# A Model of Value in Engineering

This paper examines the reflection of one of the central themes in philosophy – that of "the good life" – onto "good engineering" by developing the concept of the value of engineering. As an initial advance on this issue, a simple, utilitarian model of that concept is put forward, and the determination of the model parameters is discussed and illustrated by a mini-survey.

## 1 INTRODUCTION

### 1.1 Philosophy and Engineering

Philosophy of Engineering is a subject matter that has seen an increasing level of activity in the last decade [1]. There is some debate as to whether it should be called Philosophy of Engineering, or Philosophy in Engineering, or perhaps most appropriately just Philosophy and Engineering, emphasizing that the nature of this subject matter is an exchange of knowledge and ideas between philosophy and engineering. By applying methodologies and viewpoints of philosophy to engineering, we can obtain a deeper understanding of many processes that have been developed within engineering on a mainly heuristic basis. Conversely, the exponential rise of modern technology provides inputs to and new perspectives on traditional philosophical issues. Furthermore, the mutual interaction, reflected in both the way in which engineering is influenced by society and the way in which society is influenced by engineering, involves in itself significant philosophical issues, as discussed by Wang [2].

The most significant point of contact between philosophy and engineering has been in the area of ethics. This interaction has generally been concerned with the behaviour of individual engineers; how should the requirements on personal behaviour and living "the good life", as expressed e.g. by Socrates (through Plato) and Aristotle, be reflected in a Code of Ethics for engineers? The definitions of "the good life" provided by various schools throughout the history of philosophy have generally been formulated as rules of behaviour; either "negative" rules for what one must not do, or "positive" rules for the attributes of actions that would qualify a person as being virtuous or leading "the good life". In some cases the rules are concerned with the behaviour of the individual in isolation, i.e. for its own sake and relating only to the state of the individual, such as the absence of pain or experiencing pleasure, as exemplified by Epicurus. In other cases, the rules are concerned with the behaviour of the individual within a society, such as in the schools of Aristotle and Kongzi. All of these rules could be viewed as providing a framework within which individuals and/or society can operate harmoniously, but say little about what one should aim to do within the framework. That is, the rules do not define a purpose of our actions, nor provide anything that would allow us to value or measure our contributions towards achieving any purpose.

There is a well-known analogy of such a framework; it is called a Quality System. It is defined by a set of rules, embodied in the international standard series ISO 9000, which defines what an enterprise must conform to in order for it to produce quality work. However, it says nothing about what the work should be or about its value, and it is quite possible for an enterprise to have, and conform to, a perfect quality system and still go broke. Another example of the difference between the attribute of an action and the value of the action is if one utters the sentence "A dog and a stone are two different things"; one is being truthful, which is a virtue, but does uttering this sentence have any value? A contemporary example is the much promoted concept of "no harm"; the most certain way to ensure that is to do nothing.

To paraphrase Socrates, we might say "It is not engineering, but the good engineering that is worth doing", which immediately begs the question: What is good engineering? We propose to throw some light on that question by considering the concept of the *value* of engineering and, in particular, to develop a model of value that exposes some of the main features of that concept.

Focusing now on engineering, these general questions about purpose and value become particularly important because of the nature of engineering as a creative activity and, even more importantly, because of its pervasiveness in our society. Looking around us, there is hardly an object that has not been created by engineers or that engineering did not play a role in its creation. The extent to which society has become dependent on technology, the power of industry and its influence on society, and the role of engineers in all of this has led a number of people to express concerns and even predict dire consequences for the wellbeing of society. This was particularly the case in the first half of the twentieth century, and a good account of this, as well as a detailed, if at times over-enthusiastic response to such concerns was given by Friedrich Dessauer, first in *Philosophie der Technik* [3] and then in *Streit um die Technik* [4]. While both technology and society have changed since these books were written, many of the insights and arguments put forward in them are just as relevant today.

One might think that the objects created by engineers and surrounding us today, while they make our daily lives more convenient, less physically strenuous, etc, being inanimate cannot change our human nature, our values and beliefs, but that is clearly not the case, as a few examples demonstrate:

a. Until a couple of hundred year ago, objects were truly "man-made", and there was a direct connection between an object and its creator and an appreciation of this connection by the object's owner; a relationship that today is mostly reserved for art objects. The majority of the objects that surround us in our daily lives are mass produced, and the link to the designers, as the intellectual creators, is lost. As a result, our relationship to this world of objects has become disrespectful and blasé; who considers the true marvel of the mobile phone, an intellectual *tour de force* surpassing the greatest cathedral, painting, or symphony? Once the next version comes along, the old is simply chucked in the bin.
b. Advances in electronics and software have led to a class of objects called intelligent devices. Here a new type of relationship is developing; people become attached to their capabilities and features, and interacting with these devices can replace human interaction. Where people used to converse, they now surf the internet on their mobile devices. And we are seeing only the beginning; a thought-provoking view of the not-too-distant future is presented by the Swedish TV series Real Humans [5].
c. Engineering has produced a large number of devices, from the telescope to the Large Hadron Collider, that have been, and still are, giving us an increasingly deep and detailed understanding of the physical world, and reducing the need to call on divine intervention to explain physical phenomena.
d. Finally, astonishing advances in biomedical, genetic, and bioelectronics engineering are starting to blur the distinction between the natural and the artificial. Debates about genetically modified organisms and crops, about patent right to genes, about artificial organs, and about extending "life" through supporting systems are just some of the symptoms of this transformation of our view of the world and our place in it.

What these examples illustrate can be considered as the emergence of a "composite" species, whose individuals are closely coupled systems of humans and engineered devices, with the latter extending and transforming the characteristics of the "original" humans. The idea of technology as organ projection was put forward already in the early considerations of the philosophical aspects of technology, e.g. by Kapp [6] and Espinas [7], although they had primarily the mechanical extension through machines in mind.

The issue of The Good Life and its relationship to engineering is the subject of a recent book [8], and in Chapter 3 of this book Ruut Veenhoven looks at the quality of life in a technological society and actually proposes a way of determining the influence of the application of technology on the quality of life as a correlation between the extent of that application (measured by number of Internet connections per 1000 inhabitants and also by the fraction of GNP due to agriculture) and Happy Life Years (the product of longevity and the outcome of happiness surveys). The positive correlation she demonstrates may provide some comfort that the application of technology is having a positive effect, but provides no measure of the contribution of the engineering to the application of technology.

The desire of Veenhoven to characterise the application of technology by some measurable parameter is close to the purpose of this paper, which is to characterise the value of engineering by some measurable parameters; in both cases the measure is external to the process. Whether or not there is any intrinsic value to engineering, as suggested by Florman [9], is not relevant to this paper; the value of engineering is determined solely by the effect is has through the application of technology.

As is the case of our life generally, engineering takes place within a framework; a framework consisting of standards and legislation. But conforming to this framework is not an end in itself; engineering creates new objects, ranging from individual devices to large systems, and in doing so both supports and shapes the development of society. Furthermore, engineering is most often involved with the consumption of limited resources, so that additional questions arise with regard to the value of different options. To pursue these questions and examine possible answers we need to define "engineering" in a manner that makes it amenable to such philosophical enquiries. That is, we need to have an agreed understanding of what engineering is about; the things we can talk about and address our philosophical enquiry to. In other words, we need to have an "engineering ontology", or defined vocabulary. This was presented in previous publications [10], and is outlined in the next sub-section in order to make this paper more self-contained.

## 1.2 An Ontological Framework for Engineering

There are a number of well-known ontological frameworks, or upper ontologies, and most of them include an entity called a *process*. In the present context, we shall define the class of professional processes by the following definition of a class member:

a. It is 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.

Engineering forms a sub-class of this class, distinguished by the nature and content of the resource base and that of the knowledge base, which together constitute the *technology*. The practitioners of the process are the *engineers*, and the instances or members of this class are *engineering projects*.

The identification of the resource and knowledge bases as constituting "technology" is a deviation from the use of "technology" by philosophers, where it is used in a much more encompassing manner, such as "the production and use of artifacts". 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), no engineer would speak of ‘doing technology”. The tension between the usage of “technology” in engineering and in social science is discussed in considerable detail in Chapter 6 of [8].

In the above definition, it should be pointed out that the meaning of purpose and stakeholders may not quite conform to what many readers might be used to. Purpose includes everything that the project is expected to accomplish; not just its immediate technical function, but also such requirements as making a profit for the investors or meeting certain legislated parameter values regarding energy efficiency, etc. Stakeholders, on the other hand, are limited to those persons, or bodies, that have a say in setting those requirements and an expectation that they will be met; they do not include all persons affected by the project.

By considering the purpose of engineering projects, it is possible to distinguish two broad groups,

- In the first group are projects that apply the existing resource and knowledge bases to meet a need expressed by all or a part of society; the *application projects*.
- In the second group are projects that develop technology by increasing the resource and knowledge bases; the *development projects*.

For reasons that were presented in [10], this paper is limited to considering application projects only, although in reality many engineering projects contain a mixture of the two types.

