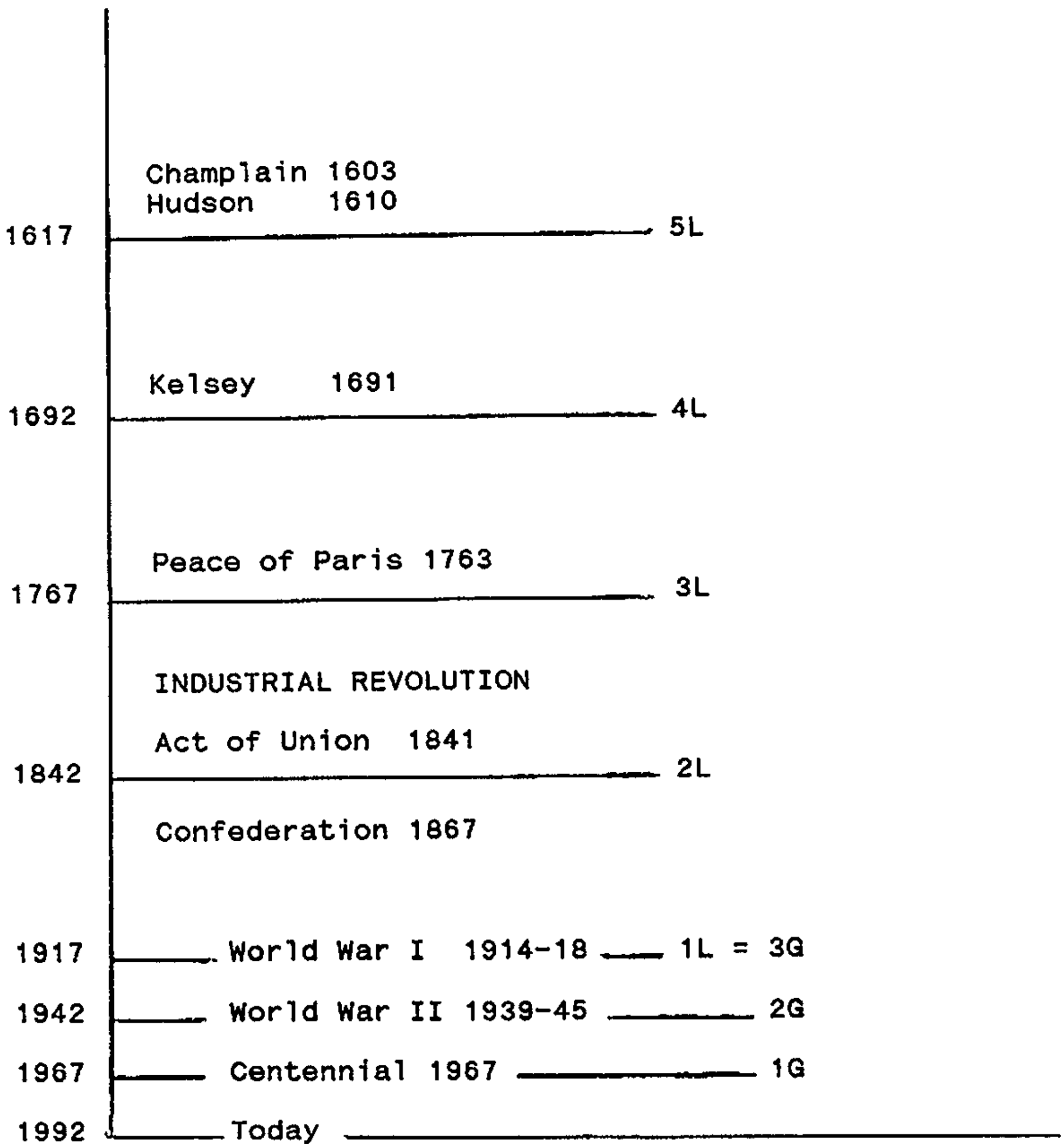

Figure 2

innovation. Indeed, economists have been trying for years - with only limited success - to develop a usable theoretical framework which links R&D with economic growth. It is quite clear, however, that the inventors behind a successful innovation <u>can</u> be scientists from a research laboratory - for example, the Shockley, Bardeen, Brattain team who invented the transistor, and we all know how it has influenced many other innovations and the techniques of engineering practice itself. But the chances are that the innovation stage which follows an invention is most often handled by engineers and their supporting technical people rather than by research scientists, since application is part of the essence of engineering. So it may well be that, in a particular analysis of the economic impact of an engineered product or process, account must be taken of the post invention/innovation stages - including those dealing with regulation - <u>as well as</u> those associated directly with research and development. Indeed, in many cases the R&D element may not be directly applicable.

