The Value of Engineering to Society

A Different Perspective on Engineering Ethics

A monograph designed as a basis for cooperative development of the subject between philosophers and engineers

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1 Introduction

The work of engineers, i.e. *engineering*, is a significant component of our culture. This was noted e.g. by C.P Snow [1] and S.C. Floorman [2], and in the decades since their books appeared, the importance of that component and its visibility in society has increased exponentially. Just look around, and everything we see, every appliance, our furniture, housing, clothing, books, cars, roads, power supplies, much of our food; everything was produced by processes and machines created by engineers as applications of *technology*. It is therefore reasonable that any philosophical enquiry into the human condition; our existence, society, and values should take account of engineering, and accordingly the last fifty years or so have seen an increasing interest and activity in the philosophy of engineering, or, perhaps more appropriately, in the connection between philosophy and engineering [3].

However, society does not experience the work of engineers directly, but as the output of a process that converts engineering into *services* desired by society or groups within society. As a result, engineers and engineering are, to a large extent, invisible to society (even though the process is often called "the process of engineering", as will be discussed in Section 2). The entity that embodies this process is what we, in a general sense, call *industry*, and because engineering and its application of technology are hidden within industry, it is common to use the word "technology" for the view of industry presented to society in the form of the services provided. There is a considerable literature and current activity by sociologists and philosophers related to this meaning of "technology", such as in Science and Technology Studies (STS) and in the Philosophy of Technology, and although there is often no mention of engineering or engineers, much of this material is relevant to the purpose of this monograph. We shall only have to carefully define how we use those terms that have a somewhat different explicit or implied meaning when the focus shifts from industry to engineers, and that is the main content of Section 2.

The role of engineers can be viewed from a number of perspectives, including as independent professionals, as employees in industry, and as members of society, and they will all have to be considered in order to understand how engineers relate to society. That is the main content of Section 3, which continues earlier work by the author [4] and focuses it on the subject matter of this monograph – the value of engineering to society.

The intersection between philosophy and engineering is not easily delineated or defined, and any collaboration between philosophers and engineers in exploring this intersection is made difficult by their very different approaches to their work: the utilitarian, practical, and (in the view of the philosopher) simple-minded approach of the engineer, and the critical, contemplative, and (in the view of the engineer) unproductive approach of the philosopher, as described by Goldberg [5]. Another issue is the tendency of philosophers to view engineers in an idealised and independent fashion, much as they view scientists, and this is understandable, given the much greater maturity of the philosophy and history of science. But this may then mask some of the essential features of engineering that arise from it being embedded in industry. However, these difficulties cannot mask the nexus between philosophy as the understanding of our existence and engineering as an increasingly important component of that existence.

The most immediate aspect of the connection between philosophy and engineering is ethics, and so a significant part of the literature is concerned with ethical issues in engineering; either explicitly or by implication [6]. Much of this, as reflected e.g. in the various Codes of Conduct produced by engineering institutions, relates to the behaviour of individual engineers in their contacts with other engineers, clients, and other members of society with whom they come in contact in a professional capacity. In Section 5 we shall see that the concept of the value of engineering puts a different perspective on the relationship of ethics to engineering.

Another immediate connection is in the area of epistemology, where a philosophical approach can be applied to the nature and acquisition of engineering knowledge, and numerous publications have appeared in this area (see e.g. Section 2 of *Philosophy in Engineering,* referenced in [3], and also [7]).

The connection of the metaphysical concept of value to engineering is less immediate, and sometimes what is presented as a component of the value of engineering is, on closer reflection, an issue of ethical behaviour. An action can be ethical without having any value, depending on the definition of value. As an aside, one might ask "does ethics have any value at all?". Or is the maxim "do to others as you would have them do unto you" a simple recipe for the destruction of the human species? The core of the difficulty of developing the concept of the value of engineering is that value is in the eye of the beholder and depends on personal belief or a personal value system, whereas ethics of personal behaviour, although also not without a dependence on individual belief, has a much more generally accepted foundation. Accordingly, Section 4 is concerned with developing the philosophical perspective on value that underlies the application of this concept to the relationship between engineering and society.

Because engineering is involved in producing most of the items that we use and consume every day, it is very natural to equate the value of engineering with a cost-benefit measure, as in "for only $400 this TV is really good value", and similarly for the projects that produce the goods and services; their value is measured by a parameter such as Return on Investment. That is not what is meant by value in the present context; if it were, then it would be related to accounting and have little connection with philosophy. The concept of the value of engineering to society presented in Sec. 5 is an attempt to develop a measure that provides a basis for considering such issues as the influence of engineering on the relationship between the individual and society and engineering's role in the development of that society. In particular, on an abstract level, the value of engineering should be seen as engineering's contribution to sustaining and increasing the quality of life and to the ongoing evolution of the intellectual component of our existence. Engineering has so far led to significant improvements in our daily lives by providing us with more spare time; however, the value of that spare time is greatly reduced if it is only spent surfing the Internet, fiddling with a mobile phone, or in the pursuit of what has been termed "conspicuous consumption". Those issues, and the reluctance of engineering to confront them, constitute the underlying reason for the decline in the standing of the engineering profession in the opinion of society, and it is the purpose of this monograph make a start on confronting them by elaborating the implications of the question: What is the value of engineering to society?

The present monograph draws together and expands on notes, lectures, and publications by the author related to the subject of the value of engineering, reflecting over fifty years of practice gained in the US, Switzerland and Australia, covering fields as diverse as microwave components, power electronics, quantum electronics, and communications, and ranging from basic research to corporate management. It is the view of an engineer and not that of a philosopher, but placed in a framework that should be familiar and reasonably acceptable to philosophers. It is also, as are most works of a philosophical nature, a work in progress, and intended as much as a current personal understanding as an invitation to further debate and development. In particular, it expands on a previous publication with a similar title [8], which was an initial attempt at providing a semi-quantitative model of the value of engineering, but from a utilitarian point of view rather than embedded in a philosophical framework. However, as mentioned above and as will be discussed in Sec.4, any definition of value is inherently embedded in a belief system, and the belief underpinning our value concept is presented there.

One of the forums dedicated to exploring the connection between philosophy and engineering is the forum on Philosophy, Engineering, and Technology (fPET). fPET-2012 was hosted by the University of the Chinese Academy of Sciences in Beijing; and fPET-2010, the inaugural meeting, was held in Golden, Colorado at the Colorado School of Mines. The papers presented at fPET-2012 [9] demonstrate the many and varied issues that connect philosophy and engineering; ranging from ethical issues to the identity of engineers in society and the purpose of engineering education. However, in a more or less directly identifiable manner, the issue underlying them all can be summarised by the concept of “the good life”; a concept first used by Socrates [10] in the sense of a virtuous life based on reason. Because engineering is a ubiquitous and ever more intrusive part of our lives, the value of engineering must in some way be related to how engineering influences our ability to lead “the good life”. This relationship immediately identifies the two main issues we shall have to clarify before we can attempt any assessment of the value of engineering: how engineering interacts with and influences our lives, and how we define “the good life”. But even before that we need to have a clear understanding of what we mean by such terms as “engineers”, “engineering”, and “technology”, something that has been emphasized previously by Koen [11], and so the structure of this monograph is as follows:

1. Introduction (this section)
2. Definition of Engineering and Technology
3. Relationship of Engineering to Society
4. Philosophical Framework
5. Value in the Context of Engineering
6. Implications for Engineering and Society

Because it is hoped that this monograph might provide the basis for discussion and further development of the concept of the value of engineering, particularly within fPET and also within the Royal Society of NSW, the sections are presented with their own references, so that, if so desired, discussions can be directed at individual sections. The nature of the subject matter is inherently a combination of philosophy and engineering, and so only a forum with a corresponding combination of participants will be able to address it adequately.

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2 Definition of Engineering and Technology

As a prerequisite for any investigation into the value of engineering, we need to have a clear understanding of the meaning of the terms "engineers" and "engineering", as well as the meaning of the related term "technology", and provide definitions that are useful. That is, they must be complete and unambiguous, and they should fit into an accepted *ontological framework*. There are numerous definitions of engineering; for example:

"The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation or safety to life and property" [1].

"The application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems" [2].

"The work of designing and creating large structures (such as roads and bridges) or new products or systems by using scientific methods" [3]

"The branch of science and technology concerned with the design, building, and use of engines, machines, and structures; the action of working artfully to bring something about" [4].

"The discipline, art and profession of acquiring and applying technical, scientific, and mathematical knowledge to design and implement materials, structures, machines, devices, systems, and processes that safely realize a desired objective or invention" [5].

These definitions are neither entirely consistent not specific enough to provide a point of departure for developing a deeper understanding of what engineering is. In particular, by combining activities like "designing", "constructing", and "use of" on an equal footing, they seem to imply that these are equal components of engineering and, by implication, of what engineers do. This has the effect of obscuring and submerging the essence of engineering in its industrial environment and thereby making it very difficult to assign any precise meaning to such a concept as "the value of engineering", as will be discussed in considerable detail in later sections of this monograph. In order to develop adequate definitions, we first need to develop a common vocabulary, we need to understand what engineering *is about*, in the sense of the *things* we speak about in engineering. The totality of these things is what is used to express the engineering Body of Knowledge; it is obviously going to be a very large and complex vocabulary, and although we will need only a small part of this vocabulary for our purposes, we will need some form of systematic approach in order to develop it.

An ontology can be defined as consisting of a set of specifications, each of which specifies a concept. The specification specifies the meaning of the concept, the properties of the concept, and its relations to other concepts in the ontology. Meaning is defined within a "universe of discourse", i.e. the Body of Knowledge, and the properties follow largely from how the concepts are used, the level of detail required, etc. The relations are of two types – a hierarchical *class* structure of the concepts within the ontology, and the relationship to the grammatical structure of the language in which the ontology is expressed.

There are a number of such frameworks, or upper ontologies, and a common one is shown in Fig. 2.1. It is based on the Introduction to Ontology by Munn and Smith [6], but with the formal ontological relations amended by adding the relations between properties and processes, making properties symmetrical with regard to substances and processes.

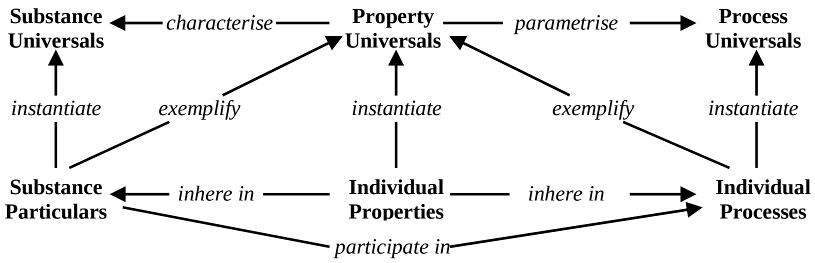

Figure 2.1 The ontological sextet and the formal-ontological relations.

A previous publication [7] outlined an ontology based on this upper ontology; for our purposes here we only need to focus on the category of processes. Within this category we can distinguish a sub-category of *purposeful processes*; these are processes that have a purpose formulated by humans, as opposed to other processes, such as the change of seasons, erosion, and the processes taking place within stars. A purposeful process satisfies the following criteria:

a. It is created and/or performed by people (the *practitioners*)
b. It has a *purpose* defined by a group of people (the *stakeholders*)
c. It is performed within a *timeframe*, starting with the definition of the purpose and ending when either the purpose is deemed to have been achieved or the attempt to achieve it is abandoned.
d. It has a *resource base*, from which the resources required to achieve the purpose are extracted.
e. It has a *knowledge base*, from which the knowledge of how to apply the resources is extracted.

The requirement for a purposeful process to take plane within a timeframe, as stated in criterion c, may at first seem an unnecessary restriction, as there are many purposeful processes that appear to be progressing with no time limit. An example would be the process of education. However, on closer examination, that process is really defined in terms of the change in the state of individual persons within a definite timeframe, and it is the multitude of these individual instances of the process that goes under the general name of "education".