Central to understanding the process involved in an application project is the realisation that its function is to meet a *need* expressed by society or a group within society as a part of a set of *stakeholder requirements* on the project. Engineers attempt to meet that need by creating an object that, when put into operation, provides a *service* that meets the need. The judgement of the stakeholders as to the extent to which the service meets their requirements is the measure of the project’s success.

The totality of what provides the service shall be called the *plant*. This is not an ideal name, as it is much broader than what is commonly understood by “plant”, and may even be mainly an organisation of people, However, identifying it as “the object” is even more confusing, as the word object has a very broad usage, and its meaning can be highly context-dependent (e.g. as in object-oriented programming or in the phrase “the object of the exercise”).

This view of an application project is illustrated in Fig.1, and the significance of the colouring will become clear as we progress our investigation of the value of engineering in the next section by first considering the context in which application projects take place.

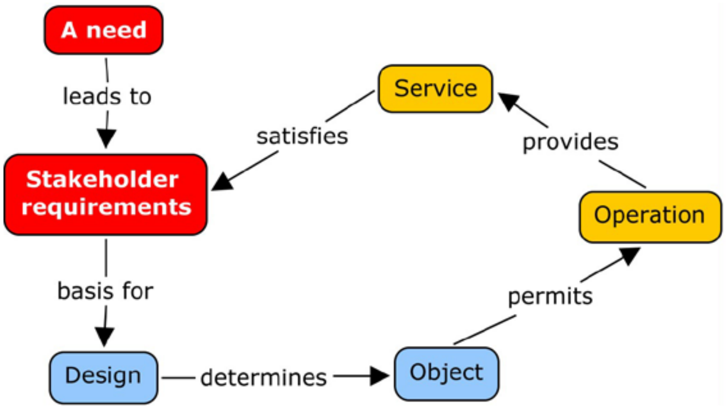


**Figure 1** The structure of an application project (from [10]).

# 2 THE PROCESS OF ENGINEERING

## 2.1 Overview

While the concept map in Fig. 1 depicts the basic process of engineering and the interaction between society, represented by the stakeholders, and engineering within a project, it conceals a number of important features and issues. Firstly, the process involves numerous activities besides those we would consider core engineering activities, such as design and implementation (construction or production, maintenance). Significant ones include marketing, sales, operation, and financing. Secondly, and related to the first point, the process involves numerous actors besides engineers, such as business people, economists, environmental scientists, investors, and users (i.e. the market).

And thirdly, the concept map does not show any other interaction between the project and its environment than the interaction between the project and the stakeholders. A project is embedded in an environment that, while it does not directly determine the requirements on the project, has a very significant influence on the outcome of the project. It includes the relevant technology, indirectly affected segments of society, financial parameters (e.g. interest and exchange rates), and political factors, such as government subsidies, new legislation, etc.

The fact that an engineering project consists of much more than just the application of technology and that it is by understanding and managing this wider context that engineering realises its full potential was emphasized in a recent keynote address by Ruiyu Yin [11]. He also suggested that it is in this broadening of the scope of engineering that many of the philosophical issues arise, and that the engineering approach to these issues is based more on experience with projects than on abstract principles of philosophy. That is the approach adopted in this paper to addressing the issue of the value of engineering; the extent to which these broader issues are included in a particular project has a very significant influence on the *scope* of engineering and on how the *value* of the engineering is assessed. In the following subsections we shall illustrate this by considering three cases, each with a different scope.

A central feature common to all the cases, and one that is becoming disproportionally significant, is the contractual framework within which a project is undertaken. In this respect, engineering is very different to both science and art. Firstly, because the outcome of the work of scientists and artists is (generally) not subject to legal challenge, whereas that of engineers is. Secondly, because engineering, as a professional activity within a development project, is constrained by the commercial imperative of meeting agreed requirements at the lowest possible cost. This contractual framework seems to be a feature that is largely overlooked in the current literature on the philosophy of engineering, and which sometimes gives the discussion a simplistic and unrealistic flavour.

## 2.2 Design to Defined Requirements

The first, and in many respects simplest case is the "design only" contract, either as preparation for a construction contract or as part of a "design and construct" (D&C) contract. It is a case where the engineering is limited to the design of an object for which there is a set of unambiguous and measurable requirements on the object and its performance in the form of parameter values to be achieved, as well as, possibly, requirements on any aspects of the design process, such as a staged design and review process and a corresponding time frame. Depending on the level of detail of these requirements, the project affords the engineers more or less freedom in choosing features of the solution and the optimal methodology for achieving the solution. But as they have, theoretically, no knowledge of what the object is to be used for, the value proposition on which the project is based (i.e. the business case), or the environment in which it will be used, the only value that can be assigned to the engineering is its contribution to the cost of the creation of the object through, on the one hand, a low design cost, achieved through an efficient methodology and, on the other hand, through the choice of components and materials, and by giving due consideration to constructability. This value measure has a negative nature, in the sense that it consists only of a minimisation of cost (and a limited scope for that as well), rather than any contribution to the outcome of the project and the performance of the object in its operational environment.

This case, which in effect segregates the major part of the engineering within the project from the rest of the project, both with regard to the project life cycle and with regard to the breadth of issues and considerations involved in the project, brings to the fore a number of points that are central to the value of engineering:

a. The assessment of engineers becomes an assessment of *competence*. A "competent engineer" takes on the meaning of one that fulfils the contractual requirements; no more and no less. This is also the view on which much of engineering education is based; acquiring the knowledge and skill to convert requirements into specifications of objects that meet those requirements constitutes a major part of the curriculum, and it is practised and tested in the form of solving given problems. It is also (disappointingly) the view taken by many engineering organisations.
b. Engineering is sometimes considered a combination of (or related to) three main components: science, art, and trades. This is illustrated in Fig. 2, and the case of designing to fixed requirements places engineering close to the trades corner. An advanced trade, perhaps, but still basically limited to applying an acquired set of skills. However, being assessed as a trade does assign a value to engineering, just as it does to any other trade, such as plumbing, and is reflected in salary or hourly rates.

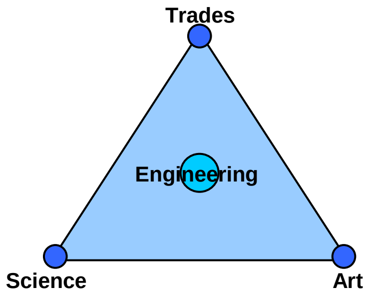


**Figure 2** Engineering at the intersection of science, art, and trades.

c. The isolation of the engineering from the rest of the project means that it is also largely isolated from the project's environment, including the stakeholders and the general public. As a result, the public gains little understanding of what the contribution of engineering to the project really is, and the engineers gain limited feedback from the public regarding the performance, benefits, and undesirable effects of their design, thereby frustrating any attempt to assign a value to the engineering beyond its cost.

## 2.3 Create a Service Delivery Facility

The second case is one in which the purpose of the project, i.e. the service to be provided, has been identified and the principal features of the solution defined in some version of a concept design, including a budget, but all further development of the project up to the point where the service can be delivered is left to the Engineer in a contractual arrangement that often goes under the name of EPCM (Engineering, Procurement, and Construction Management). Within this type of contract there are a number of variants with regard to the form of remuneration, the liability accepted by the Engineer, and the influence of the Principal; for this case let us assume that the Principal's involvement is limited to financial control and a quality assurance function, and that the remuneration is on a fixed fee (lump sum) basis.

While in this case the role of the Engineer is greatly expanded compared to that of the first case, and now, in addition to design, encompasses such activities as stakeholder interface management, community consultation, contracting strategy development, and contract management, it is still focused on delivering the solution (the plant) to defined requirements within the agreed timeframe and budget. That is, the need, the service that will meet that need, the deliberations that lead to the concept selection, as well as the value of providing the service are all issues outside the scope of the EPCM contract. The value that can properly be ascribed to the engineering is determined by the cost-effectiveness of the delivery of the service throughout the life cycle of the project, whereas the value of the project is additionally determined by its ability to meet the need and thereby produce a revenue and so, ultimately, by the return on investment. The issues arising with regard to value in this case include the following:

a. The need may have been inadequately identified and assessed. The project may deliver the required service perfectly, but it is the wrong service for meeting the real need, and so the project is deemed to be of little value. The issue here is what Warfield called the "problematique" [12]; the realisation that a need arises in a particular *context*, and that context must be understood and taken into account when developing the service requirements.
b. The understanding of the need and its context, leading to the definition of the service requirements, depends on the background and experience of the group of persons performing that stage of the project. All too often that group does not include the appropriate engineering expertise, so that neither the engineering approach to problem definition and assessment nor the understanding of the opportunities and pitfalls of current technology are brought to bear, and so this value that engineering could have contributed to the project is not realised.
c. EPCM contracts are usually won on a competitive basis through a tendering process, so that the Engineer is compelled to minimise the extent of the engineering in order to win the work. But, on the other hand, the documentation provided to the tenderers often does not reveal much of the deliberations and work that went into defining the concept, and has a legalistic format designed to shift as much of the risk and liability onto the Engineer as possible. So, the Engineer either accepts the concept design as presented and the risk of it being flawed, or adds the work required to verify the concept into the tender, thereby greatly reducing the probability of winning the job.