The fourth heresy is that 'cost is not enough'.

As noted earlier, engineers are cost-conscious and also understand life-cycle and benefit/cost analyses as these apply to engineered products and processes. But the question has to be asked: Do they usually carry these analyses far enough to capture the full economic impact of what is to be, or has been, engineered? Indeed, in terms of money-based benefit/cost analysis, economists may in practice have the technical edge since they deal with both micro measurements, such as the costs of individual engineered projects, and with macro measurements relating to productivity, incomes, investment, gross domestic product, and so on. Both sides are perhaps equally comfortable with 'hard' money-based numbers which carry the assurance of certainty. For example, Building X cost $100 million to design, erect and make operational, and in the first ten years the operating costs averaged $1 million a year. But full impact analysis requires that benefits and costs be calculated <u>in both directions</u>, that is, before the product was made or built as well as afterwards, and including - where applicable - the benefits and costs of any relevant R&D, as well as the benefits and costs incurred by the owners, users and others, in addition to the $1 million a year already mentioned. Among these 'others' are tax-collecting governments with their hands in the pockets of owners and users alike but who, earlier, may have subsidized the relevant R&D or some aspect of the engineering or construction.

There may, however, be some of the 'before and after' benefits and costs that are not exactly calculable in 'hard' terms - only in terms of ranges or other 'soft' figures. And still others may be in dispute or not calculable at all - as, for example, in the case of environmental improvement or damage, or where the benefits/disbenefits are in related to personal comfort or discomfort.

The final heresy has to do with the 'engineering process', which has been laid out in Figure 3.

Basically, engineering will not be done at all unless there is an actual or potential client or customer, to which should be added the enterprise/entrepreneurship of the engineers willing to undertake the work. So, while engineers may take credit for the engineering that is done, they may have to relinquish to others some or all of the credit for those other activities that go into engineered products and processes, such as entrepreneurship, financing, research and development, the education and training of the people involved, and the setting of appropriate regulations. Also, the engineers who do the engineering are not always in possession of all of the information needed to complete their part of a project and must seek this from 'outside' sources, which could include engineering and other types of consulting firms. And the engineers are not always the eventual owners or operators of the product or process.

In other words, to engineer a product or process usually requires the inputs, resources and talents of several different kinds of people. In this light, the activities of development, design, manufacturing, processing and construction - which are the principal engineering ones - become linked with what I have called in the Figure the 'science', 'experience and technology', 'education and training', and 'planning and consulting' connections. They are also linked to research, financing, purchasing and supply, quality control, inspection, regulation, operation, and maintenance, and to ownership - all of which, to complicate matters, may have engineering components.

So when we speak of the economic impact of engineering, we are speaking about the impact of a process, the central element of which is engineering. Putting this in a historical context, we are then able to identify the continuum of activities, over time, which contribute to this impact.

A FRAMEWORK

The measurement of the economic impact of engineering in a historical context is not an easy thing to do, for reasons which emerge from the discussion above of the heresies. Ideally, this measurement should take the form of a 'hard' benefit/cost ratio or multiplier, covering a decade, a generation, or a lifetime - or even 2 lifetimes, if we are looking at the engineering impact of railroads, for example. For each million dollars spent on engineering, the economy-at-large will benefit to the extent of ten, twenty or fifty million dollars, or whatever. But there are some of the difficulties.