The category of purposeful processes contains two sub-categories. One is what we shall call *realisation processes*; these are processes that convert the results of intellectual work into *services* useful to society or to groups of society. The other sub-category is what we shall call *professional processes*. These are distinguished by the extent of the knowledge bases and the intellectual effort required by the practitioners to acquire and apply this knowledge; in effect, by the investment in education and experience. This sub-category includes the class of engineering processes, but also a wide range of processes outside of engineering, such as medicine, dentistry, architecture, and economics. Professional processes are further distinguished by the fact that each one is related to and, to some extent, embedded in, a corresponding realisation process. Law is related to law enforcement processes (without which law would be without value), medicine is related to health care processes, and so forth. Engineering is related to the *industrial processes*, which are processes that involve a conversion of natural resources in order to fulfil their purposes, but the distinguishing feature of engineering is that *every instance of the* *engineering process is embedded in an instance of the industrial process* (this is also true of architecture, which is embedded in a subset of the industrial processes: the building industry). This means that we cannot consider the value of engineering, or any other effect of engineering on society, without considering the associated industrial process. Engineering without industry is just like dreaming.

The foregoing framework is illustrated in Fig. 2.2.

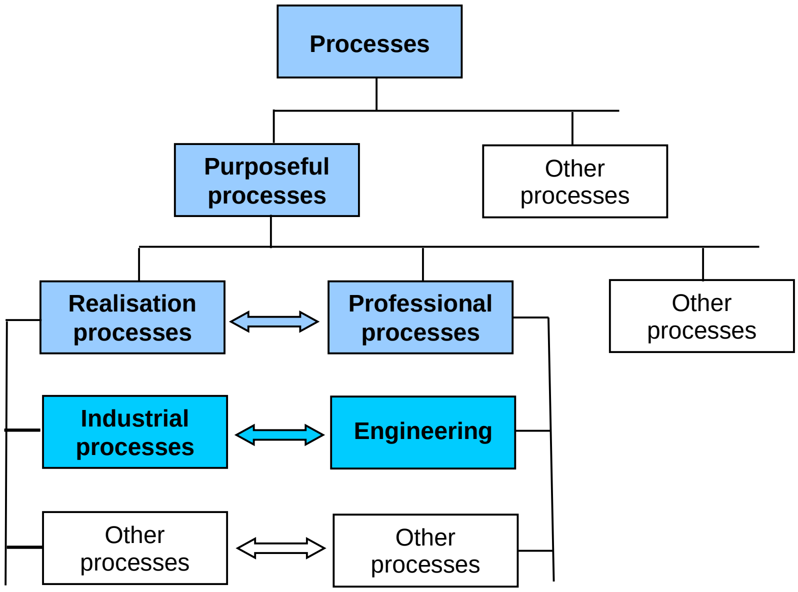

Figure 2.2 The framework of processes within which engineering is defined.

If we call an instance of a process a project, then every engineering project is embedded in an industrial project. Each of these two projects has, according to the definition, a purpose. *We shall now assume that the two purposes are identical.* This will allow us to consider the concept of "the value of engineering to society" as being provided directly by industrial projects, which in the following are simply called *projects*, and indirectly as a contribution by the engineering within these projects. To what extent this assumption is true, and if so, if this congruence is appropriate, and also the consequences of any discrepancy, will be discussed in subsequent sections.

The embedding of engineering within industry is a major difference to other professions, such as medicine, where there is a direct interface between the profession and society, as illustrated in Fig. 2.3, and this fact will be a major factor when we consider the relationship between engineers and society in the next section.

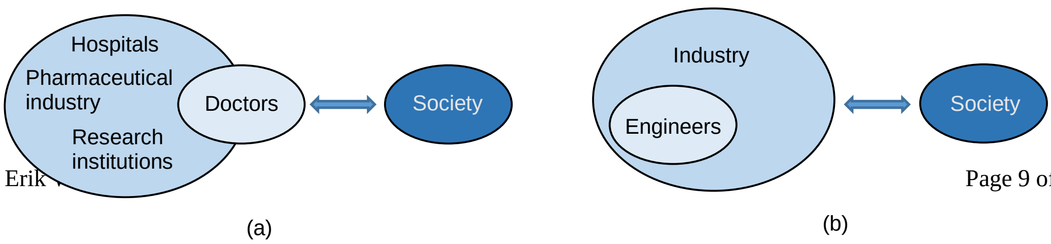

Figure 2.3 Doctors, in (a), have a direct interface to society, whereas engineers, in (b), do not.

At this point it is necessary to point out a semantic problem: It has been common to refer to the whole process of providing a service that meets an expressed need as "the process of engineering", both because engineers are, to varying degrees, involved throughout the process, and because the general public does not see inside the process and so uses convenient labels like "technology" and "engineering" without reflecting on the precise meaning. This common usage was also adopted in a previous publication by the author [8], but it is not appropriate for the current purpose, where we are concerned with a philosophical aspect of the relationship between the work of engineers and society, as opposed to the role of engineers in the commercial relationship between industry and society. That is why we have identified engineering as a separate process, albeit embedded in an industrial process.

Achieving the purpose will in almost all cases require the participation of numerous people and professions besides engineers, such as business people, economists, environmental scientists, trades people, labourers, investors, and users (i.e. the market). Consequently, the actual involvement of engineers, although essential, may constitute only a small part of the expenditure on a project, and the outcome of the project, i.e. the extent to which it fulfils its purpose, may be only partially determined by the engineers. As we shall see later, it will be useful for us to view this multitude of project participants as consisting of three groups: the engineers, the *technical workforce* and the rest. The technical workforce includes technologists, technicians, drafters, and trades persons; all persons that require access to the combined knowledge and resource bases we call *technology*.

The resource base consists of the millions of standard construction elements, ranging from reinforcing steel bars to microprocessors, that engineers and the technical workforce can draw on in executing projects, as well as the facilities within industry for fabricating and constructing plant. The knowledge base is comprised of textbooks, standards, published papers, operating manuals for tools and instruments, etc, and spans a continuum from advanced research to Tables for everyday use. Both of these bases are dynamic: new construction elements are continually being added and older elements are being phased out; new knowledge is being generated through research and experience, and what was advanced knowledge yesterday is tomorrow's accepted practice. The importance of these two bases in engineering was noted in [11], and handling this continuous transformation, as well as the current exponential increase in volume, becomes an important factor in increasing the value of engineering to society, as we will see in Sec. 6.

The point to note here is that, in the sense of understanding, maintaining, and being competent in using, various actors relate to different parts of technology, as illustrated in Fig. 2.4. This structuring is defined formally, and to a large extent also in practice, by education and training, but experience and individual interest and aptitude can result in a significant blurring of the boundaries. For the present, we shall define an engineer as someone with a degree from an accredited four-year university course and meeting certain requirements for Continuing Professional Education (CPE). Engineers are the practitioners of the process of engineering, and the engineering disciplines, such as civil, chemical, electrical, and mechanical engineering, are distinguished by the subdivision of the resource and knowledge bases reflected in their education.

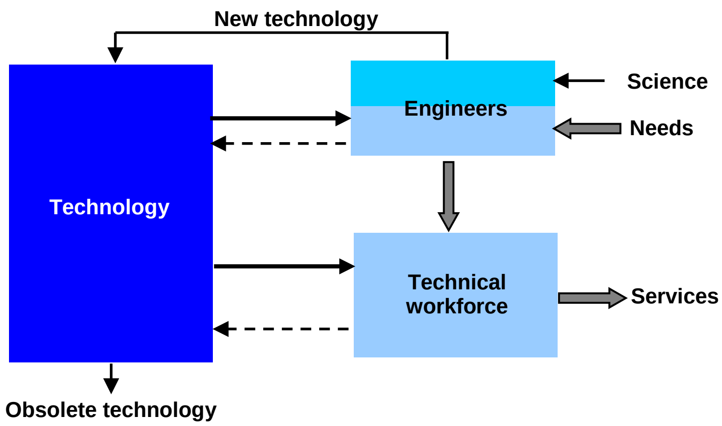

Figure 2.4 The interaction with technology by engineers and the technical workforce. The dotted arrows indicate that all engineering projects provide some input to technology in the form of experience, and the subdivision of the engineers illustrates the two types of engineering projects (see below).

The identification of the resource and knowledge bases as constituting "technology" is a deviation from the use of "technology" by philosophers and sociologists, where it is used in a much more encompassing manner, such as "the production and use of artefacts". And many publications on the philosophy of technology make no mention of engineering at all. However, while much of what philosophers say about technology can be reflected onto engineering; it is important to keep the distinction in mind; in particular, the above definition of technology does not include any activity. Whereas philosophers see technology as an activity (or at least including activities), as e.g. in [12], no engineer would speak of "doing technology".

The concept of "technology" is also used extensively in sociology, as we shall consider in some detail in Sec. 3. The tension between the usage of "technology" in engineering and in philosophy and sociology was discussed briefly in [13], but a useful perspective on the everyday use of the concept is given by Leo Marx [14], where he shows that the character and representation of "technology" changed in the nineteenth century from discrete, easily identifiable artefacts (e.g. a steam engine) to abstract, scientific, and seemingly neutral systems of production and control. As a result, the newly refurbished concept of "technology" became invested with a host of metaphysical properties and potencies that invited a belief in it as an autonomous agent of social change, attributing to it powers that bordered on idolatry.

A closer inspection reveals that the above definition of engineering is philosophically inadequate and circular, in that the definition of what constitutes technology is determined by engineers, and engineers are the practitioners of the engineering process, which is again defined by technology. The same problem, in a slightly different guise, was discussed by Davis [9] and again by Mitcham [10], but they concluded that a pragmatic approach is acceptable as a basis for philosophical enquiries into characteristics of engineering. In this case it means simply accepting that engineers are persons meeting minimum standards of education and practice defined by nationally and/or internationally recognised professional engineering organisations or institutes (e.g. for admission as Chartered Engineer), and engineering is the work done by engineers.

The requirement for each project to have a purpose allows us to distinguish two groups of engineering projects according to the nature of their purposes:

- projects that utilise the existing resource and knowledge bases to meet a *need* expressed by all or a part of society; and
- projects that increase the resource and knowledge bases.

Let us agree to call these two groups of projects *application projects* and *development projects*, respectively; this grouping will be useful in what follows, and was already anticipated in Fig. 2.4. However, in practice there might not be a sharp delineation between these two groups of projects, and in any case, every application project also leads to an increase in technology, if by nothing else than simply by acting as an example for later projects, as also indicated in Fig. 2.4.

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3 Relationship Between Engineers and Society

3.1 The Industrial Environment

Engineers, as defined in the previous section, can be characterised in a number of ways, such as

- and independent group of professionals;
- employees in industry; and
- members of society.

While we shall occasionally consider various roles, for the purpose of this monograph we shall generally view engineers as a group of professionals within industry, and it is primarily in this role that we shall investigate their interaction with society in this section.

The relationship between engineers and society involves numerous actors, is multi-faceted, largely indirect, and dynamic; in short, it is complex. And so, in order to develop a better understanding of it, we can adopt a systems approach and view all the entities involved as elements of a system, with an architecture determined by the interactions between the elements. The properties of this system and, in particular, the relationship between engineers and society, can then be explored by viewing this system from a number of perspectives. That is done in this and the next three subsections, and the first such view is that of the environment in which engineers work.

In the previous Section we saw how engineering is always embedded in a project. In the context of a specific project, industry encompasses everything directly involved in executing and completing that project. The inclusion of the word “directly” is important, and for now an intuitive understanding is hopefully adequate. For example, the machine tool operator that goes to work every day on the project is directly involved, whereas his wife, who stays at home and manages the family life is only indirectly involved. The debt provider (e.g. bank) is directly involved, whereas the people who put their savings into the bank are only indirectly involved.

The meaning of “industry” in a general sense, without reference to any particular project, is then simply everything directly involved in executing and completing projects. This industry has an internal structure; it consists of legal entities called *enterprises*, and examples of such enterprises are private companies, public companies, sole traders, incorporated joint ventures, and government bodies or corporations. Projects are carried out within a legal framework created by the enterprises directly involved in the projects and the interfaces between them, which take the form of *contracts*. The nature of this framework varies significantly, from the case where multiple projects are performed completely within a single enterprise to the case where a single project is performed through the involvement of numerous enterprises in a framework containing several types of contracts, such as alliance contracts, lump sum contracts, and cost-plus contracts. This framework defines not only who does what, how, and when, but also who carries the liability for the various possible deviations from the agreed project performance.