## 2.4 Provide a Service

The third case is one in which the Engineer also takes on the roles of Principal and Contractor, thus eliminating these contractual interfaces, and actually delivers the service. This case is most often found when the need is expressed as the need for a product, and the service consists of delivering this product. The context in which such projects take place is one in which the interfaces with the environment are directly between the Engineer and the components making up the environment, such as debt providers (working capital), government bodies (legislative requirements and their enforcement), and the market (user requirements). The value of the engineering is now more directly reflected in the acceptance of the product by the market.

There is a large number of well-known companies that were started and run by engineers and that have successfully delivered product after product; examples are Hewlett-Packard, Microsoft, and Daimler-Benz, and a prominent witness to engineering value is the Eiffel Tower.

## 2.5 Aspects of Current Practice

The three cases outlined above bring out some aspects of current practice that are important for the following development of the concept of the value of engineering.

a. The process of engineering is a continuous process, from problem definition through solution identification and optimisation to realisation and delivery, and much of its cost-effectiveness lies in this continuity within each project of the steadily increasing understanding of the problem and its implications, the associated step-wise development of the solution, and the ongoing support throughout the lifetime of the project. The temporal subdivision of the project into contractually separate parts, for all its intent of cost reduction through increased competition, can be nothing but detrimental to this cost-effectiveness.
b. There is currently a tendency to see the project management (or project delivery) as separate from the engineering and to perform the former increasingly as a formalised, inflexible contract management process with features determined largely by the selected management software. This means that the dynamic, integrated optimisation process characterising best engineering practice cannot be effectively implemented.
c. The focus on an efficient (minimum cost), contractually tightly circumscribed design as the main engineering contribution to a project suppresses, to a large extent, the creative side of engineering, The Engineers are forced to reduce their efforts to the minimum that will produce an acceptable solution, rather than striving to achieve the overall best outcome for the project.

# 3 VALUE AND ENGINEERING

## 3.1 Some Initial Thoughts

So far, we have developed what might be called elements of the background on which we can approach the main subject of this paper: the value of engineering. We have developed a description of engineering in terms of a defined vocabulary centred around the concept of projects, and we have considered some of the settings in which engineering projects are carried out. We must now start that approach, and we shall do so in what is essentially a top-down fashion, by first addressing some general characteristics of the two components of the subject – value (of engineering projects) and engineering (within engineering projects) – separately, but in the context of the subject.

Value must always be value *to somebody*. Just as beauty is in the eye of the beholder, value is assessed by the beneficiaries in accordance with their needs. In the case of the most basic needs the value may be simply a case of supply and demand, but beyond that the demand is driven by more complex needs. For example, in the case of jewellery, the need includes improved self-esteem, a reinforcement of the belief in human capabilities, and a diversion from the ordinariness of daily life. In the case of engineering, it is useful to go back to the earliest days of what could be called engineering, such as the construction of the first water-wheels and mills for grinding corn, or devices for military use. The value to the owner was the improvement in his business outcome (lower cost, increased throughput) or his ability to wage war successfully. The value to the engineer (or, at the time, craftsman) was threefold: a payment to sustain the existence of himself and his family, a sense of self-actualisation through having been able to solve a problem and having harnessed the power of nature, and the increase in self-esteem through the recognition of his skills by society. These three components of the value to the engineer remain valid today.

This simple case of a value related solely to the owner (or the body commissioning the work) soon became the exception. With the increase in size and complexity of communities and the increase in the capabilities of engineering, most engineering works became valuable to a variety of benficiaries. A Roman bridge might be built with the primary purpose of being better able to move troops, but it benefited the local community and others as well, for which they paid in taxes and tolls. A sawmill was of value to its owner, but also to the people who were able to get sawn timber at an affordable cost. Instead of a direct exchange of value between engineer and owner, it became a *value chain*.

It is worth noting here that this is a major feature distinguishing engineering from such professions as medicine and law. Both doctors and lawyers provide their respective services directly to the users, whereas engineers work for an employer (industrial firm, government entity, etc.) which then provides the service to the users. Engineers and their involvement in providing the service are generally “invisible” to the users.

Furthermore, in contrast to some other crafts, such as baker or cobbler, the value of an engineered object was generally not realised in an instant or over a short time; it accumulated over the *life cycle* of the object, and so two other aspects of the value of an engineered object became apparent. Firstly, the *operation* and *maintenance* of the object became important factors in determining its value. Secondly, since the cost of the object preceded the value or revenue obtained from owning it, it was an *investment*, and so there arose a new group of participants in the value chain, the investors, and their organisation, the capitalist system.

As engineering evolved from a craft to a profession, engineers did less and less of the manual work involved in manufacturing, building, or constructing the engineered object, and so there arose another distinct group of participants in the value chain: the workers that depended on the outputs of engineers for their livelihood.

Finally, there are a number of groups of people that, while not receiving any value directly from an engineered object, are *impacted* by the existence and operation of that object. That impact may be positive or negative, and while the impact on each individual in the group may be small, when integrated over the whole group the impact may be considerable and should somehow be taken into account in assessing the value of the engineering. Also, the impact of a project may persist long after the project is completed. As a limiting case, this includes the impact of engineering on the existence of humanity on Planet Earth.

The engineering in a project, i.e. the work of engineers that enters into the creation, operation, and maintenance of an engineered object, has a number of components. And, as we saw earlier, the extent to which these components are significant varies from project to project.

## 3.2 A Simple Value Framework

### 3.2.1 A Taxonomy of the Beneficiaries

The picture of the value of an engineering project that emerged from the brief discussion in the previous subsection is a very complex one. However, as our purpose here is not to develop a rigorous economic account of engineering projects, but to understand the principal factors that determine the value of engineering and to relate those to the components of engineering in order to say something about how engineering should evolve, through practice and education, to maximise that value, we will propose a model that is simple enough to be readily understood by a non-economist, but still adequate to support our purpose and convince an economist of the basic validity of our arguments.

The first step is to identify a small number of groups of people who are significantly affected by a project, either through receiving a direct benefit or by being impacted in some way.

1. *Engineers*. Either as individuals, as engineering companies and organisations, or as the community of engineers as a whole.
2. *Users*. The group of people that benefit directly from (and pay for) the service provided by the project.
3. *Industry*. The people and organisations involved in delivering (and receiving the revenue from) the service.
4. *Environment*. That part of society only indirectly affected by the project. It may be represented by government or by special interest groups.

It is evident that this grouping, and indeed any such grouping, is to some extent both arbitrary and ambiguous, and in many cases a person may belong to more than one group. But a more detailed definition of the grouping would have to refer to, and take into account, the characteristics of individual projects, which is unsuitable as the basis for a general framework for the value of engineering. The justification of this grouping will emerge mainly through the usefulness of the model based upon it.

In the above definitions of the affected groups we have introduced the concept of the *society*. In theory this could include all of humanity, but in most cases it is limited to a local community or a nation, and its extent should be evident from the context of the topic of discussion. With a bit of licence we can state that

$$\text{Engineers} + \text{Users} + \text{Industry} + \text{Environment} \leq \text{Society}.$$

### 3.2.2 Value to Engineers

In a reflection of Maslow's hierarchy of needs [13], the value of the engineering within a project to the engineers involved can be considered to consist of the following aspects of the value:

i. *Remuneration*, in the form of salary or hourly rates, dividends from a shareholding plan, and any other form of direct payment, but also including fringe benefits, such as tax-effective salary sacrifice arrangements, the use of a company car, attendance at conferences, sabbaticals, etc. This component of the value can be quite accurately and unambiguously determined as a monetary value.
ii. *Job security*. All employees value job security because it allows them to plan the economic aspects of their lives and to enter into longer-term financial obligations. It also reduces or eliminates the need to maintain a viable alternative. Engineering offers job security due to the needs of society, which can increasingly be met only by the

application of technology, and due to the relatively high entry requirements (education and training).

iii. *Work environment*. The work environment encompasses the physical environment (office, laboratory, site), the technical support systems, the social and administrative systems and activities, and the collegial atmosphere created by people with similar education, experience, and interests. For engineers, this latter factor is of particular importance, and the strength of many successful engineering companies is, to a large extent, due to fostering that atmosphere.

iv. *Self-esteem*. This aspect is determined by respect, admiration, and recognition provided by others, and so not determined solely by the work done by the engineer. It is also determined by the values and attitudes of society; and by the opportunity for the work to become known.

v. *Self-actualisation*. This is the sense of achievement engineers get from solving a problem and seeing the solution implemented; from being challenged and required to employ the full extent of one's professional abilities.

The weighting of these five aspects will vary significantly among individual engineers, and this must be kept in mind when we, later on, attempt to develop a holistic measure of "good engineering".