THE ENGINEERING PROCESS

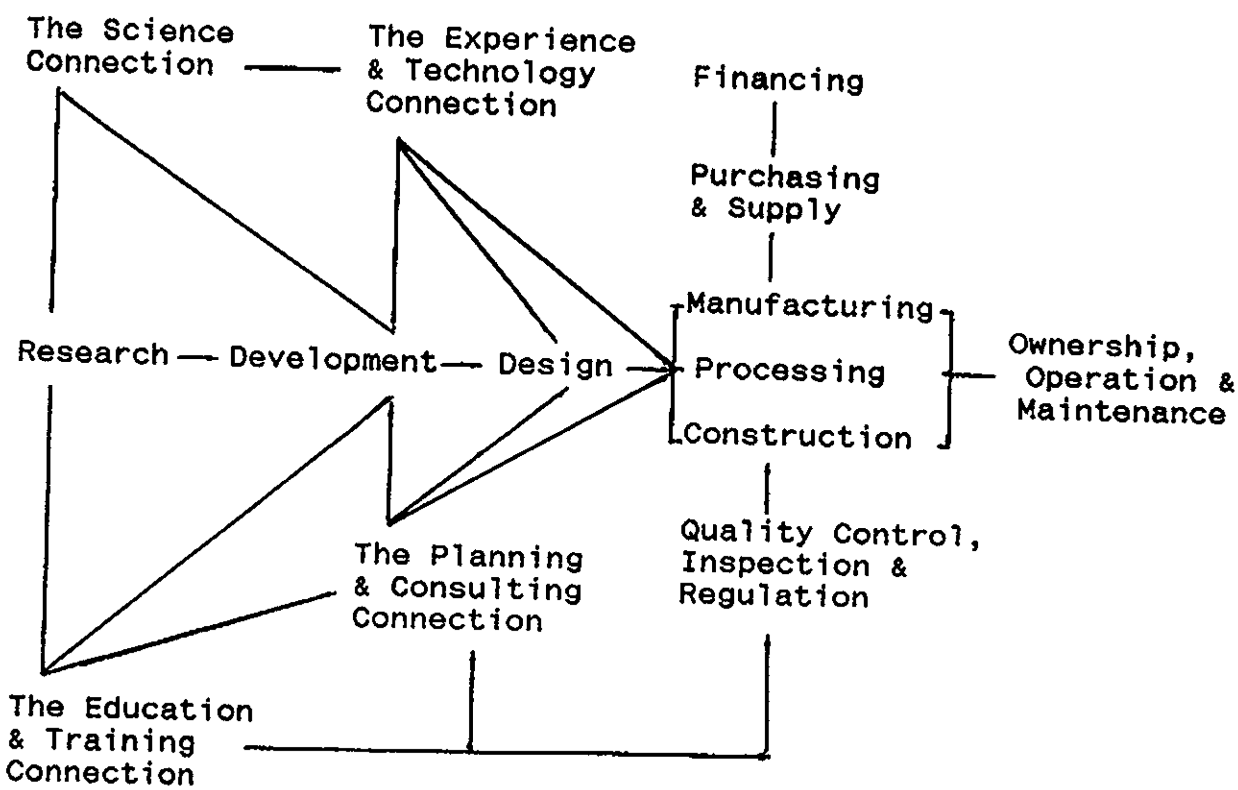

Figure 3

One of these concerns time, and it gives rise in turn to several 'sub-difficulties'. For example, with regard to railroads, should we count up the benefits and costs since these were first engineered in Canada in the 1836, limit the arithmetic to the CPR, CNR, or the other railroads, or to specific period in which important engineering progress was made? Then there is a decision to be made when doing the arithmetic for longer periods of time or for periods of high inflation: Should current or constant dollars be used and, if the latter, for which base year? And even if this question is settled, can we realistically compare a decade in the 19th century with one in the 20th? Time also changes the technology which engineers use. But not only money values and technology change, so do laws, regulations, relative values and standards in both the social and political senses, employment and trade patterns, and the roles of governments.

Another difficulty concerns the engineering profession itself, and again there are some sub-difficulties. For example, at the beginning of the 20th century there were only a few thousand engineers working in Canada. Fifty years later, this number had risen to 13,000, and as we approach the Year 2000, the number should exceed 150,000. The number of engineers per million of the Canadian population has increased accordingly. In other words, the potential of the profession to contribute to economic impact has increased significantly over only 1 lifetime. But what was once, is now, or will be a decade from now, the optimum number of engineers for Canada? This is not an easy question to answer since in engineering, unlike medicine or law in which practitioners practice for all or most of their working lifetimes, there is a tendency for many of those who begin in practice to move to less technical and more managerial positions as their careers progress. They may nevertheless have a significant influence on what engineering is done.

Yet another difficulty is to decide how - or if - meaningful comparisons can be made between engineering work done in the different disciplines. For many years, the dominant one in Canada was civil, with its application to infrastructure and buildings of all kinds. More recently, the non-civil disciplines with the largest memberships - mechanical, electrical, chemical, and metallurgical - have been growing in importance as a result of the growth of manufacturing in Ontario and Quebec and of processing in the rest of the country. Mining is as old as civil in its influence, but is relatively small nowadays in terms of the numbers of practitioners and graduating students. Much the same may be said about agricultural and forest engineering. And disciplines such as petroleum have grown since World War II, but only in one section of the country. The economic impact of the disciplines has therefore been quite uneven, and has been changing rapidly over the last generation.