Within this framework, each engineer is *employed* by an enterprise. This is also a contractual relationship, defining rights and obligations of both parties. Besides requirements for ethical behaviour, a central requirement is for the engineers (as for any employee) to support the aims of the enterprise, and irrespective of other aims, the aim of any enterprise must be to make a profit, without which it will generally not survive. Thus, the individual engineers on a project find themselves enmeshed in a set of relationships and requirements that may be complex and, in many cases, somewhat contradictory. This is illustrated in Fig. 3.1, and we need to keep this picture in mind throughout the rest of this monograph. In articles and presentations considering the interaction between engineers and society, one can sometimes find that this discussion proceeds as if it were a direct interaction, as e.g. in the case of doctors and patients. As we shall see, that is the exception; the majority of that interaction, and thereby the engineer's ability to provide value to society, takes place within the industrial environment outlined above.

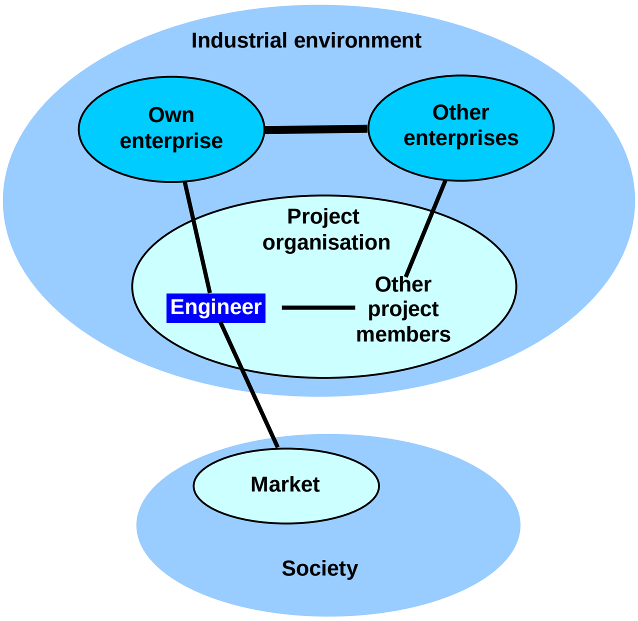

Figure 3.1 The industrial environment, in which the individual engineer is enmeshed in a complex set of requirements arising from the contractual relationships between all the participants,

Within a typical project organisation, engineers are required to interact with a number of other members, including, besides other engineering disciplines, technologists, drafters, project support and management staff, owner's representative, and the debt provider's representative. Some of these interactions are part of performing the engineering tasks, and they are shown as heavy lines in Fig. 3.2, whereas others are related to the many non-technical actions an engineer needs to undertake in order to integrate the engineering into the overall project.

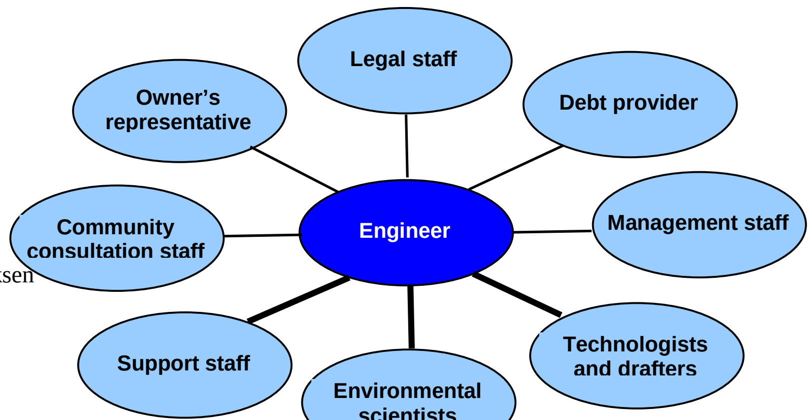

Figure 3.2 The interactions between engineers and other members of the project organisation. Interactions related to technical activities are shown as heavy lines.

Finally, there is the fact that all the project members shown in Fig. 3.2 are also members of society, and so the industrial environment provides a further, quite direct relationship between engineers and society. However, this relationship is, as far as transmitting any value to society, again limited by the requirements of the project and the necessity of giving "what's good for the project" priority.

3.2 The Sociologist's View

An interesting view, although somewhat peripheral to our purpose, is represented by a very significant body of work within sociology that treats the relationship between technology and society. This work is clearly related to the subject matter of this monograph, but there are some significant differences, and the first of these is the meaning and treatment of "technology". Most of the items of this body of work do not contain any definition of "technology", and where there is an implied definition, such as in the Introduction to [1], the relationship of society to technology is seen as a relationship to things. And while engineers are mentioned, there is relatively little interest in how engineers relate to technology. Nor is there much discussion of the relationship between industry and technology. It appears that sociologists view technology mainly as a "black box", relying on our intuitive and everyday understanding of the concept, and focus on its external interactions.

This is in marked contrast to their treatment of society, which is considered to be a complex system and subjected to a variety of views, such as gender, social status, education, power, etc. And so, this deeper understanding of the nature of society on the part of sociologists and the better understanding of engineering, industry, and the internal workings of "technology" on the part of engineers could be an area of fruitful collaboration between the two disciplines.

Sociologists also appear to take a more pragmatic approach; they do not worry so much about if something is "good" or "bad"; they are mainly interested in understanding how it works. How does technology influence society, and *vice versa*? And so they view the world as a giant laboratory in which experiments are going on all the time, and they observe, record, and analyse. The result is numerous and varied valuable insights into the interaction between society and technology and, in particular, the understanding that this is a two-way interaction; something that resonates strongly with the view of the value of engineering developed in this monograph. Quoting again from [1], the view that technology just changes, either following science or of its own accord, promotes a passive attitude to technological change. It focuses our minds on how to adapt to technological change, not on how to shape it. It removes a vital aspect of how we live from the sphere of public discussion, choice, and politics.

In studying the works of sociologists, it is also important to recognise what appears to be a frequently shifting framework. In this monograph, we are focusing on a single relationship, that between engineers, as a well-defined professional group, embedded in industry, and society, defined as the people affected by engineering projects. In sociology, the boundary at which the interaction takes place varies. For example in [2], Bijker proposes a theory of technological development based on three detailed case studies, and demonstrates that sociotechnical change cannot be understood as the product of one prominent actor, be this inventor, product champion, a firm, or a government body, but involves all of these in essential ways. Here, society comprises all of these actors, and technology is the "thing", in these three cases the bicycle, bakelite, and electric lighting. But in an article by Hughes [3], where he introduces technological momentum as a concept located between technological determinism and social constructivism, the interface is between the technological system, which is close to what we call industry, and (the rest of) society.

Finally, in this very limited review of some of the relevant works in sociology, the article by Callon [4] relates to our view of engineers and their potential for contributing value to society. He questions the claim that it is possible to distinguish, during the process of innovation, phases or activities that are distinctly technical from others, such as economic or commercial. It is often believed that at the beginning of the process of innovation the problems to be solved are basically technical and that the economic, social, political, or indeed cultural considerations come into play only at later stages. But right from the start, all these considerations have been inextricably bound up into an organic whole.

3.3 The Content View

This view is concerned with the *content* or type of the interaction between engineers and society, and it is useful to adopt a high-level framework, based on the definition of engineering provided in Sec.2, and illustrated in Fig. 3.3.

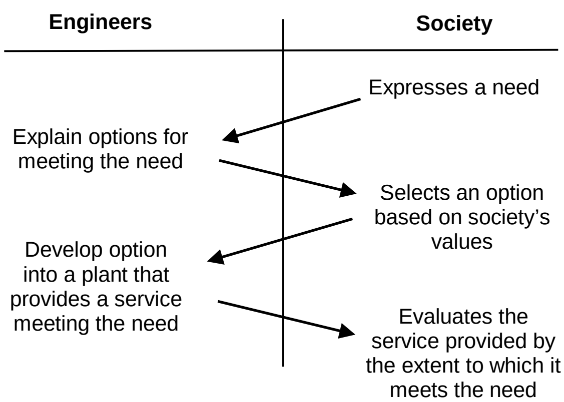

Figure 3.3 The relationship between engineers and society, as instantiated by a project.

There are a number of points to note about the process depicted in Fig. 3.3:

a. The term "society" means all of or any group within society, such as a particular segment or market, an industry, a company, a government body, etc.
b. The term "service" must be understood in a wide sense. It is whatever is required to satisfy the need; it may be a service in the narrower sense, such as education, health, or transport services, it may be providing infrastructure services, such as electricity, gas, water, and waste water services, or it may be providing products, such as food, clothing, houses, cars, toys, etc.
c. The term "plant" means the physical object that provides the service. It usually consists of a combination of equipment, structures, and organisations, in widely varying proportions, and includes all activities required to provide the service, such as design, manufacturing, operations, maintenance, sales, etc.

What this simple picture suggests is that the interaction between engineering and society may be thought of as taking place on two levels, or as being of two kinds, although in any particular project it may be difficult to completely separate the two. At the upper level, engineers provide advice and information to society, and the value of this activity is measured by the extent to which it supports society in making decisions about the best options. Of course, in making such decisions, a great deal more than engineering advice and information is often required, but the engineering component would be dominant, and so it is the responsibility and duty of the engineers to ensure that the advice and information is complete, accurate, and unbiased. The use of the expression "advice and information" is important, because while information is factual and can be verified, advice is based on experience and involves the engineers' judgement, and it is in providing (or withholding) advice that ethical issues arise.

At the lower level, the activity of the engineers is to ensure that the selected option provides its specified service at the lowest overall cost, where "overall cost" includes not only acquisition, operating, and maintenance costs, but also cost of environmental impact, of accidents, of blocking future options, etc, and so this provides a more clearly defined measure of value. While still involving experience, this activity is much less dependent on judgement, as it is heavily circumscribed by standards, legislative requirements, and, generally, by technology.

3.4 The Interaction Channel View

The two-level picture presented above, while useful in developing an understanding of the value of engineering, does not account for what is the most important aspect of the interaction of engineers with society: the *interaction channel*. In the great majority of projects, engineers do not interact directly with society, but through the intermediary of industry, as illustrated in Fig. 3.1, and this indirect mode of interaction is one of the main differences between engineering and two other professions; medicine and law. This difference has been pointed out by various authors [5] and is alluded to in an essay by Mitcham [6], to which we shall return below. Again, a simplified picture is useful, and we can consider the interaction channel to be one of three types. In the first type, engineers interact directly with society through involvement in public inquiries, by providing articles in newspapers and magazines, by appearing on TV panels, etc. In the second type, which is quasi-direct, engineers provide advice and information to public institutions and departments, such as defence and various infrastructure (energy, water, transport, etc.), and, perhaps most importantly, through education. In the third and most common type, engineers work within the industry structure required to realise a project; a framework that involves many other people besides engineers, including politicians, business men, lawyers, financiers, marketing and sales personnel, technicians, tradesmen, and labourers, so that what society experiences is often influenced only to a limited extent and in an indirect manner by engineers. And, what is equally important: society has little insight into and understanding of exactly what this extent and manner are. These three types of interaction channels are illustrated in Fig. 3.4.

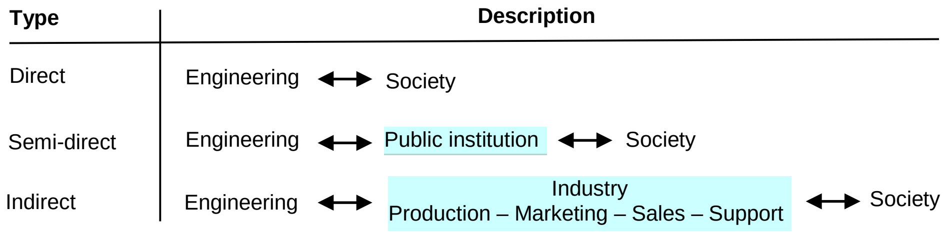

Figure 3.4 Schematic description of the three interaction channels.