### 3.2.3 Value to Users

The users do not see the value of engineering directly, but indirectly through the value to them of the services provided by projects. The concept of a service is used here in a very generalised form; it is the output of any project. As consumers, or end users, we would think of such items as health care, education, electricity, gas, water, telecommunications, entertainment, transport, and air conditioning, whereas a steel maker would think of the supply of coal and iron ore, and a car manufacturer would think of the supply of steel.

Let us, for the moment, measure value to the users in terms of two parameters only: the Quality of Service (QoS) and the price of the service. The QoS is a measure of the extent to which the service meets the need, and would be something like a weighted average of numerous characteristics of the service. For some services, such as the supply of water or electricity, the weighting of the characteristics would be very similar for the majority of users, but for the transport service provided by a car, the weighting would be very different for different groups of people. For some the car is simply a means of getting about, for others it is an important status symbol, and for others tinkering with it might be their hobby.

The importance of the price will also, for most services, vary from person to person. Not only because of the difference between rich and poor, but also because the need met by a particular service will occupy a different place in a person's hierarchy of needs. The measure of value we are after is a measure of "value for money", or *cost-effectiveness*, and the value of engineering to the users is measured by the contribution engineering makes to this cost-effectiveness.

The value of a project to its users is not dependent simply on the characteristics of the service and the need of the users; it is dependent on the availability of other services that satisfy the same need and/or change the position of the need in the users' needs hierarchy. Engineering plays a significant role in this competitive process; a role that needs to be taken into account in determining the overall value of engineering.

### 3.2.4 Value to Industry

Industry encompasses the entities involved in delivering a service. This may be single persons, companies, organisations of any sort, or government bodies. The delivery of a service requires the application of resources, limited or renewable, scarce or abundant, but in any case this must be viewed as an investment in a particular project instead of in other projects. Consequently, the value of an engineering project to industry may be expressed as a *return on investment* (ROI) [14]. This ROI is the product of a number of factors related to the project, one of which is the engineering included in the project, and so the value of engineering to industry can be measured by the influence of engineering on the ROI.

At this point we should note that these measures of the three components of the value of engineering are not orthogonal, in that the ROI depends on the return (or revenue), which also enters into the cost-effectivness to the users, and it also depends on the investment, which again depends on the remuneration of the engineers. However, the components do represent independent *views* of the value of engineering, in the sense that the coupling is not explicit, and so it is still appropriate to use them as the components of the overall value of engineering. With the possible exception of the value to engineers, the values are to a large extent a matter of the *perception* of the groups of people involved.

### 3.2.5 Value to Environment.

The impact of an engineering project on the group of people we have called the environment can be both positive and negative. Positive impacts include improved infrastructure (e.g. medical and educational facilities for communities near major industrial or mining developments), reduction in pollution, and new business opportunities. Negative impacts include increased pollution and degradation of the physical environment, disruption of community life (e.g. through a highway, railway, or dam), and job loss (through technology displacing existing occupations).

## 3.3 The Components of Engineering

### 3.3.1 Component Identification and Description

As we have seen, the activities carried out by engineers within a project are numerous and varied, so as in the case of the value, we want to develop a simple picture that is tailored to our purpose. It is quite common to identify engineering activities by the part of the project life cycle they occur in, such as concept development, detailed design, implementation, operation and maintenance, and decommissioning, but there are two reasons why this is not ideal when it comes to attributing value to engineering activities. Firstly, because of the increasing pace of change of both stakeholder requirements and technology, the dynamics of many projects tends to blur the boundaries between the parts of the life cycle. Secondly, the value of a certain *type* of engineering activity is not primarily dependent on which phase of the life cycle it is employed in. If a capability is valuable, it is valuable whenever it is called upon within the project life cycle; the fact that in most projects it may be called upon mainly in a particular phase is not our concern here. Therefore, in the following identification of components of engineering and in the subsequent use of these components in building a value model, it is important to keep the distinction between a project phase and a component of engineering clearly in mind.

To find a suitable characterisation of engineering activities, we take a step back and consider engineering to be the process that employs technology to solve problems. By "problem" we shall understand the demand for a service, and as "service" is a very general term, including product, capability, and "real" service, such as public transport, "problem" takes on this same broad meaning. Technology consists of the resource and knowledge bases, as already defined, and the solution is in the form of an entity that provides the service; an entity that we have called the plant (even though, as previously noted, it may be in the form of an organisation consisting almost entirely of people).

With this understanding, the following types of engineering activities, or *components of engineering*, can be defined:

1. *Problem development*. This component has a number of sub-components:
   i. Understanding who is involved in the need, i.e. who the users will be. There may or may not be an engineering involvement, but it would rarely be significant.
   ii. Need capture. This is the elicitation of the true nature of the need. It involves asking the right questions, and then formulating the need in complete and unambiguous manner. The need is something that exists, it only needs to be captured, but because it is generally complex, the role of engineering here is the structuring of the definition of the need, using the tools of systems architecting.
   iii. Need assessment. Determining the value to the users of meeting the various components or aspects of the need. The result would ideally be an analytic expression in terms of a monetary value; the problem is putting a monetary value on widely differing perceptions of the need. Here engineering can make a significant contribution, e.g. by multi-criteria analysis and the approach described by Warfield [9].
   iv. Service development. The first step here is to identify possible and realistic services that could meet all or parts of the need. It is an essential step, as all too often the users are presented with a plant instead of a service and asked to evaluate to what extent this service would meet their need (and thereby determine the value of the service). In this first step engineering plays an essential role in ensuring that the services put forward for evaluation are realistic, both in terms of the state of technology and based on experience. In the following steps, to select and define the preferred service, engineering should play the dominant role.
2. *Solution development*. This component includes the well-known steps of pre-feasibility, feasibility, and concept design, and terminates with a fully developed and approved (or

otherwise) Business Case. Engineering activities include the identification of possible solutions (the solution space) and the narrowing down of this space to a preferred solution through cost-benefit analysis, trade-off studies, etc. Also, during this work numerous other stakeholders beside the users are identified and become involved, and a significant part of the engineering is the coordination of their work and the integration of their inputs into the solution.

3. *Solution implementation*. Work under this heading varies greatly from project to project, and includes detailed design, prototyping, pilot plant construction and testing, simulation, production facilities construction (e.g. production lines, casting yards, slipways, launching pads, just to mention a few), manufacturing, construction, testing, and commissioning. From a very general point of view, the engineering component involved in this work can be considered to be a conversion of a concept design into something (the plant) that will deliver a required service, whether this service is that of the purpose of the project or an intermediate service, such as providing test results. A special case is decommissioning, where the "service" is that there should (ideally) be no trace left of the decommissioned plant.
4. *Operation and maintenance*. This component of engineering, which encompasses manufacturing and production, will generally be closely related to the activities in the corresponding project life cycle phase, but the engineering activities in this component, which are mainly related to engineering management (planning, scheduling, staffing, organising, supervising, inspecting) will be found in various forms in the other life cycle phases also.

### 3.3.2 Discussion

In the foregoing, there is a certain distinction between our approach to the value of engineering and the approach to the components of engineering. In the former we are concerned with the value of engineering to different groups as it is practised in any application project, i.e. in application projects in general; we are not intending to develop a model of the value of individual projects. In the latter, we emphasized the difference between an engineering component and a project life cycle phase. This was necessary because the engineering activities involved in such diverse projects as creating a new motorway, a space station, or a million washing machines will vary so greatly that it is impossible to generalise the type of engineering involved in a particular phase. However, when we, in the following, develop our value model and discuss its implications, we will differentiate projects on the basis of their content in terms of components, and are thereby able to say something about in what type of projects engineering can make the greatest contribution to the value of the projects

# 4 A MODEL OF THE VALUE OF ENGINEERING

## 4.1 Purpose of the Model

The point of departure for the development of the model is the understanding that the value of engineering is tied to its application in projects, and that the value is only realised through the service provided by such projects. We need to be clear about the difference between the value of engineering and the value of the results of the engineering. That is, the intrinsic value of engineering as a process for converting a set of requirements into an object that will meet these requirements, and the value of the object (e.g. as the book value in an asset register). This is in contradistinction to science, where the measure is the truth of the result (new knowledge) rather than its value to society (although we also speak of "a very valuable research result" as one that is expected to lead to beneficial applications). Scientific knowledge has an intrinsic value; engineering knowledge has value only to the extent that it is employed.

Thus, the value of the engineering employed in a project is measured as that part of the value of the project that can be assigned to the engineering. The value of a project will consist of its value to the different groups we identified, and the value of the engineering can be subdivided into the value of the components we identified. So, what we shall endeavour to establish is the web of relationships between the groups and the components, at least qualitatively, and therefore the model will be more of a *view* of this web rather than an executable model. But this is adequate for our purpose, which is to identify "good" engineering and, above all, to indicate how engineering should evolve in order to become "better". That is, to provide more value to society.