Then there is the problem of dealing with Canadian engineering for clients and customers abroad , and the participation of Canadian consulting firms in this market, especially over the last generation. Undoubtedly this activity has contributed in some measure to the Canadian economy and to the development of expertise that could also be applied domestically. But there are two questions that still need to be answered: What has been the economic impact abroad of the work done for foreign clients and customers? And what has been the economic impact in terms of the spin-off benefits to Canada?

Yet another difficulty is determining how far 'down the line' economic impact should be traced. For example, engineering firms earn profits, which they may distribute or retain for further investment. Their engineering and other staffers earn salaries and wages for their work and spend these on housing, food, transportation, vacations, and many other things, and they pay taxes which governments then spend. Similarly, a hydro project will provide needed power to users in industry and in the public sector, from which further products can be made and revenues earned. These 'secondary' products can then be sold, some of them in the domestic sector where further earnings are not a prime consideration. The hydro plant itself may also have some impact on the physical environment, and this may be deemed positive or negative, or some of both, depending on the views of those affected. But this particular impact may not be calculable in conventional dollar terms. Similarly, some of the products made using the power from this plant may deemed be environmentally enhancing or damaging. And some degree of economic impact will also accrue through those who take advantage of the earnings of those who engineer a product or those who own or use it. For example, the employees of the food stores use their wages to buy their own groceries. And so it goes on.

In spite of these difficulties, it is possible to put together a framework for the analysis of the economic impact of engineering, in which the benefits and costs associated with the following are examined:

- the engineering itself, and the other parts of the process that may be relevant;

- the supply of materials, equipment, services etc. for what was engineered;

- the ownership of what was engineered;

- the initial or subsequent use of what was engineered;

- the advantage taken by others of the economic impact accruing to those in the four categories above;

- the advantage taken by still others of the economic accruing to those in the fifth category above.

And this is probably as far as we should go.

A full-scale analysis of the application of this framework has not so far been attempted, and cannot be until sufficient case-based information has been collected. In all likelihood, the first attempts will be fairly simple, will involve few benefits/costs to which judgement rather than money measures need to be applied, and will cover only 1 decade or generation. However, from a historical point of view, some of the more interesting analyses will go back many years further. They might possibly include some of the 10 outstanding examples of Canadian engineering which were recognized in 1987 during the profession's Centennial - for example: the St Lawrence Seaway, the Québec High Voltage Transmission lines, the 'Beaver' aircraft, and the Polymer Plant at Sarnia. To these might be added the Peterborough Lift Locks, the original power plant at Niagara Falls, the CN Tower, the Old Pumphouse at Hamilton, the two Halifax-Dartmouth bridges, the Lion's Gate Bridge at Vancouver, and the irrigation systems in Southern Alberta.

Meanwhile, using some simplifying assumptions and a little imagination, it may be possible to anticipate what such an impact study might look like when completed using the framework suggested above.

Assume a small, conventional diesel-engined power plant, built in 1925 and in operation until 1950, and a zero inflation rate for the money involved over that time. Assume all of the 'hard' and 'soft' numbers represent costs alone or benefits net of costs. Suppose the original engineering cost for design etc. was $500,000, and the cost of building it and getting it started-up was another $5 million. Assume that the operational cost averaged $500,000 per year throughout its lifetime, and that at the end of this lifetime the building was demolished and the engines etc. consigned to scrap. Suppose that those who owned the plant earned an average of $1 million a year, net of expenses, that all of the users of the power, together, earned an average of $10 million a year, net of expenses, on products which they would not have made in the absence of the power. Assume that the net gains to those who took advantage of the earnings of the people involved in the engineering, manufacturing and construction, power production and use cannot be determined precisely but could possibly be within the range of $5-8 million a year. Finally, assume that there were no adverse environmental or other 'judgemental' effects from the building of the plant, but that there were some associated with its operation and with the uses of the power produced. The economic impact arithmetic may therefore look something like this, with the figures representing total $ millions:

	Hard Numbers	Soft Numbers	Judgements
	$ millions		
Original engineering	1/2	-	-
Materials & Start-up	5	-	-
Operation	12 1/2	-	Environment?
Owners of power	25	-	-
Users of products of power	250	-	Environment?
Takers of 'Advantage'	-	125-200	-
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	293	125-200	

The overall 'hard' number multiplier, therefore, is 275/18, or just over 15, meaning that the engineering and operation of the plant resulted in subsequent net economic gains 15 times as high over the 25 year period. In addition, there were some considerable 'soft' gains in the range of 7 to 11, but some environmental concerns that could be the subject of debate. Whether or not the 'hard' and 'soft' gains would be wiped out as a result of this debate must remain as speculation!

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