While the first two channel types are more or less direct, even here the engineers are imbedded in an industry structure. The education industry has its own agenda, as does the consulting industry, and engineers are, just as in the third type of channel, constrained by the agendas of their employers. It is the employment situation that is a main difference between engineering and the two other professions (although the independence of doctors and lawyers is being eroded, too), as discussed in [5]. The peculiar situation engineers find themselves in is that they are both employers and employees; not like ordinary workers, where their organisations – the unions – are quire distinct from their employers and their organisations. Not only are the two roles of engineers, employers and employees, evident in industrial companies, but also in the organisations that are supposed to represent the interests of engineers, such as the institutions of engineering. In these organisations, the leadership is usually from the management side of either industry or academia, and there is a potential, and often a real, conflict of interest. The adage “what is good for General Motors is good for the US” is here represented by “What is good for industry is good for engineers”.

Through the two first channels, engineers can be seen to provide engineering input to public policy and advice to policy makers. This role is discussed in a recent paper by Mitcham [7], in which he refers to a book by R. Pielke Jr [8]. That book is concerned with science policy, but it distinguishes four basic roles of an adviser that would seem to be equally applicable to any profession and, in particular, to engineering. These roles are: pure knowledge exponent, advocate, arbiter, and honest broker, and an important measure of these roles is the level of professional knowledge involved in the interaction. It is highest in the case of the pure knowledge exponent – so high, in fact, that the interaction is probably close to useless. It is also quite high in the case of the honest broker, as society will be required to have an in-depth understanding of the implications of the options put forward. The arbiter essentially performs requirements elicitation in order to bring society's understanding of the issues involved to a point where society can make its own decision, employing and (hopefully) imparting a modicum of professional knowledge along what can be a lengthy process. The least use of professional knowledge in the interaction is in the case of the advocate, but it is also the case most susceptible to industry interference, making the engineer a salesperson for particular industry interests.

3.5 The Process View

Much of the early work on the influence of technology regarded it as taking part between two separate spheres of existence; a genuine (or intrinsically, or unsullied) human sphere and a sphere in which technology is prevalent. Technology was seen as developing under its own imperative, and so the interaction was a one-way process, with conflicts arising at the interface between the two, and with humans sometimes seen as the "victims" of technology. More recent work sees the interaction as a process that is both two-way and so dynamic that it is not possible to make a clear-cut distinction between humans and technology. Humans are always hybrids of supposedly human and technical aspects, and what is of interest are the different kinds of human-technology interactions. This is treated in an article by Dorrestijn [9], to which we shall return in Sec. 5 in a discussion of the relationship between value and ethics; in the present context it is interesting to note how this two-way process is reflected in the system introduced in the beginning of this section. All of the actors in this system (or actor-network, as used e.g. by Callon [*op. cit*]) become hybrids, and so the relationship between engineers and society takes on a dynamic character.

The important point here is that when we, in Secs. 5 and 6, consider how engineering can provide value to society, it is not the one-off value of what engineering delivers to society, but the value of how what engineering delivers changes the *development* of society. The hybrid changes, and it is this hybrid that drives the development of society.

3.6 Further Aspects of the Relationship

An important aspect of the relationship between engineers and society is *alienation*; a concept attributed to Hegel, but developed in much more detail by Karl Marx, as described and analysed by Wendling [10]. Marx was concerned about the alienation of workers (or the proletariat), but the analysis provided by Wendling is highly relevant to the present work; we just have to specialise workers to engineers and capitalism to industry. Basically, alienation means that humans lose (or are alienated from) part of their essence as humans by the conditions in which they find themselves, and for Marx, this alienation had five overlapping dimensions: theological, political, psychological, economic, and technological. For each dimension, there is a corresponding metaphysical object into which the human essence is alienated: God, the state, ruling class ideology, the commodity, and the industrial machine.

In the case of engineering, engineers are being alienated from the essence of engineering, which most definitions of engineering manage to capture in a more or less satisfactory manner as the development and application of technology for the benefit of mankind, by being embedded in the metaphysical object of industry. Industry has its own ideology and norms, described by such concepts as profit, value, turnover, growth, return on investment, efficiency, loyalty, etc, and as long as these norms appear as natural features of society, rather than as something imposed on society, there is little incentive for engineers to question their current role or these norms.

The realisation that the role and outlook of engineers is conditioned by industry is not new; in the essay *The Captains of Finance and the Engineers*, Thorstein Veblen wrote; "It is perhaps unnecessary to add the axiomatic corollary that the captains have always turned the technologists and their knowledge to account in this manner (for their own gain) only so far as would serve their own commercial profit, not to the extent of their ability; or to the limit set by the material circumstances; or by the needs of the community" [11]. It is also discussed as part of a recent essay by Newberry [12]. In particular, he makes reference to the suggestion by Noble [13] that industry has forcefully shaped the mechanisms for engineering education and professional socialisation in order to produce a "domesticated breed of engineers". However, it is important to realise that this "domestication" is not a malicious behaviour, nor is it a lack of regard for engineering, nor an attempt to subjugate engineering, on the part of industry. On the contrary, industry supports engineering through grants and prizes. It is simply that the current view and utilisation of the engineering profession has become so entrenched that few even entertain the thought that it could be different, and even fewer see that it should be different. If one wants to consider the role of engineers in society, and their social and political responsibilities, one must first look at the current role of engineering in industry. It is not a role ordained by Nature; it is a role that has developed and received its current characteristics as part of the capitalist system, and it is a role that can be changed.

A well-known example of the interaction between engineers and society, and of how this interaction is modified by industry as an intermediary, is the issue of standardisation. Engineers see standardisation as a means of rationalising the industrial design and production processes and lower the cost of products to society; it is also something desired by society for a number of reasons, including ease of replacement, reduced need to learn new operating instructions, and greater ability to maintain and repair products. However, industry often sees standardisation as detrimental to branding, differentiation, market position and, in the end, to their profits. Here is a conflict of interest only too familiar to all of us in the form of the variety of chargers for mobile electronic devices. This conflict was also recognised and detailed by Veblen in his two publications, *The Theory of Business Enterprise* [14] and *The Engineers and the Price System* [11], and has been analysed in an article by Knoedler and Mayhew [15].

The issue of engineering's relationship to society is discussed by Mitcham [6] under a different and somewhat narrower perspective: Is the education of engineers adequate for them to fulfil their obligations with regard to public safety, health, and welfare? He concludes that it is not, stating "a philosophical analysis of engineering reveals a substantive inadequacy, not to say incoherence or contradiction, in the profession: a commitment to public safety, health, and welfare that is incapable of enactment". He then goes on to illustrate this by a comparison with medicine and law: "The first-order ends of health and justice operative in the professions of medicine and law, respectively, are not enclosed within some second-order end of public good; they are the public good. In engineering, by contrast, the first-order technical end, however defined, which was once assumed to be itself a public good, is now conceived as subordinate to a second-order end that is not operative in the profession itself." This analysis pinpoints the problem, but then relates it to an inadequacy of the engineering education, which, in our opinion, is a "second-order" source of the problem. Firstly, one has to ask: Why is "the technical end" no longer considered a public good? Surely, more than ever, it is technology that is underpinning our daily life? Secondly, the assertion that the commitment to public safety, health, and well-being is not "operative in the profession itself" needs some careful qualification. There are certainly many examples of this commitment; one of the most outstanding one is provided by a great engineer, Gustave Eiffel, who constructed the Eiffel Tower in the 1880s without a single fatality and with concern for the safety of the public using the tower [16]. It is important not to sheet home to "the profession" what is really a feature of industry. And, thirdly, while the analysis correctly assesses the issues relating to engineering education as it applies to public safety, health, and well-being, this needs to be put into the context of engineering education in general and its appropriateness for addressing all the issues relating to the application of technology in our society.

The diminishing role of engineers in society has been recognised and discussed for decades, an example is the paper delivered by Sutcliffe at the IEAust Engineering Conference in 1986 [17]. He correctly identified most of the symptoms of the problem, but did not identify the employment situation and the role of industry as the main causes, nor did he suggest what practical measures could be taken to improve the situation. An interesting aspect of this paper is the implied view of engineering as elevated above business, and that the requirements of engineering excellence should take precedence over such mundane issues as cost and schedule. This is exactly the view that has done much to diminish society's regard for engineering, and while it is not a view accepted by the engineering community in general, it can still be perceived in both the education and published work of engineers.

3.7 The Influence of Risk

An important factor in the relationship between engineering and society is the (lack of) understanding of the concept of *risk*. On the one hand, risk is encountered in everyday life in various guises: the risk of an accident, the risk of draught, the risk of bad weather or flood, the risk of one's house burning down, the risk involved in any new enterprise, and so on; it is basically the uncertainty associated with the future. It is something that is accepted without too much introspection, and we are aware that some risks can (and some must) be insured against. But when it comes to engineering there is a hidden assumption on the part of society that statements by engineers have an absolute value and that services provided by projects are defined in absolute terms, instead of realising that they are subject to exactly the same uncertainty. As a result, this uncertainty is translated into a perception of engineers as untrustworthy. Engineers are getting better at making this uncertainty explicit (which is why engineering documents are starting to look more like legal documents), but there are a couple of factors that are causing problems in this regard.

One relates to the risk of exceeding budget and/or not completing work on time. Most engineers are quite conscious of adhering to cost and schedule, but often the costs put forward by management at the start of a project are deliberately less than the best estimate in order to win the work or for the project to get approved, so that an overrun against the original budget is already built in. Also, if an estimate is given as X ± 30%, there is a tendency to publicise only the value X, and so anything above that appears to the public as an overrun.

Another factor is a lack of understanding of what is meant by "random", as in "random failures" or "random fluctuations". It means that there is *no* control over when the failures or the fluctuations will take place, nor is there any control over the rate of occurrence; it is simply an observable parameter. And, furthermore (and this is not well understood even by some technically trained persons), there is no accessible "root cause"; if there were, we could control the occurrence of the events by controlling the root cause. But random failures are often presented to the public as faulty design, and even major industrial companies can have a requirement for "zero probability of a fatal injury".

Society's perception of risk, and what level of risk is acceptable, is extremely context dependent and also highly subjective and emotional, as the acceptance of tens of thousands killed in automobile accidents every year demonstrates. In this regards, risk has many similarities with value, as we shall see.

3.8 Summary

In summary, and for the purpose of this investigation into the value of engineering, the main point regarding the significance of the relationship of engineering to society is that this is mainly an indirect relationship, with industry, in its various forms, as the intermediary. That is, the picture we need to keep in mind is that shown in Fig. 3.5. Only rarely do engineers interact directly with society, free from any considerations of their ties with industry.

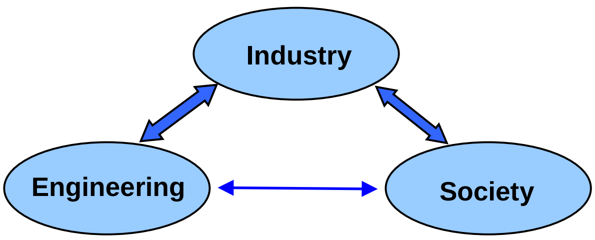

Figure 3.5 The relationship between engineering and society, with industry as an intermediary.

The interaction between engineering and society can be characterised by level (content) and channel type. The role of industry in directing and restricting the interaction is most pronounced in the lower of the two levels in Fig. 3.3, but it is also the level where it is most appropriate, as the aim of engineering to provide society with a good product at the lowest price is, to a large extent, also the aim of industry. It is in the upper level that engineers have lost credibility and let themselves become sidelined by industry and vocal, special-interest groups.

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4 Philosophical Framework

Why do we need to establish a philosophical framework in order to investigate the concept of the value of engineering to society? In the next section we will propose that the value of engineering can only be understood as the extent to which it enables society to realise "the good life", and the form of that enabling can only be of a material kind. Engineering does not supply any spiritual guidance or support. However, while what engineering provides to society is material in nature, the basis on which it is evaluated can be spiritual or religious. For example, if the evaluation is based on the belief that Nature is God's creation and any tampering with it is an abomination, it is clear that engineering will not fare very well. Therefore, as we want to propose a measure of the value of engineering in the next section, we must first define the philosophical framework within which it is intended to apply. Such a definition should be as simple and clear as possible (recognising that philosophy is not simple and the author is not a philosopher), and not include anything that is not relevant to the purpose.