## 4.2 The Model Framework

An initial issue relates to the groups of beneficiaries we identified in sec. 3.2. While all four of these groups are groups within society that are significant in accounting for the value of engineering projects, there is a special relationship between the first group, the engineers, and the other three groups. It is a sort of supply-and-demand relationship, but one in which the three groups create a demand for capability (quality and quantity), and supply is provided by the engineers through the balancing of the effort required to attain this capability and the value to the engineer. We reflect this relationship in our model by developing it in two parts; one based on the economic value of engineering projects, e.g. as reflected in the GDP, and one based on the supply-and-demand relationship. Both will provide insight into the relative value of the different engineering components.

The starting point of the first part is the definition of a matrix that relates the importance of the engineering components to the value of projects to the three groups within society, i.e. excluding the engineers. The matrix is a 3 x 4 matrix with elements $g_{ij}$, where the index $i$ denotes the group, and the index $j$ denotes the component. Within each group, the importance is only relative, so we can normalise it by the requirement

$$\sum_{j=1}^{4} g_{ij} = 1.$$

Next, we need to consider the value of a project to each of the three groups. This will, of course, vary greatly from project to project, so that when we introduce project-independent *weightings*, $w_i$, this will have to be understood as some form of weighted average over all projects. This is discussed in the next subsection. Again, we can normalise these weightings by the requirement

$$\sum_{i=1}^{3} w_i = 1.$$

We complete the first part of the model development by defining what we shall call the *economic importance factors*, $e_j$, as follows:

$$e_j = \sum_{i=1}^{3} g_{ij} w_i .$$

That is, $e_j$ represents the importance of the engineering component $j$ to the value of engineering.

The second part of the development starts with defining a second matrix; a 5 x 4 matrix, with elements $h_{kj}$. The index $k$ identifies the subdivision of the value to the engineers group, the aspects of value defined in sec. 3.2.2, and the index $j$ identifies the components of engineering, as before. The value of a matrix element represents the importance of that value aspect to engineers engaged in that activity. And again, as we do not intend to put any absolute figures on values, we can normalise the elements,

$$\sum_{j=1}^{4} h_{kj} = 1.$$

Where we before introduced a weighting of the groups by averaging over all projects, we now introduce the weighting of the value aspects, $v_k$, by averaging over all engineers, normalised by

$$\sum_{k=1}^{5} v_k = 1$$

The entity **v** = {$v_k$, k=1 to 5} can be viewed as a vector in a 5-dimensional space, and for any individual engineer, it takes on a particular value, determined by a large number of factors, such as education, experience, financial situation, obligations, etc. In principle, we can imagine that a survey of all engineers has been carried out, resulting in a distribution of **v** values and a corresponding *average* **v**, which is what we shall understand **v** to signify. (We note that even for a limited population of engineers, this is a very difficult survey to carry out, as it is difficult to formulate the survey questions so as to obtain reliable, quantitative answers.)

It will also be useful to introduce what we shall call the *engineers importance factors*, $a_j$, defined by

$$a_j = \sum_{k=1}^{5} h_{kj} v_k \, .$$

That is, $a_j$ represents the importance of the engineering component *j* to the value of engineering, as perceived by the average engineer.

An interesting feature of this part of the model is that it allows us to ask the question: To what extent are the components of engineering that contribute most to the value for engineers also the components that contribute most to the rest of society? Or, in other words, how should engineering be changed in order to optimise the supply-and-demand relationship we mentioned earlier? It has been said that engineering must move away from thinking about what it can do for society to thinking about what society expects it to do, but this expresses only one side of the issue. The other side is that society must come to terms with what it is appropriate to expect engineering to do.

Our model can contribute to this issue if we form the *overlap* of the two vectors **e** and **a**,

$$\Gamma = \frac{\sum_j e_j a_j}{\left(\sum_j e_j^2\right)^{1/2} \left(\sum_j a_j^2\right)^{1/2}} \, .$$

The above framework can be illustrated diagramatically as shown in Fig. 3.

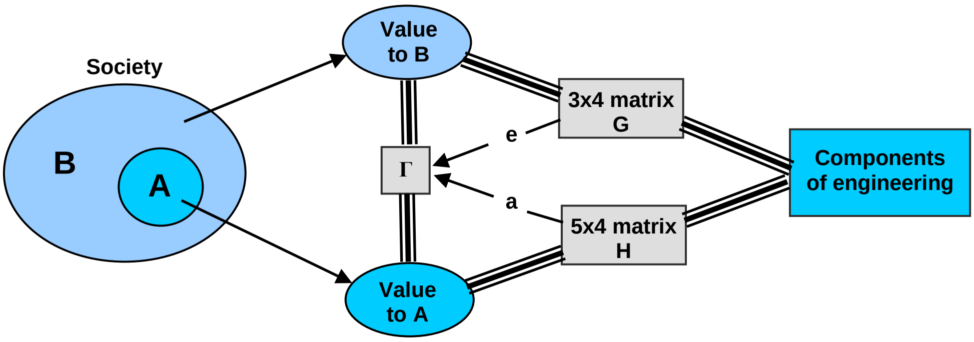


**Figure 3** Framework of the value model. The supply-and-demand relationship between engineering, identified as part A of society, and the rest of society, part B, arises from combining the two value matrices **G** and **H**, together with their weighting vectors, **a** and **e**, and is labelled Γ.

## 4.3 Parameter Values

### 4.3.1 Approach

Having set out the framework of the model, the main task is to assign values to the various parameters. A well-grounded approach to this task would constitute a very substantial amount of work, and require special skills in the area of developing surveys and in evaluating the results. A comprehensive survey (or set of surveys) will cover participants of widely varying education, experience, cultural environment, and current situation, and this would have to be expressed in some form of taxonomy and taken into account both in the formulation of the survey questions and in the processing of the raw answers. Clearly, this is a body of work suitable for several multi-disciplinary graduate projects.

In the following part of this paper, which may be considered only an initial, exploratory step, the parameter values have been assigned by the author based solely on his own experience. This experience was gained in Switzerland, the US, and Australia, in a wide range of fields, including theoretical physics, telecommunications, power electronics, and process control, and covered positions in both line and project management of research, engineering, and production, as well as more than a decade as an Adjunct Professor in the Faculty of Engineering at the University of Technology, Sydney. Nevertheless, it is unavoidable that the parameter values and the interpretation of their significance are highly subjective and, in part, controversial.

In order to mitigate that to some extent, six experienced engineers with different backgrounds and current positions were asked to provide their views on what the parameter values should be. The questionnaire, the result, and the evaluation of this result are contained in the Appendix, but it is clear that, due to the extremely small size of the sample, the only purpose of this survey is to give a “sanity check” on the values provided by the author. All together, the numerical parameter values are provided mainly as part of the purpose of this paper to act as a seed for a discussion rather than to present any definitive results; further work would require a review of the wording of the questionnaire, which may not be ideal with regard to conveying the intent of the survey, and extending the survey population beyond the engineering community.

### 4.3.2 The Weighting **w**

Consider now the imaginary entity we mentioned briefly earlier: the *average engineering project*. There is probably no project that looks like this, but it is perfectly well defined in the sense that if we characterise engineering projects by a set of parameters, then, if we at any point in time measure any one of these parameters for all existing projects, we can form the average value, and doing so for every parameter in the set, we have defined the average project at that point in time. As already stated, whenever we speak of a project in this paper, we shall mean this average project.

One of the parameters is the value, and we have chosen to express the value of the average project as a sum of three components; the value to the users, the value to the industry (i.e. the provider of the service), and the value to the environment (i.e. that part of society that is indirectly impacted by the project), where the latter can be, and often is, negative.

The engineering content of a project makes a contribution to that value, and we shall not need any absolute measure of value, we have decided to normalise that contribution to 1. The value of a project is then obviously greater than 1; how much greater is not our immediate concern, but we will return to this issue later. The engineering contributes value to each of the three groups, and it is an assumption of the model framework that the proportions are given by $w_i$. The contribution to the value to the environment often takes the form of a reduction of the size of the negative value; however, it is still a positive contribution as far as the engineering is concerned.

So, what values should we assign to the $w_i$ at the present point in time? To industry, a project is an investment opportunity, and the value to industry may be considered to be essentially the return on investment. We shall return to this issue in the discussion in sec. 4.4; it is an issue with a significant philosophical content. For the time being, let us simply accept the following definition of Return on Investment (ROI):

> Let C be the discounted value of all costs attributed to the project, and let R be the discounted value of all revenue received by the project; both over the project life time. Then the ROI shall be defined by

$$ROI = 100 \cdot (R-C)/C \ [\%].$$

Let us furthermore assume its value to be 10 %, a not atypical value.

How should we define the value to the users? It is the value of the service provided to the users by the project, but is it what the users thought the service would be worth to them when they procured it? Or what it turned out to be over the lifetime of the service? Or some measure of the change in living standard? Whatever measure we choose, it will depend on numerous individual influences (including fashion, advertising, culture, competing services, etc.), so if we, for the moment, want to avoid going into that level of detail, the simplest approach is to say that the value to the users is just what they pay for the service, i.e. the revenue, R. With that, and our assumption of a 10 % ROI, the value to the users is an order of magnitude greater than the value to industry.

There remains, then, to provide an assessment of the value an engineering project provides to the environment. That is, the value it provides in addition to the value provided to the users and the industry. As already mentioned, this value component can be positive or negative for the individual project, so that in order to relate it to the average project, we need to take its absolute value. The influence of engineering, to be discussed in the next section, is then to either decrease the negative value or increase the positive value.

However, determining the magnitude of this contribution to the value is difficult, due to the great variability across projects and the many factors affecting individual projects. A few of the latter are:

- In principle, there is always a negative factor arising from the fact that any project uses resources (funds, raw materials, human resources, etc.), and as resources are limited, this means that some other project or activity experiences a decrease in value. This is most visible in the case of allocation of government funding, but is a well-known effect within industry and the subject of what is known as portfolio management.
- Projects with a large environmental footprint, in particular infrastructure projects, will almost unavoidably entail a negative impact on some (generally small) part of the community in the form of visual or noise pollution, or hardship associated with relocation, etc.
- Projects may sometimes have significant additional benefits if they are viewed as the elements in a value chain rather than as stand-alone projects, as already mentioned. One form of this is where the waste produced by one project is used as the raw material for another project, as e.g. described in [15]. However, the development of such eco-projects is still in its infancy.
- Because it is practically impossible to foresee all the possible interactions of a complex project with its dynamic environment, it will often have *unintended consequences*. They can be either detrimental or beneficial, but on the average they would be small compared to the intended purpose of the project. The most prominent such unintended consequence of engineering projects is global warming, but the magnitude of its impact is a highly controversial subject.

As these few factors demonstrate, not only do they vary greatly in the magnitude of their impacts, but they will also change with time, as environmental issues take on increasing importance. At the present time their value, averaged over all projects, is significant, but usually substantially less than the value to users, so say 25 % of the value to users. The primacy of the value to users is discussed in the essay *Can we design for well-being?*, Chapter 21 of [8]. The weighting is then as shown in Table 1.

| *i* | Group | Value | Justification |
|---|---|---|---|
| 1 | Users | 0.76 | The price they are willing to pay, reflected in the revenue to industry |
| 2 | Industry | 0.068 | The Return on Investment |
| 3 | Environment | 0.186 | Less than users, more than industry |

**Table 1** Suggested values for the weightings $w_i$.

### 4.3.3 The Elements of the Matrix **G**

An element $g_{ij}$ of the matrix **G** expresses the relative importance of the engineering activity *j* in determining the value of a project to the group of beneficiaries *i*, as perceived by them. As noted earlier, both users and the environment do, in general, not see the involvement of engineering directly, so the values given in Table 2 below reflect my subjective view of this indirect link. (The choice of element value scale below is the result of a simple 3,2,1 ranking, with a sum of 7.)

| Element | Value | Justification |
|---|---|---|
| 11 | 0.43 | Of greatest importance to the users is that the project correctly addresses their problem, that it provides the service they want. |
| 12 | 0.14 | Unless fashion plays a significant role, the choice and development of the solution in reflected to the users mainly through the price of the service. |
| 13 | 0.14 | Same as for $g_{12}$. |

| | | |
|---|---|---|
| 14 | 0.29 | The involvement of the users in the operation and maintenance varies greatly with the type of project, from almost zero for the provision of power to major in the case of many IT products. But, on the average, this user interface is a significant factor in determining the value to the users. |
| 21 | 0.14 | Industry often sees the problem as something that is given, and engineers are "shielded" from the users/market by sales and marketing functions. |
| 22 | 0.29 | The identification of the preferred solution and its development, including innovation, is clearly of great importance to industry as the provider of the service, and engineering plays the main role here. |
| 23 | 0.14 | Solution implementation is, of course, important to industry, and requires involvement of engineering. However, the scope of engineering is limited; implementation is usually constrained by current practice. |
| 24 | 0.49 | To the service provider, the ease and economy with which the service can be provided over the lifetime of the project is paramount, as much of the Life Cycle Cost is to be found here. The high parameter value also reflects, to a certain extent, the future, due to the fact that sustainability is taking on increasing importance in engineering projects. |
| 31 | 0.14 | Whether the problem is correctly identified or not may not significantly affect the impact on the project's environment. The most likely impact is that the waste resulting from incorrect identification will take resources away from providing other services. |
| 32 | 0.43 | It is in the development of the solution; i.e. deciding on how the service will be provided, that engineering has its greatest influence on what the impact of the project on its environment will be. In particular, in correctly identifying and assessing the various components of this impact. |
| 33 | 0.14 | The influence of engineering on the environmental impact due to the implementation is limited; the main influences here would be commercial and political. |
| 34 | 0.29 | Various environmental impact factors are strongly dependent on operations and maintenance; in particular, factors relating to the natural part of the environment. Oil spills, burst tailings dams, Windscale and Chernobyl are well-publicised examples. |

**Table 2** Suggested values of the elements of the matrix **G**.

#### 4.3.4 The Weighting **v**

The vector **v** expresses the relative value the average engineer places on the five aspects of value defined in sec. 3.2.2, and a set of values, together with very subjective justifications, are given in Table 3 below. Based on my experience, the overarching desire of average engineers is to be allowed to get on with their work and solve the problems set before them, without being sidetracked by non-engineering related administration, competing for position, etc. Engineers generally have a strong belief in their professional abilities and want the opportunity to exercise them.

| *k* | Aspect | $v_k$ | Justification |
|---|---|---|---|
| 1 | Remuneration | 0.2 | The relatively low value does not mean that engineers do not appreciate salary as reward for good work, and that they will not switch jobs for a better salary, all else being equal (i.e. it is only a relative value). |
| 2 | Job security | 0.3 | The high value reflects not wanting job hunting, competing for positions, job anxiety, and company politics to interfere with the work. |
| 3 | Work environment | 0.1 | Engineers see the main importance of the work environment to be its support of their work, and it is accounted for under item 5. The social side of the environment is generally less important. |
| 4 | Self-esteem | 0.1 | In general, engineers do not have a big ego and therefore have less need for this to be continually boosted by their work experience. And while their professional performance plays an important role in |

| | | | |
|---|---|---|---|
| | | | their self-esteem, they tend to be less dependent on external evaluation of their performance and have more confidence in their own evaluation than is the case with many other professions. |
| 5 | Self-actualisation | 0.3 | Less than only artists and scientists, engineers value the satisfaction arising from doing good engineering; it is a significant part of what they consider to be the purpose of their lives. |

**Table 3** Suggested values of the weightings $v_k$.

### 4.3.5 The Elements of the Matrix **H**

An initial set of values for the elements of the matrix **H** is given in Table 4 below:

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| Remuneration | 0.14 | 0.14 | 0.29 | 0.43 |
| Job security | 0.14 | 0.29 | 0.29 | 0.29 |
| Work environment | 0.29 | 0.14 | 0.43 | 0.14 |
| Self-esteem | 0.14 | 0.43 | 0.29 | 0.14 |
| Self-actualisation | 0.29 | 0.43 | 0.14 | 0.14 |

**Table 4** Suggested values of the elements of the matrix **H**.

These values, which are, again, my subjective assessment, are based on the following considerations:

a. The importance of remuneration is, to a large extent, the inverse of the importance of self-actualisation. If I take a job that offers less in the way of opportunities to exercise my skills and engineering abilities, it is because it offers better pay (and thereby the ability to pursue activities in addition engineering.
b. Job security is important to most engineers, if not always for the same reasons. Engineers are, on the average, not risk takers; those involved in problem development maybe more than the average, as they are more closely involved with other disciplines, such as economics, law, and business, and ten to be more mobile (and perhaps more likely to eventually leave engineering).
c. The work environment is particularly important to those involved in solution development, as implementation requires team work and a well-structured, smoothly functioning environment.
d. Self-esteem and self-actualisation are both of central importance to engineers engaged in solution development. This is where personal achievements are most likely to be recognised, in patents, journal and conference papers, naming of devices (Diesel engine, Jameson cell, Yagi antenna, Fisher-Tropsch process, Eiffel tower), etc.

## 4.4 Discussion

### 4.4.1 The Derived Quantities

First of all, let us see what the choice of parameter values implies for the three derived quantities we defined as arising from the model, $e_j$, $a_j$, and $\Gamma$.

The normalised economic importance factors, $e_j$, take on the values E = (0.36, 0.20, 0.14, 0.3), implying that engineers provide the greatest value when they are engaged in developing the problem (i.e. ensuring that the problem is correctly identified and fully understood) and in assuring the through-life performance of the solution.

The engineers importance factors, $a_j$, take on the values A = (0.20, 0.30, 0.25, 0.25), implying that, when judged by the engineers relative to their concept of value, there is no great difference between the groups of activities, but the solution development (i.e. mainly design) comes out slightly ahead.

Finally, the overlap, Γ, takes on the value of 0.91, or 91 % overlap. If engineers' perception of the most valuable area of engineering activity had coincided exactly with that of the three other groups, the value of Γ would have been 1, or 100 % overlap, which would be ideal in terms of attracting engineers to the areas where they are considered most valuable by the rest of society.