Before embarking on this task, we need to keep in mind that what we shall develop is a philosophical perspective on the value of engineering to society; it is not an attempt to fit engineering itself into a philosophical framework or to the discuss the many connection points - ontological, epistemological, and ethical - between philosophy and engineering, although we shall comment briefly on the connection between value and ethics in the next section. The evolution of the interest in the relationship between philosophy and engineering, and in building a philosophical framework for engineering, has been described by various authors, such as Mitcham [1] and numerous articles and further references can be found in [2]. Engineers are seen as being motivated by the challenge of being able to do something that has not been done before; extending our control over Nature, developing faster, smaller, more powerful and efficient devices, and the like, whether there is a practical need for these or not. The engineering can be seen as an expression of an inherent human need to overcome uncertainty and fear of the unknown, and to be able to dominate and exploit our environment. It may be the same force that drives evolution, the force reflected in our belief in "progress" and our worship of "growth", and it is a force about which there are divided opinions. Dessauer [3] saw it as an expression of God's plan for mankind, which would lead us to independence from material restrictions and elevate us to a spiritual level. Heidegger [4] recognised the achievements of engineering and the benefits of technology, but thought that there were already indications that this force was controlling us, that Nature in itself was losing its value and becoming simply something to be exploited, and that a run-away situation could arise. And Ellul [5] essentially saw the force as evil and the evolution of technology as the Devil's work. And, of course, we should not forget how we were banished from Paradise by tasting the forbidden fruit of the tree of knowledge [6]; a parable that makes the engineer's role somewhat akin to that of the snake, tempting society to move ever further away from its "natural" state.

The classification of a philosophical framework is, to a non-philosopher, a daunting task, with a multitude of possibilities. Under "list_of_philosophies", Wikipedia lists hundreds of –isms and related classification terms. However, for the purpose of locating the framework on which our evaluation of engineering is based in this maze, we can proceed by a process of elimination, which will quickly let us focus on a much smaller subset. Firstly, if we consider all the –isms to fall into two main groups, those that have a deist or religious foundation, and those that are secular, then our framework shall be located in the secular half. Engineering can only influence the material qualities of human existence; if they are subservient to a higher authority or ideal, any attempt to assign a value to engineering becomes indeterminate. If an eleventh commandment had been "Thou shall not engage in engineering"; well, that would have put paid to any value of engineering with one stroke of the chisel, so to speak.

Society is a system with individuals as the smallest elements, and it is the interaction between individuals that determines the characteristics of a society; these characteristics are the emergent properties of the system. An important component of that interaction is the moral component, and through the acceptance of Kant's categorical imperative humanity can, if properly ruled by moral and judicial laws that are held in common, maintain a society that, although thoroughly human, nonetheless represents a harmonious and ordered whole. However, while such a harmonious and ordered whole may be a necessary condition for "the good life", it is not sufficient; the categorical imperative defines what an action must conform to, but does not say anything about what actions one should engage in, or if one should engage in any at all. Similarly with politics; it is necessary for a society in order to manage different viewpoints and desires, but it is not sufficient. For a view of the actions to be undertaken by an individual, we might turn to Nietzsche. Although often reviled for some of his more extreme views, such as "war is good", a recent book by Luc Ferry [7], which is highly relevant to the purpose of this monograph, explores the positive aspects of Nietzsche's view of the most enlarged or valuable life as the most singular, the richest, the most intense life; as a life rich in diversity, but without conflict (Nietzsche's "grand style"). The driver is the will to power, but "power" should not be interpreted narrowly as physical power, but rather as power over one's self; the power to exercise one's abilities to the full. Simplistic, romantic notions of "the good life" as happiness or harmony with Nature, as a cow standing in a field of clover or, as Kant remarked, an oyster in its shell, discount the essential human characteristics of intelligence and will and do not give any meaning or aim to life.

In his book, Ferry explores Nietzsche's view of human life, as we are living it now, in the present, as the proper object of our thoughts. Nietzsche was not an amoral person; he just believed our values should be based on our own analysis and judgement of life as we are experiencing it, not on some external authority or deity. Ferry quotes Deleuze [8] stating this as "instead of the unity of an active life and an affirmative thought, one sees thought take on the task of evaluating life, of contrasting it to values claimed to be superior and judging it by those values, of limiting it, of condemning it. In so doing, thought turns negative, we see life depreciated, ceasing to be active, reducing itself to its weakest forms, morbid forms compatible only with the so-called superior values." However, Ferry also points out that basing our philosophy on what is human does not have to mean that we reject any form of transcendence, if by transcendence we understand "immanent, not created by reason" rather than "an external agency". Kant introduced "transcendental" in the sense of "a priori", something not produced by our senses, but which allows us to perceive objects as objects, and there is no reason why there would not also be something "hard wired" into our brains that would influence how we form value judgements. In contradistinction to materialism, where values are produced by humans, values, or the basis for making value judgements, are in the human and have to be discovered. Ferry call this "horizontal transcendence" rather than "vertical transcendence"; that is, it is focused on fellow humans rather than on a deity, and he gives good arguments for why this appears to be so, and that this is indeed a central component of what it means to be human.

Our philosophical framework is therefore located within secular humanism, and this philosophical perspective provides the basis for the definition of the value of engineering to be developed in the next section. However, there is a very important implicit assumption involved in accepting that perspective: the belief that increasing the scope of human will is beneficial or, in other words, that the human will as the force now driving evolution will lead to a better life, as we have defined it. To put it very simply, the belief that a collection of "good" elements interacting to form a system (society) will also be "good". Given the complexity of human nature and, consequently, of the interaction between humans, it is very difficult (or impossible) to see what all the emergent properties of society will be as it evolves under the rapid increase in the modes and intensity of the interactions. In view of recent episodes, some scepticism with regard to a "good" outcome is understandable, but is there really any alternative? There can no longer be any doubt about the fact that the development of humanity and our environment is driven by us. We are no longer the pawns in Nature's game of the survival of the fittest in a distribution created by random mutations; we run the game. Adam Smith's "invisible hand" is no longer invisible; it is our hand.

Our belief is based on an analysis of human history. Despite many setbacks, in the form of wars and ideological subjugation, there can be little doubt that the "richness" of life, both on the average and in total, has increased exponentially in historic times. In most of the world, the opportunities for self-fulfilment available to the average person through material well-being, education, and an intellectually stimulating environment have led to societies that are again promoting those same factors, while attending to the various issues, moral and otherwise, accompanying that development. While it may appear that "the good life" has become synonymous with material success; it must not be overlooked that the access to and participation in all forms of art and political, scientific, and religious discourse, as well as a greater understanding of our environment through education and widespread dissemination of information have greatly increased the non-material content of the average person's life.

To recapitulate, then, under this perspective the ultimate "good life" is whatever humanity is developing toward, driven by the human will, and at any point in time "the good life" is a life that supports and promotes that development by enabling the free exercise of the will. It is, in this sense, a differential definition of "the good life", recognising the dynamic nature of society. Such a view of a dynamic society and of engineering as an integral feature if it has been put forward by Wang [9]. He argued that if we see both engineering and human nature from the evolutionary perspective, there is no conflict between them, and engineering will aid that evolution by overcoming human limitations and improving physical and mental conditions.

It is, perhaps, the manner in which the issues accompanying the development of society are dealt with that is most controversial, and as in all matters whose consequences lie in the future, there is the concept of *risk*. That is most easily illustrated when it is applied directly to one of the technologies driving the evolution of our society, such as nuclear power or genetic engineering, and this was essentially what was discussed in the previous section, but there is a much subtler, underlying issue: Consider humanity on a global scale, structured into regions, nations, communities, organisations, families, and individuals; all interconnected and forming an extremely complex system. This system is evolving, not slowly and as a result of adaption to a changing environment, as was the case in the past, but with increasing rapidity and as a result of human will. In driving that evolution, there might be a broad consensus regarding the aims, i.e. to give humans a better life in the form of health, peace, justice, self-fulfilment, and so on, but in applying our intellectual power to achieve this, there is a risk that we might be getting it wrong. So, instead of focusing on what we want to achieve, should we balance the application of our intellectual power more evenly between product and process, so as to minimise the risk to the evolution of our society? Heidegger was concerned the object of engineering was the intensification of means, without considering ends, leading to development for its own sake. That is not really correct; the desired ends are reasonably clear, and the proliferation of means available for consideration to achieve them can only be good; it is the choice of process that is the issue. And, in particular, the risks involved in the process; do we understand them, and are we employing the our best resources in order to minimise them?

The issue of risk is also raised by Ferry in the last chapter of his book in relation to the concept of a "second modernity", and he refers to the book by Ulrich Beck [10], where this issue was brought to public attention a couple of decades ago. In that book, the hazards leading to risk are seen as being predominantly related to technology, such as nuclear energy and the industrial contamination of water, air, and foodstuff. But Beck also states "Risk must be seen in a social setting. While technology may be the most obvious cause, the risks are created and effected in social systems; the magnitude of the physical risk is a function of the quality of the social relations and processes; and the primary risk is therefore the social dependency on institutions and actors that may be alien, obscure, and inaccessible to most people affected by the risks in question.", and with a small amount of interpretation, this expresses the risk associated with the process of applying and developing technology, as was discussed in Sec. 3.

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5 Value in the Context of Engineering

5.1 Some Initial Thoughts

The meaning of the word "value" is highly context-dependent. The value of a commodity is not the same as the value of a work of art, which is again different to the value of an action, and the value of a parameter is something quite different again. Then there is the use of the concept within different disciplines, such as philosophy (ethics), sociology, and economics, and there are almost as many variants as there are –isms in philosophy, including moral and natural value, instrumental and intrinsic value, economic value, market value, exchange and use value (as defined by Marx [1]), and the related concepts of price and utility. It is not our purpose to describe, analyse, or contribute to this vast body of intellectual work on the nature of the concept of value; our purpose is to focus specifically on the concept of value in the context of engineering as a process, and our approach will be very pragmatic.

However, it is worthwhile to refer to a point emphasized by Dessauer [2] about the need for a holistic view of engineering (although, as mentioned earlier, he (and German literature) talks about "technik"). The issue is not the value of engineering in individual projects, but of engineering as an integral part of our existence. Although Dessauer and some of the authors he quotes, such as D. Brinkman, have a strong religious perspective and go so far as to see engineering as driven by the desire for salvation from the limitations of our physical existence, this does not invalidate the argument that engineering is an expression of a component of all forms of life: adapting to, taking advantage of, and becoming independent of the threats posed by their environments. The value of engineering must be seen in the totality of its influence on the development of humanity, not measured by individual projects. Of course, that does not mean that we should not endeavour to reduce the occurrence of projects with a negative impact, and it is a central theme of this monograph that that will require a more direct and trusting dialogue between engineers and society.

At the outset of our investigation, we need to recall our definitions of engineering and technology in Sec. 3 and, in particular, that we consider technology to be the knowledge and resource bases of engineering. We therefore consider technology, and the work to develop technology, which we called development projects, are neither good nor bad; the engineering in a development project cannot be evaluated until the technology is applied, and then it is the application project that we evaluate. Also, we need to distinguish clearly between "good" engineering and "valuable" engineering, or between the quality and the value of an engineering project. The quality of a project is the extent to which it meets the agreed requirements, as well as the simplicity and elegance of the solution, irrespective of what those requirements are, and is something that is judged by the engineering community. If, for example, the requirements are to produce a device of specified size and weight that, when deployed, will cause a certain amount of destruction, and to produce it within a given timeframe; then, if those requirements are met, it is good engineering, independently of to what use the device is put. To what extent it is also valuable engineering is a different matter, which we shall now consider.

We proceed in a slightly elliptical manner by posing a few questions:

- Is there an intrinsic value to engineering, or is it an instrumental value only?
- Value to whom?

- How is value transmitted from engineers to the benficiaries? That is, what is the product that carries the value?
- What is the engineering content of that product?
- How can value be measured?
- How does value relate to ethics?
- How is value related to what Mitcham [3] calls ”the service ideal”?

5.2 Does Engineering Have an Intrinsic Value?

Let us first consider the question of whether there is an intrinsic value to engineering, as the answer to this follows almost immediately from our definition of engineering as a process. It is very difficult to think of any process where one could assign a measure of value to the process itself without relating it to the results of the process. Florman [4] introduced the existential pleasure of engineering; i.e. the pleasure the engineer derives from doing engineering, as opposed to the value realised from operation of the engineered object, but on closer scrutiny that pleasure arises from the result of the engineer’s work, in the form of “an elegant design”, “a brilliant solution”, etc. Even the value of, or pleasure derived from, doing cross-word puzzles, arises from the result, i.e. in having met the challenge of completing it. And as far as engineering is concerned, the value is to be sought only in the results it produces.