### 4.4.2 Some Issues

In the foregoing, fairly brief development of a model representing the value of engineering, there are a couple of issues that require further elaboration and discussion.

The first issue is to define and understand what is meant by return on investment, ROI, as we used it as the measure of value to industry. Normally ROI is understood to be the return to the investors in a project, i.e. the equity providers, and so depends very much on how the project is financed. That is a reflection of the structure of the economic system employed by a society and the roles of financial institutions; the distinction between equity and debt is simply a characteristic of a particular way of managing capital. That is not relevant in our case; what we have called the cost, C, is the total amount of resources (capital, human, material) expended in providing a service, and R-C is the *added value*, for which the users are willing to pay.

This leads us directly to the second issue; which involves a philosophical issue at the core of the value of engineering. If the revenue obtained is no greater than the resources expended, then our model says the ROI and the value of the engineering to industry are zero. So why is this important? A project with an ROI close to or at zero might still provide great value to its users, and certainly provide value to the engineers involved. It is important because of the relationship between the four groups of beneficiaries involved and the central position of industry, illustrated in Fig. 4.

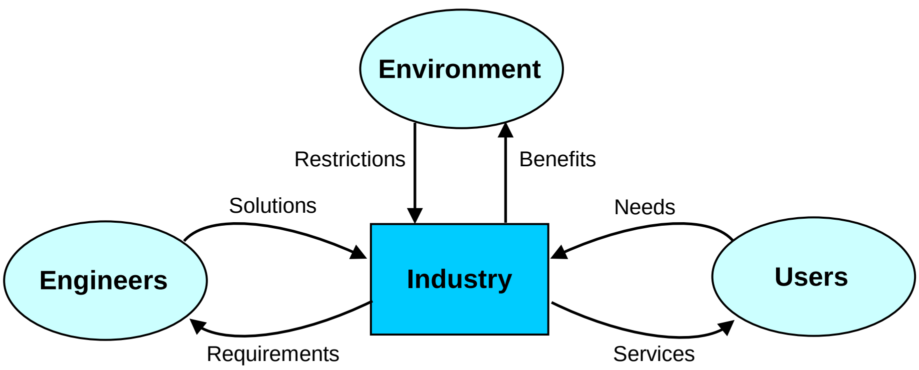


**Figure 4** The central position of Industry in the relationships between the groups of beneficiaries of engineering.

The diagram in Fig. 4 illustrates again the fact that, in contradistinction to many other professions, engineers do not interact directly with the users (or the environment), but only through their involvement in industry. If engineering would not provide a value to industry, industry would not be able to maintain itself, and engineering, as we know it today, would no longer exist. It is the creative part of engineering that provides the added value to industry and that is therefore the part of greatest importance. It also follows that any attempt to discuss philosophical aspects of engineering without recognising that it is embedded in an industrial framework will have little relevance, as was implied in the previously referenced paper by Ruiyu Yin [11].

In principle, there should not be a distinction between the benefit to society and to industry; our modern society and industry are inextricably linked. It is a symbiosis; industry needs society as its market, and society needs industry to meet its needs. However, in practice this may not be such a simple relationship. There used to be a saying, “What is good for General Motors is good for America”; history demonstrated that one also needs to consider the converse, “What is not good for America is not good for General Motors”.

The philosophical issue involved here is the premise (belief?) that the evolution of human society is good, and “the good life” is a life that promotes and is in harmony with this development. Human society is a system consisting of humans (as the elements) and the interactions between them, and while the elements may be changing very slowly (through genetic changes), the interactions are changing quite rapidly in both quantity and quality, and the changing properties and behaviour of this society are the *emergent properties* of the system. This evolution is, to a significant extent, underpinned by the creative part of engineering.

Of course, if one does not see any value in this evolution, and hankers back to a “natural” state of mankind, in the vein of Rousseau, or if one believes in divine providence, then it becomes difficult to see that engineering has any value. If banging on a hollow log has the same value as a Beethoven symphony, and if sitting at the cave entrance and gazing uncomprehendingly out over the landscape has the same value as an appreciation of the beauty and complexity of the forces and interactions displayed by Nature; well, then engineering is also of little value.

# 5 IMPLICATIONS OF THE MODEL

## 5.1 Good Engineering

Returning to the question “What is good engineering?” posed at the beginning of this paper, we have now arrived at the following answer: “Good engineering is the creative application of knowledge and resources to enable the further development of society.” Engineering does not, in itself, determine the direction of that development, but influences it through its interaction with the other components of society and, as mentioned earlier and discussed by Wang [2], this is a two-way interaction. On the one hand, engineering determines the new possibilities for development offered to society; society chooses which ones to accept. On the other hand, the choices made by society influence the course of engineering. “Good engineering” reflects this, on the one hand, by creating new possibilities for using the available resources in a cost-effective manner; on the other hand, by being responsive to the demands and aspirations of society in a manner that is consistent with the engineering knowledge base.

Good engineering is the result of an intellectual effort to, first of all, understand the problem and all its implications, and then to identify all practically relevant solutions, some of which may have been previously used, but one or more of which may be new and specific to the current problem, representing *innovation*. Problem analysis and innovation are the two most important characteristics of good engineering. In his well known book, *The Sciences of the Artificial* [16], Herbert A. Simon discusses these two characteristics, although in somewhat different terms. In one section he defines a solution as an entity whose properties lie on the “thin” boundary between the natural laws within it and the natural laws without, and which meets its requirements by adapting the former to the latter. We would say that “the natural laws within” are represented by the existing technology, and “the natural laws without” by the problem analysis; “adapting the former to the latter” is the innovation.

In the following, some of the implications of the model for the three entities most directly affected – engineering education, industry, and the engineering profession – are discussed. Again, the implications identified reflect, to a certain extent, the author’s view of their importance, and should not be taken as the only possible implications of the model.

## 5.2 Engineering Education

The implications of the foregoing for engineering education have been the subject of numerous conferences, reports [17], and papers [18]; however, how to implement the corresponding changes is not straight forward and subject to many practical limitations and conflicting requirements. A recent publication [19] by Wnek and Williamson proceeds from the premise that engineers are value creators, and then examines the attributes of what the authors call the “New Economy Engineer”, one with abilities focused on value creation. The three core attributes are *Analysis* (the ability to define and solve problems in quantitative terms), *Translation* (the ability to use the languages of different constituencies), and *Perception* (the ability to perceive new opportunities), and the authors propose that the development of all three should be integrated into the undergraduate curriculum, in part through greater emphasis on individualisation, as value creation has a significant personal element.

The arguments for broadening the engineering education beyond the purely technical put forward in the referenced paper, as well as in many other papers and books over the last three decades, are all generally valid, and many engineering faculties have taken corresponding actions. But there are two inescapable boundary conditions to be taken into account:

a. There is a limit to how much knowledge the average student can absorb per year of study; and
b. the engineering body of knowledge is growing at an accelerating pace.

So, if further non-core (or non-technical) subjects are to be added to the curriculum, the extent of the core subjects will have to be reduced, to be achieved either by reducing the depth of the subjects or by increasing specialisation. As a very simple model, the material contained within a first degree course can be viewed as consisting of four components:

1. Science foundation (physics, chemistry, etc) and mathematics
2. Engineering foundations (problem structuring, design methodologies, quality assurance, documentation, etc.)
3. Enabling subjects (social skills, philosophy, economics, environmental science, etc.)
4. Engineering discipline subjects (leading to a degree as “xxx” engineer)

Each of these components can (in principle) be characterised by a depth, $a_i$, and a width, $b_i$, with $i$ = 1 to 4, and such that $c_i = a_i \cdot b_i$ represents the total hours of effort (classroom, lab, study) expected to be required to acquire the knowledge and mastery of that component. The duration of the course, D, in years, is then given by

$$D = \frac{\sum_i c_i}{q},$$

where *q* is the number of hours per year the student is expected to devote to the course. This latter quantity is an important factor (and often left out of discussions about curriculum design), as many students have one or two part-time jobs to support themselves through the course, and some may even have family obligations. So, once D and *q* are given, the top level of curriculum design becomes a balancing of the eight parameters, $a_i$ and $b_i$.

There are a number of aspects to finding an optimum balance; based on my own observations and the above discussion with regard to the value of engineering, I would make the following comments:

1. There is too much emphasis on educating engineers to be competent problem *solvers*, without knowing how to find and understand problems. This is driven to a certain extent by demand from industry, but that demand has arisen largely as a result of a political or ideological development which has aimed to remove any distinction of educational levels within engineering, such as the practical engineer and the university-trained engineer. Another driver is the change of universities from government funded institutions to business ventures with an emphasis on reducing the cost of producing graduates.
2. A related issue, and a barrier to innovation, is a lack of understanding the foundations of many of the engineering processes and methodologies. That is, the engineer is familiar and competent with applications without knowing on what the applications are based, and so unable to see beyond the known applications to how that same base could be applied in different circumstances.
3. There needs to be a more dynamic evaluation and appreciation of the rapidly developing computer-based support structure in which engineering is embedded, in the form of sophisticated CAD tools and digitally controlled machine tools and processes. As an example, fifty years ago, engineers would design a mechanical part, and a machine operator would machine it on a lathe or milling machine; engineers were not expected to operate these machines themselves. Today, the machine operators are disappearing, the machines are computer controlled, and the equivalent of the machine operator should now be a computer operator using a CAD tool. However, very often it is an engineer spending his or her time on operating the software instead of on problem analysis, solution identification and selection, innovation, and interfacing with the non-engineering project participants. There needs to be a more explicit understanding of what the brain can and should do and what the computer can and should do, and the engineering curriculum needs to be clear about where the interface is located and what it should look like; the format and level of the engineer's outputs must change with technology.