This above question should not be confused with the question as to whether engineers themselves are instrumentalists or not, i.e. if they see the value of engineering in the plant created by them, as measured by conformance to specification, or in the service produced by that plant, as measured by the users, and this question has been investigated in a recent essay by Newberry [5].

5.3 Value to Whom?

Having determined that the value of engineering is in the results of the engineering, we are led immediately to the question “Value to whom?”. In a previous paper [6] the beneficiaries were identified as the engineers, industry, and society, and a model was developed to underpin a supply-and-demand view of the relationship of engineers to their environment. While that view might have some merit in investigating e.g. the dynamics of the engineering population, it does not appear appropriate in the more general context of the present investigation. The value here is to society as a whole; it is the value of engineering, as we defined engineering in Sec. 2, irrespective of who the beneficiaries of each particular project are.

This leads to a further question: How do we define “society”? Local community, state, country, the world? Engineering projects often involve more than one of these; often all four. The significance of the increasingly global reach of engineering projects was discussed by Kreiner and Putcha [7], and while they were concerned primarily with ethics, the same issues arise with regard to value. As we shall base our definition on a cost-benefit measure, it would be most convenient to adopt a national measure, but given the increasingly international span of engineering projects, we shall define “society” to include all entities (people, organisations, communities, etc) affected by any particular project.

5.4 How Is Value Transmitted?

Next, we consider the question of how value is transmitted, and here lies a problem that bedevils many discussions about "engineering". As we saw earlier, in Sec. 3, what society in general experiences as the result of the work of engineers depends not only on that work, but on a number of other people and organisations involved in engineering projects; this is particularly true of application projects. Therefore, when we speak of the value of "engineering", do we mean the value of the projects in which engineering is embedded, or the value of the work of engineers within those projects? On the one hand, seeing how closely entwined the engineering activities are with the other activities on most projects, is it practically possible to separate out the value of the engineering? On the other hand, it seems unfair to assign zero value to a brilliant design that did not get realised due to such external factors as change of government, outbreak of war, or the emergence of a Global Financial Crisis.

And there are other factors that influence the value to society of a project; an important one is the ability of society to use the plant created by engineers, as the value only emerges through use. In some cases engineers are responsible for developing that ability as part of the project (e.g. through training and support), but in many projects that is not the case.

Our approach will be as follows: Because we want to define value as value to society, it must always be the value of the project, because that is what society experiences. This approach has the consequence that abandoned projects, i.e. projects that never produce a service, must be given zero value. This is clearly open to objections; for example, a project that is abandoned may yield very valuable results that can then be used in subsequent projects. More significantly, it sets the value of all development projects to zero. These objections can be largely countered by the fact that such projects contribute to technology, and through that to application projects, and as we are not interested in evaluating individual projects, but in the value of engineering as a whole, our approach does not exclude any component of that value, even if the inclusion is indirect. This is also in agreement with our definition of technology as a resource whose value is only realised through application in projects.

We can now define the value of engineering as the extent to which the services provided by projects allows society to realise "the good life" and to progress towards a more fulfilling life for its members, as we discussed in the previous section. But who is to be the judge of that? Let us for the moment say that society would be the judge, and come back to the problems associated with that shortly. But this definition says nothing about how we would actually measure that extent and in what units, nor does it say anything about how we would determine engineering's contribution to that measure. And the fact is that we are not going to provide any absolute and quantitative measures of these parameters, and it is doubtful if that is even possible in any meaningful manner. What we will do, however, in the next section, is to identify factors that influence these two parameters (extent and engineering's contribution) and what should be done to increase the value of engineering. This approach is very much in the same spirit as the differential definition of "the good life" in the previous section.

There is a temptation to equate the value of engineering with the success of industry, and most publications that discuss the importance of engineering to society do so in terms of engineering's effect on GDP, growth, and national competitiveness [8]. But the success of many projects depends as much, or more, on such activities as marketing and financing as on engineering, and the value of some successful projects to "the good life" is also questionable. Our concept of value has no direct relationship to the common project measures of cost, revenue, and profit. That is why a project that is abandoned before it has any influence on society's ability to pursue "the good life" is not given a negative value, even though it may have expended significant funds. However, projects can have a negative value, if society deems the service provided by them to have a negative impact on society's ability to pursue "the good life".

5.5 How Does Value Relate to Ethics?

But this lack of a quantitative measure does not stop us from considering the question of how this definition relates to ethics, or what its ethical content is. As already mentioned in the Introduction, ethics is the main interface between engineering and philosophy, and there is an extensive literature on the subject of engineering ethics. Most associations of professional engineers (e.g. IEAust, IEEE, NSPE) have a Code of Ethics; most of them are very similar, and besides points that really apply to all human conduct and to which we shall return shortly, they have in common three points that specifically address the execution of engineering:

i. to give due consideration to the safety, health, and welfare of the public;
ii. to improve, both within society in general and within the engineering profession, the understanding of technology, its appropriate application, and potential consequences; and
iii. to undertake work only if qualified by education and experience.

We can then ask: Is there any conflict between these points and our definition of value? If by "due consideration" we understand "as prescribed by society through standards, legislation, and acceptance", then no. But if one sees in this requirement something absolute, as is sometimes implied by such a wording as "hold paramount" or "cause no harm", then yes. Our definition of value accepts that the evolution of society will have effects that, by themselves, are detrimental to safety, health, and welfare. We accept that thousands are killed by car accidents every year as part of the price we pay for the benefits of mobility at an affordable cost, and we accept that every activity has the potential to cause harm; it is no more possible for society to function and develop without causing some harm than it is to convert heat into work without generating some waste heat.

In addition to these three points, engineering Codes of Conduct contain requirements on honesty and integrity that (should) apply to every human. Our definition of the value of engineering does not contain any requirements in this regard; a real bastard can still produce valuable engineering. Producing valuable engineering does not in any way excuse immoral or unethical behaviour; the two things just need to be assessed separately, and this separation of the evaluation of behaviour and product is not peculiar to engineering.

A perceptive comment on the position of ethics in engineering, and one that illustrates the point made about the role of industry in the relationship between engineers and society made in Sec. 3, was made by Langdon Winner a couple of decades ago [9]:

“One might suppose that the technical professions offer greater latitude in dealing with the moral and political dimensions of technological choice. Indeed, the codes of engineering societies mention the higher purposes of serving humanity and the public good, while universities often offer special ethics courses for students majoring in science and engineering. As a practical matter, however, the moral autonomy of engineers and other technical professionals is highly circumscribed. The historical evolution of modern engineering has placed most practitioners within business firms and government agencies where loyalty to the ends of the organisation is paramount. During the 1920s and 1930s there were serious attempts to change this pattern, to organise the various fields of engineering as truly independent professions similar to medicine and law, attempts sometimes justified as ways to achieve more responsible control of emerging technologies. These efforts, however, were undermined by the opposition of business interests that worked to establish company loyalty as the engineer's central moral concern (Edwin Layton, Revolt of the Engineers: Social Responsibility and the American Engineering Profession, Cleveland: Case Western Reserve University, 1971, ch.1,2). Calls for a higher degree of “ethical responsibility” among engineers are still heard in courses in technical universities and in obligatory after-dinner speeches at engineering societies. But pleas of this sort remain largely disingenuous, for there are few legitimate roles or organised settings in which such responsibility can be strongly expressed.”

However, the potential for a serious conflict between ethics and our definition of value, or, perhaps more accurately, for a serious deficiency in our definition of value, lies not at the level of the individual, but at the level of society. By defining the value of engineering to be determined by society’s evaluation of the results (i.e. the services provided) and basing that on a belief in the progress of society towards a more fulfilling life for its members, we have sidestepped the central ethical issue of engineering’s role in what might (hopefully) be considered “fluctuations” in the direction of this progress. What we are calling “society”, i.e. all entities affected by the projects in question, is not a homogeneous substance, analogous to a gas that exhibits only small, very localised fluctuations easily characterised by statistics; it is more like a complex mixture of substances with very different chemical potentials that, as they are brought into closer contact through the mixing process, result in locally violent chemical reactions before an equilibrium state is reached. These “local societies” often have widely differing beliefs and values, not always based on the secular humanism presented in the previous section, and some of them, which are always put forward as higher ideals in such terms as “racial purity”, “national interest”, “the Glory of God”, “in the defence of liberty”, and “manifest destiny”, are examples of justifications for some of the worst atrocities in recent history. The related engineering projects would obviously be given quite different values by these “local societies”; some positive, some negative, and our concept of value would be the weighted (by size of the “local societies”) average of these different values. There is no guarantee that in any particular case this value would reflect any ethical standard - indeed, it is easy to think of cases where it clearly did not, but underlying our value concept is the belief, as stated in Sec. 4, that in the long term it will. Without this belief the human race does not seem to have much of a future at all, and engineering will provide the means of its demise.

In addition to the relationship between our definition of value and ethics discussed above, there is a much more complex relationship, arising on the one hand from a more subtle understanding of ethics as it applies to our relationship to technology and on the other hand from the dynamic nature of the relationship between engineering and society, as raised in sec. 3.5. We have defined the value of engineering to society as the extent to which the services provided by projects allow society to progress toward "the good life". But that progress is driven by the individuals making up society, irrespective of the various institutional forms they may choose to employ for that purpose, so a further requirement can now be formulated as follows: Are the services we are providing allowing people to actively engage with governing and fashioning their own way of being in relation to the conditioning circumstances induced by the services? This is, essentially, the ethical issue raised by a number of thinkers, notable among them Michel Foucault, and given a thoughtful treatment in an article by Steven Dorrestijn [10], in a manner that is very relevant to our purpose.

Foucault was concerned with power relations and the resulting "discipline" people had to conform to, but rather than focusing only on the negative aspects of such disciplines (as did e.g. Heidegger and Ellul, as mentioned in the previous section), he studied the historical circumstances that had fostered them, and considered to what extent their present forms were still relevant and how they should be changed. Power relations are inescapable in a society; they are a fundamental characteristic of the interactions that form individuals into the system we call "society", but their effect on and benefit to society should always be subject to a critical assessment. In particular, the influence of applications of technology on these power relations is a central issue in answering the question posed above. Dorrestijn discusses how other philosophers, such as Bruno Latour, Don Ihde, and Peter-Paul Verbeek are now formulating this issue as technical mediation, and how this approach can be seen as a continuation of Foucault's historical analysis and a confirmation of the importance of his work to the philosophy of technology, even though Foucault himself did not identify philosophy of technology as a component of his work.

It is important to be quite clear about both the difference and the relationship between the concerns described by Dorrestijn (sec. 4.2 of *op.cit.*) and our concerns regarding the responsibilities of engineers. He is investigating the relation between subjectivation and technology, i.e. how people perceive and conceptualise the influence of technology on themselves. These articulations of the mediating effects of technology are simultaneously ethical problematisations of how one's own mode of existence is affected by technology

We are concerned with the role of engineers in providing that technology and, in particular, in what form it is provided, which will have a significant effect on how it is perceived and conceptualised. As far as engineers go, the issue can be formulated as follows: What characteristics must a new application of technology have in order to give a positive answer to the question posed above? The elaboration, to the very end, of the necessary implications of this question (to paraphrase Deleuze), is what this monograph hopes to encourage, as it will provide an essential foundation for realising the intellectual potential of the engineering profession, as defined in [11].

5.6 How Can Value Be Measured?

Having made society the judge of the value of engineering, how does it perform this role? And how well is it performing it? At present, society's evaluation of the value of the service provided by projects is an ad hoc, largely incoherent process; influenced, to the extent that it is performed at all, mainly by special interest groups and individuals with often only a vague understanding of the technology applied and of the wider consequences of the service provided. Predicting the effect on society, both long- and short-term, of a service can be very difficult; it requires education, experience, and considerable effort, and even then one often ends up with several differing predictions. But the same can be said for many non-engineering projects on which a democratic society passes judgement via the political process: free trade agreements, military alliances, monetary policy, education policy, medical research ethics, and so on. Each one of these will, in varying degrees, influence society's development and its progress toward "the good life". The evaluation and decision-making process is complex, being driven by a small number of people directly involved in each project or issue, with information disseminated to society by a process somewhat analogous to osmosis, through the media, through public meetings and hearings, through word of mouth, and so on, and in the end, a majority opinion is expressed at the ballot box. This is not an ideal nor efficient process, but it is the best one available, and it will improve as the level of education and the time free from meeting basic needs increase. So, in the case of the evaluation of engineering projects, it is not a case of looking for a different process, but of improving the effectiveness of the present one, and that is what the next and final section of this monograph is concerned with.

5.7 What Is the Engineering Content of a Project?

Regarding the question of what part of the value of projects can be attributed to engineering, any answer must recognise that this will vary greatly from project to project. Not only because the engineering content varies, but also because of the great variation in the ability of the engineers to influence both the purpose and the outcome of projects. In particular, and referring to the picture presented in Sec. 3 of the interaction between engineering and society taking place on two levels, it is mainly the extent of the interaction at the upper level that is significant. To take a concrete example, society has for quite some time expressed a need (or desire) to move towards renewable energy sources, and engineering has provided many options and also a great deal of advice regarding these options and likely developments in the near future. This corresponds to the upper level in Fig. 3.1. The choice of options and the willingness to pay for them is then up to society; it is not up to engineers to decree "thou shall convert to renewable energy sources".

5.8 How Is Value Related to the Concept of a Service Ideal?

In his article *A Philosophical Inadequacy of Engineering* [3], Mitcham considered the conceptualisation of engineering as a profession defined by two key features: technical knowledge and commitment to a service ideal, and then identified this service ideal with the commitment to public safety, health, and welfare. His concern was that the engineering profession is currently incapable of enacting this commitment, in part due to an inadequacy of the engineering education and in part due to a "can-do" attitude. Seen from the perspective of a practicing engineer, the understanding and enactment of public safety and health is reasonably well established within the profession and embedded in modern industrial practice; it is public welfare that is more of an issue, in particular from a philosophical standpoint. What is welfare? How can it be defined in practical terms against which the engineering profession can be assessed? "Welfare", as in "the welfare state", is about looking after those who are not able to look after themselves; it implies a measure of superiority on behalf of the one who is providing the welfare. It can also mean quality of life, as measured by such additional parameters as the environment (built and natural), access to education, job security, leisure time, etc. It is not quite clear what the exact meaning is in the various Codes of Conduct, but presumably the intention is not that engineers should instruct society about what is good for it, but that engineering should endeavour to conform to society's view of welfare. In that case, the "service ideal" would appear to be very close to our definition of value.

5.9 Summary

The position presented above is that

a. the value of engineering to society is the extent to which engineering sustains and promotes further development of "the good life";
b. the evolving definition of "the good life" can only be provided by society itself; and
c. the driving force of that evolution is the free exercise of the will of the individuals making up society.

There is a weakness, or circularity, in this definition in that "better" is simply whatever direction humanity is headed in at any one time (or perhaps better, in any time period, in the sense of a sliding average, so as to smooth out such aberrations as Stalinism, Nazism, the Khmer Rouge, and the excesses of organised religion). That is, the basic premise underlying this position is that the force driving evolution of life is inherent in life itself and that it is good. And, considering the current pre-eminent role of the human species in that evolution, it is a belief that humanity contains within itself the ability to judge the best way forward.

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6 Implications for Engineering and Society

6.1 Overview

As indicated in the Introduction, the motivation for the investigation documented in this monograph is the concern that engineering, as a profession, is not realising its full potential with regard to providing value to society at a time when the sophistication and volume of technology and the influence of its applications on society are increasing at an accelerating rate. Engineering is the main driver of both the application and development of technology, so the interaction between engineering and society is clearly of great importance to both parties. In the foregoing, we developed the concept of value as a measure of this interaction, but is this a useful concept? In particular, does our understanding of this concept have any implications for engineers and for society, as well as for industry as the intermediary in most of the interaction between engineers and society? This issue can be explored by posing a few questions:

- What is inhibiting society from extracting the greatest possible value from engineers, considered as a resource at the disposal of society?
- How could society change in order to increase the value it extracts from engineers?
- How should engineers change in order to increase the effectiveness of their interaction with society and maximise the value they provides to society?
- How can industry facilitate these changes?

These questions clearly reflect the fact that our concern in not about the role of engineers in developing technology and delivering technology applications to society; a role that is embedded in industry and has been considered elsewhere, e.g. in [1], and was also discussed in Sec. 3. There has been, and are, many brilliant engineers who drive technology forward and enable industry to deliver a plethora of applications (Steve Jobs and Bill Gates are popular current examples). The commercial success of these applications is determined by the acceptance by society, and under the influence of these successful applications society transforms itself. The issue is on what basis society makes its choices regarding the applications of technology and whether society realises the wider implications of these choices. Clearly engineers should play a key role in providing relevant information and insight, but do they? That is the concern.

6.2 Inhibiting Factors

With regard to the first question, one inhibiting factor is what might be described as the symbiosis of engineers and industry, as discussed in Sec. 3. The purpose of industry is to make profits, grow the business and build value for the owners, and as long as the activity stays within the limits imposed by society, that is appropriate in a free, competitive market. Society determines which projects will be successful and which not, and in most cases that process works well. However, in my experience most engineers would be confronted at least once in their careers with a situation in which the progress of a project is not in accordance with best practice as they know it, or in the best interests of the client, but they are restricted from doing anything about it by requirements on company loyalty, confidentiality agreements, and being “team players”, in addition to their own careers and livelihoods being tied to the commercial success of the projects. And in many projects the opportunity does not even arise, as the interface between industry and society is provided by business people and marketing professionals; engineers have let themselves be relegated to “backroom boys (and now, also girls)”.

Another inhibiting factor, which is in a sense the converse of the first, is that in cases where there is no conflict with being part of industry and where engineers would like to provide society with a better understanding, there is no effective means of doing so. In terms of the picture presented in Section 3 of the information channels, the first two are in a poor state. They have been withering away over the last hundred years or so, during which the role of engineers changed from the shining knights spearheading society’s way into a glorious future to invisible intellectual labourers, following in the path of the workers of the industrial revolution, anonymously providing the fuel for industry’s relentless drive to transform society into a consumer society, with Growth as the Holy Grail and with marketing and advertising as its handmaidens. As a result, and despite such highly visible successes as the moon landing, the Internet, and the mobile phone, engineering as a profession, and engineers as individuals, have lost their position of trust, authority, and acceptance within society, and with it, the channels of communications. For example, the major daily newspapers have columnists and occasional contributors from numerous different professions, but rarely from engineering.

The result of both of these factors is that society is not receiving the greatest possible benefit from the engineering profession, but before we go on to consider what society could do to change that, we should ask: Does society really care? Is the current situation a matter of ignorance or is it simply a matter of “can’t be bothered”? Observing how the democratic political process is lurching along under the influence of small special-interest groups due to a lack of interest on the part of the majority of citizens, is it reasonable to expect society to engage in a dialog with engineers regarding what are, in most cases, relatively complex technical matters? The answer is that of course it is not to be expected, nor feasible, for society at large to engage with engineers on a professional level; the engagement has to be based on *trust*. And this is perhaps the core of the whole issue of providing value: We have arrived at a point where engineers are not seen as trustworthy when it comes to considering society’s best interests. A reason often given for this is that in any particular case, we find engineers supporting opposing solutions. In the case of renewable energy, some are for nuclear, some are against, some are for solar panels, others are against, and so on. But should that necessarily be a problem? If we compare with the legal profession, in any case before the court, the prosecution’s team of lawyers will argue that the defendant is at fault, the defence team will argue that the defendant is blameless; that is what they are employed for, and nobody thinks that we should distrust lawyers for that reason. Correspondingly, engineers put forward the views of a case that suit their industry employers.

The big difference is that in the legal case there is then a judge (or a panel of judges) that decides, and society accepts that decision (possibly subject to an appeals process) and, by implication, acknowledges the trustworthiness of the judicial system. In the engineering case, there is no corresponding person or body, and it is left to a body, usually comprised of politicians, executives representing their industries, engineering academics with no practical experience, business people, and lawyers, hand picked by whoever is in charge, to make decisions on matters that require a detailed understanding of, and experience with, the process of engineering. None of these participants have an interest in transferring the decision-making to an impartial and suitably qualified body, and so it remains for society to re-establish their trust in engineers by demanding it.

6.3 Changes to Society

The last paragraph above is part of the answer to the second question: Society must want to avail itself of the support and active participation of engineers in addressing its problems, and this will only occur if society is willing to accept the advice provided, and that acceptance can only be based on trust. It is paradoxical that, at a time when engineering has a greater influence on the development of society than ever before, engineering has become almost invisible to society.

It is only part of the answer because it raises a further question: Why would society want to change the current situation and engage with engineers? In the developed part of the world, life is good, and getting better, is it not? Depending on one's definition of "better", yes, but there is a growing realisation that the current model of "western" society, with its three characteristics of growth, waste, and inequality, is unsustainable, and that in the changes that will be necessary in order to avoid a cataclysmic convulsion, engineers will have to play a significant role. Many of the issues involved in these changes, such as energy generation, storage, and use, the life cycle of the artificial (as used by Simon [2]) and the balance between acquisition and maintenance, and an understanding of technology growth and maturity, are complex, and their assessment requires the education and experience that only engineers can provide. But while there is a growing realisation and even an in-principle acceptance of this, there is the problem that many of these issues have timescales of tens of years, and so in practice the most appropriate solutions are ignored in favour of short-term fixes, a situation not helped by a political environment with election cycles of just a few years. This again highlights an issue in the relationship between engineers and society that we have alluded to in several places throughout this monograph: the role of industry. Industry is producing all the items that enable a society where its members can explore their intellectual potential and pursue a fulfilling life, but it also has an inbuilt momentum that requires it to keep producing and generate a return on investment, constantly seeking out new opportunities and promoting anything that can make a profit, irrespective of any overall benefits to society or long-term effects (as long as they are within the law). That is the nature of industry; it is up to the members of society, as consumers, to become more discerning. Just as democracy only works well in a society where its members are well informed and have the educational background to assess the information, the capitalist free market system only works well where the consumers make the effort to discriminate between well-founded advice and product promotion.

This also reflects the feeling or concern expressed by various authors, and mentioned briefly in Sec. 4, that the progress of technology is outpacing the ability of society to develop its means of handling it. This is perhaps particularly visible in medical technology biotechnology, but the communications technologies and associated social media are also examples of where the services offered are generating numerous unresolved issues with regard to ethics and legality (and desirability), and nuclear power has been an ongoing concern ever since WW2.

6.4 Changes to the Engineering Profession

The third question is a thorny one; not because it is so difficult to suggest some changes, but because it is so difficult to suggest realistic approaches to realising them, without which the whole exercise becomes worthless. The fundamental issue is that engineering, as a profession, has not been able to develop at the same rate as technology and its applications; in responding to the demands of industry, engineering has become a victim of its own success. This was discussed in a previous publication [3] by considering the environment in which engineering takes place. This environment, which was called *the engineering paradigm* on account of its similarity, as far as its influence on the profession is concerned, with the scientific paradigm introduced by Thomas Kuhn [4], consists of a number of components:

- The technology, consisting of the knowledge and resource bases, introduced in Sec. 2, and the associated internal structure of the profession;
- the relationships to the other participants in the technical workforce, such as technicians and technologists, drafters, machine operators and trades personnel;
- the relationships to non-technical participants in engineering projects, such as business, finance, and marketing personnel; and
- the relationships to society.

All of these components underwent rapid change in the eighteenth and nineteenth centuries, and while this change had a different character and extent in different parts of the world, it resulted in creating, particularly in continental Europe, a profession on a par with science, medicine, and law. This *vertical structuring* of the technical workforce is illustrated in Fig. 6.1, where the vertical axis is intended to be a measure of the intellectual content of the activities involved, or what we might call engineering's *value-creating potential*.

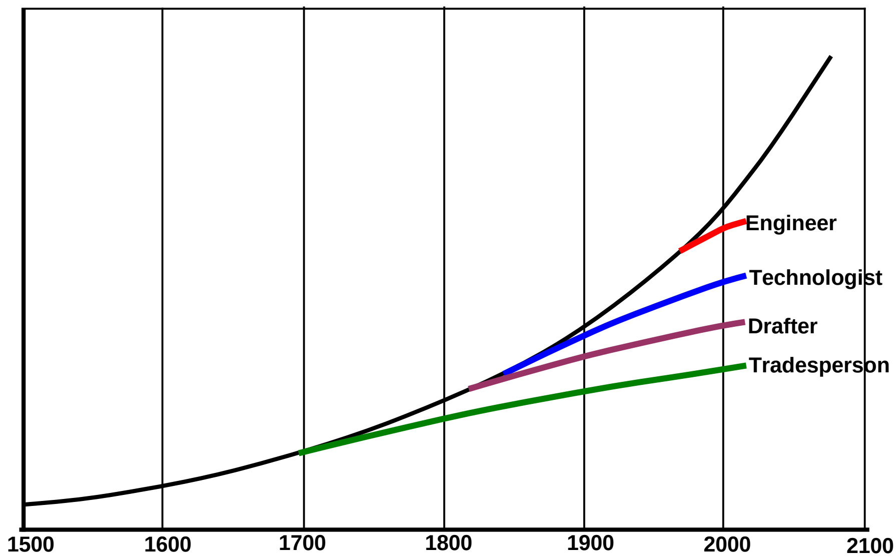

Figure 6.1 The development over the last six hundred years of one aspect of the engineering paradigm: the structuring of the technical activities within engineering projects by intellectual content (the vertical axis) (from [3]).

But in the last century, in which technology underwent an explosive expansion, the development of the other components was hijacked by industry in response to an insatiable demand for more technology-based products of all kinds, driven by a free-market capitalist business model. The most significant change has been the increase in specialisation in both the education and employment of engineers, with a neglect of subjects not directly relevant to the industrial process. In a sense, engineering became a victim of one of the underpinnings of its own success: standardisation. Technical universities became facilities for the mass production of engineers, reflecting the idea of "one size fits all" or Henry Ford's "you can have any colour you like, as long as it is black". If we, for a moment, consider the field of technical activity to be described by two coordinates, type (civil, electrical, mechanical, etc) and intellectual level (tradesman, technologist, engineer), then the enormous expansion of that field has been handled by increasing the number of types, i.e. increasing specialisation, but there has not been an increase in the number of levels. This *horizontal structuring* brought with it its own problems, in the form of interdisciplinary communications barriers and a narrow, stove-piped approach to projects. But, more significantly, it has not been complemented by a further vertical structuring; the *role* of engineers within the technical workforce is essentially the same as it was a century ago. If engineers are to take a greater responsibility for the effects of technology applications on the development of society, they need to rise above the largely routine part of the activity to be able to focus more on creativity and the concerns of society, and a new level should be created within the technical workforce to meet the needs of industry for the application of the standardised part of technology, as illustrated in Fig. 6.2.

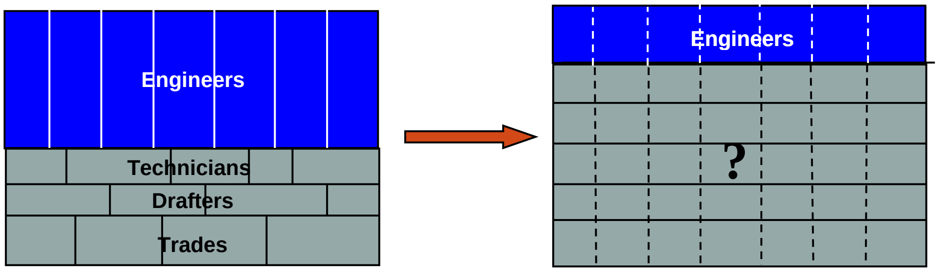

Figure 6.2 The restructuring of the technical workforce, relieving engineers of the largely standardised parts of their current workload.

Leaving aside any details of this restructuring for the moment, how could such a restructuring be effected? It is, to a certain extent, a "chicken-and-egg" situation; industry will not start to restructure before the appropriately educated and trained personnel are available, and the education sector will not restructure before there is a demand for its graduates from industry. However, this conundrum is not as severe as it might seem; it is just necessary to separate the practical from the formal. In practice, there is already a separation of skills and knowledge within the engineering community due to differences in the standard of education and differences in personal ambitions and inclinations, so that industry, and in particular government bodies relying on engineering knowledge, could draw on this existing resource and start a gradual restructuring of their workforce.

In education, only a formal, vertical structuring will yield the desired results. The present approach of adding a few non-technical subjects to the engineering curriculum is not effective. First of all, because one cannot just add material to a degree program with fixed duration, the technical part of the curriculum is necessarily reduced in scope, often without explicitly acknowledging the effect this will have. But more importantly, because what is needed is a fundamental differentiation in the approach to knowledge. In a nutshell, it is the difference between understanding and competence.

At present, engineering education and the various certifying and accrediting bodies are focused very much on competence, on being skilled in applying engineering knowledge to meeting the needs of industry. What is needed is to separate the engineering program, let us call it Eng, from the practical applications program, let us call it Tech, so that the Eng program provides the students with an appreciation of the structure and functioning of society as it relates to possible interfaces with engineering, and prepares and motivates them to take a critical and proactive role in increasing society's appreciation of the options and consequences the application of technology offers. It is a role somewhat analogous to that of journalists: working as employees within an organisational environment, while maintaining both close relationships with society and their professional independence and ability to pursue the truth.

The Tech program would be discipline-based, as it is now, and convey much the same knowledge as the current BEng program, but would illustrate the knowledge with actual applications, and assignments would focus on applying the knowledge. It would have a stronger emphasis on industry applications and the use of standards, as well as an appreciation of the role of engineering within industry, such as the relations and responsibilities to the other participants in projects. It would also provide in-depth and practical exposure to computer-based tools used in industry; in particular, to modelling tools, as models will increasingly form the means of transmitting information between the levels in the restructured workforce.

The Eng program might have a total duration of five-and-a-half years, with the last half year dedicated to completing a small research project, and would not be strictly discipline-based. While much of the basic technical knowledge, at least in the first two years, would be the same as in the Tech program, it would emphasize the place of the knowledge within a broader, somewhat more abstract framework, and introduce the system concept as an essential aspect of engineering. Following the first two years, about half of the engineering subjects would be common (mandatory) and half discipline-based (selected); they would be complemented by a common set of subjects in sociology, law, economics, and philosophy, presented with a rigour appropriate to engineering students, and always from the perspective of their relationships to engineering.

The proposed restructuring would, of course, have a significant impact on the education and training of the technical work force. The number of Eng graduates per year required by industry would be only a fraction of the current number of BEng graduates, and the number of institutions offering this degree would be correspondingly reduced. In Australia, for example, the number would certainly be limited to the Group of Eight, and perhaps not even more than half of these. The Tech qualification would formalise what is already the case for something like three-quarters of BEng graduates who go into fairly routine positions in industry, and in doing so, would allow a sharper focus on the needs of industry and make the education process more effective.

Both qualifications would provide a platform for further study and research, but the Eng qualification would lead into development of technology and the further improvement of the process of engineering through standardisation and automation, whereas the Eng qualification would lead to further integration of technology with the development of society.

Along with this restructuring of the curriculum, academic research in engineering would also undergo change. Currently there is much excellent research into both the development of technology and the application of that technology in design, manufacturing, and construction, much of it industry-funded, but little research is conducted into the relationship of the engineering to the effects of the projects on society. And where such investigations are conducted, not necessarily only by academia, but also by consultants, the work is often of a lower standard than that conducted in “hard core” engineering subjects, sometimes displaying amateurish sociology and simple-minded applications of statistics to surveys of limited significance. The importance and complexity of the relationship between engineering and society warrants the same rigour of study and research applied otherwise in engineering; what is required is the application of the engineering methodology to social issues rather than for engineers to dabble in sociology.

One might think that the institutions of engineering would take the lead in this, but under the banner of “inclusiveness” many have been more concerned with increasing their membership. They are also generally heavily dependent on industry for support, e.g. in encouraging membership and in providing volunteers, and they have been leading the drive to circumscribe the profession by means of standards and codes, reminiscent of guilds. For the institutions to play a significant role in the transformation of the role of the engineer they would have to revert to the role of truly "learned societies", which is not likely to happen in the near future.

6.5 Changes to Industry

The question of how industry can facilitate the changes involved in improving the value of engineering to society does not have a single, straight answer, because it is inextricably related to another question: How will industry itself develop, in both its internal structure and in its relationships to society? Considering its development from individual craftsmen to its present role as a cornerstone of the capitalist economic system, it seems unlikely that it will suddenly come to a halt. In particular, as the present industrial edifice is showing a number of cracks that have become increasingly visible as society is starting to draw a long breath in its headlong pursuit of consumption and the accumulation of wealth.

In the simplest (simplistic?) terms, our economic system is based on growth; initially driven by the desire for a secure lifestyle, but once this and the capital associated with the security has been achieved, growth is driven by the pressure to provide opportunities for investing this capital and receiving a return on it, as the earning value of capital (in addition to the earning value of labour) is the basic tenet of capitalism. And that is what industry provides; each project can be viewed as basically an investment opportunity. This is illustrated in Fig. 6.3.

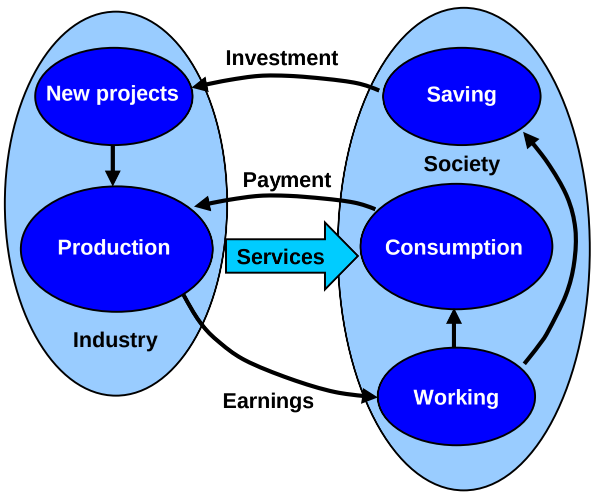

Figure 6.3 The flow of money and services between industry and society, illustrating how industry grows through investment. In this figure, "Earnings" includes earnings from both labour and capital, and "Working" must be interpreted accordingly.

The process illustrated in Fig. 6.3 displays an exponential increase in the size of the economy, as measured e.g. by GDP, and this can, of course, not continue indefinitely. A good discussion and model of long-term economic growth is given in [5]. However, in the medium term, say, the next few decades, we should expect continued and increasing economic growth and an increasing technical content of the new services, so that engineering will account for a rapidly increasing fraction of the GDP. To improve society's ability to direct this development and get the best value out of engineering, beneficial changes to industry would include:

a. A more detailed and formal structuring of both the work and the workforce so as to get a better match between capabilities and requirements, and thereby improve the cost-effectiveness of projects.
b. A more effective use of computers. In particular, improved human-machine interfaces and the increased use of skilled operators, freeing up engineers to concentrate on the innovative and creative aspects of engineering as well as on the interaction with society.
c. Change the interface with society to reflect the increasing level of education and the resultant understanding of technology and concern with how technology is mediating changes in society. This would mean a shift in emphasis from marketing and "the hard sell" to an informative dialog based on relevant engineering knowledge.

6.5 Ad Hoc Drivers of Change

But change does not have to take place within a formal, institutionalised framework; there are many examples, mostly in non-technical areas, where a group of like-minded people have come together and been the drivers of transformational change. And with the various electronic means of communications now available, distance is not a major issue, so that such groups can easily have international membership. Such informal groupings would generally have their origin in some forum with a much wider scope, such as fPET or The Royal Society in the case of changes to the engineer-society interface, but then reach out to embrace anyone with a genuine interest in developing and realising such changes. It is particularly thanks to their very diverse membership that such groups could be effective in driving changes to the interaction between engineers and society, because such changes will involve so many stakeholders: in industry, in government, in professional institutions, and in a range of special-interest organisations.

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