## 5.3 Industry Attitudes

Today's engineering is a complex process, and for it to be cost-effective, it needs to be appropriately structured and managed. That is not the case in many companies where engineering plays a significant role, and even in companies dedicated to providing engineering services, there is surprisingly little understanding of how to get the best performance, or the highest value, out of the engineering staff. Compared to the sophistication employed to manufacturing process optimisation, where every material movement is analysed and the time taken for every process step reduced to a minimum, design engineers often waste a significant portion of their time on purely clerical tasks, ranging from book-keeping, estimating, and simple paperwork to fixing IT problems and the copying machine. In addition, there is frequently much time wasted due to inadequate work planning and poor understanding of what is required in order to have a smooth work flow. This state of affairs does not encourage a value-adding approach to the work.

Another factor that in some cases influences the value industry is obtaining from its engineers is the fact that the engineering is performed for a fixed price, as already mentioned in sec. 2.5. The objective then becomes to produce a solution that meets the contractual requirements at minimum cost, which may not be the solution that provides the greatest value to the project as a whole.

In short, more value could be extracted from engineers if their work environment was optimised. And again, an appreciation is needed for the fact that engineering is a dynamic process, requiring frequent reappraisal and analysis of the tasks involved and of the most appropriate allocation of personnel with differing skills.

### 5.4 The Engineering Profession

As a profession, engineering is represented by a large number of organisations; some representing all disciplines within a region (or country), others representing a particular discipline or speciality, often on an international basis. The purpose of these organisations generally includes

- developing and maintaining the body of knowledge, through journals and conferences;
- defining the minimum requirements for membership and/or official recognition, often through accreditation of courses and the associated definition of titles, or through legislation;
- promoting excellence through awards;
- providing professional advice to government bodies based on the expertise of its members; and
- promoting the interests of its members *vis a vis* other components of society, including government.

With regard to influencing the value of engineering, these organisations have the opportunity to make a major contribution by providing a forward-looking analysis of what the role of engineers should be five to ten years from now in order to provide the greatest value to industry (in the sense discussed in sec. 4.4.), and what skills and knowledge is required in order to fulfil this role. Individual businesses and engineering faculties also think about this issue, but they are generally too occupied with today’s problems as they apply to their particular situations. The professional organisations have a unique opportunity to rise above such special concerns and interests and take a broad view of where the profession should be going. And this is not about quantity, not about how many engineers will be required (which seems to be a preoccupation of many professional organisations), but about quality, about the evolving nature and role of engineering and the evolving meaning of “good engineering”.

## 6 Summary and Looking Forward

Based on a definition of engineering in terms of projects, it is proposed that the value of engineering is the value of these projects to society, represented by four groups related to each project, and measured in terms of the contribution to the development of society. The basic premise is that that this development, or evolution, is, despite its many aberrations, basically good; in this sense, the whole concept of value is based on a belief in humanity.

A simple model of the value of engineering was presented, and a set of model parameter values suggested as an illustration of how the model works. A number of issues raised by the model for engineering education, industry, and the engineering profession were identified, all of which bear upon the overarching issue of the further development of engineering. There is a feeling, both in the engineering community and in elements of society concerned with the effects of engineering, that engineering is currently not fulfilling is potential to create value for society, and that a change is about to take place.

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# APPENDIX

## 1 Questionnaire

**Introduction and Definitions**

The purpose of this survey is to explore the views of experienced engineers regarding the *value of engineering*, as expressed by a particular *model*. This model is based on a view of engineering as a process instantiated by *projects*; each project having as its purpose to meet a need expressed by all or a group of society by applying technology to provide a *service* that meets the need. Value is always value to somebody; the model identifies *four groups* of beneficiaries:

5. *Engineers*. Either as individuals, as engineering companies and organisations, or as the community of engineers as a whole.
6. *Users*. The group of people that benefit directly from (and pay for) the service provided by the project.
7. *Industry*. The people and organisations involved in delivering (and receiving the revenue from) the service.
8. *Environment*. That part of society only indirectly affected by the project. It may be represented by government or by special interest groups.

While all four of these groups are groups within society that are significant in accounting for the value of engineering projects, there is a special relationship between the first group, the engineers, and the other three groups. It is a sort of supply-and-demand relationship, but one in which the three groups create a demand for capability (quality and quantity), and supply is provided by the engineers through the balancing of the effort required to attain this capability and the value to the engineers. This relationship is reflected the organisation of the survey questions, and the value to engineers is subdivided into five *value aspects*:

vi. *Remuneration,* in the form of salary or hourly rates, dividends from a shareholding plan, and any other form of direct payment, but also including fringe benefits, such as tax-effective salary sacrifice arrangements, the use of a company car, attendance at conferences, sabbaticals, etc. This component of the value can be quite accurately and unambiguously determined as a monetary value.

vii. *Job security*. All employees value job security because it allows them to plan the economic aspects of their lives and to enter into longer-term financial obligations. It also reduces or eliminates the need to maintain a viable alternative. Engineering offers job security due to the needs of society, which can increasingly be met only by the application of technology, and due to the relatively high entry requirements (education and training).

viii. *Work environment*. The work environment encompasses the physical environment (office, laboratory, site), the technical support systems, the social and administrative systems and activities, and the collegial atmosphere created by people with similar education, experience, and interests. For engineers, this latter factor is of particular importance, and the strength of many successful engineering companies is, to a large extent, due to fostering that atmosphere.

ix. *Self-esteem*. This aspect is determined by respect, admiration, and recognition provided by others, and so not determined solely by the work done by the engineer. It is also determined by the values and attitudes of society; and by the opportunity for the work to become known.

x. *Self-actualisation*. This is the sense of achievement engineers get from solving a problem and seeing the solution implemented; from being challenged and required to employ the full extent of one's professional abilities.

The activities carried out by engineers within a project are numerous and varied. It is quite common to identify engineering activities by the part of the project life cycle they occur in, such as concept development, detailed design, implementation, operation and maintenance, and decommissioning, but there are two reasons why this is not ideal when it comes to attributing value to engineering activities. Firstly, because of the increasing pace of change of both stakeholder requirements and technology, the dynamics of many projects tends to blur the boundaries between the parts of the life cycle. Secondly, the value of a certain *type* of engineering activity is not primarily dependent on which phase of the life cycle it is employed in. If a capability is valuable, it is valuable whenever it is called upon within the project life cycle; the fact that in most projects it may be called upon mainly in a particular phase is not our concern here. Therefore, in the following identification of *components of engineering* and in the subsequent use of these components in building a value model, it is important to keep the distinction between a project phase and a component of engineering clearly in mind.

5. *Problem development*. This component has a number of sub-components:
   i. Understanding who is involved in the need, i.e. who the users will be. There may or may not be an engineering involvement, but it would rarely be significant.
   ii. Need capture. This is the elicitation of the true nature of the need. It involves asking the right questions, and then formulating the need in complete and unambiguous manner. The need is something that exists, it only needs to be captured, but because it is generally complex, the role of engineering here is the structuring of the definition of the need, using the tools of systems architecting.
   iii. Need assessment. Determining the value to the users of meeting the various components or aspects of the need. The result would ideally be an analytic expression in terms of a monetary value; the problem is putting a monetary value on widely differing perceptions of the need. Here engineering can make a significant contribution, e.g. by multi-criteria analysis and the approach described by Warfield [9].
   iv. Service development. The first step here is to identify possible and realistic services that could meet all or parts of the need. It is an essential step, as all too often the users are presented with a plant instead of a service and asked to evaluate to what extent this service would meet their need (and thereby determine the value of the service). In this first step engineering plays an essential role in ensuring that the services put forward for evaluation are realistic, both in terms of the state of technology and based on experience. In the following steps, to select and define the preferred service, engineering should play the dominant role.
6. *Solution development*. This component includes the well-known steps of pre-feasibility, feasibility, and concept design, and terminates with a fully developed and approved (or otherwise) Business Case. Engineering activities include the identification of possible solutions (the solution space) and the narrowing down of this space to a preferred solution through cost-benefit analysis, trade-off studies, etc. Also, during this work numerous other stakeholders beside the users are identified and become involved, and a significant part of the engineering is the coordination of their work and the integration of their inputs into the solution.
7. *Solution implementation*. Work under this heading varies greatly from project to project, and includes detailed design, prototyping, pilot plant construction and testing, simulation, production facilities construction (e.g. production lines, casting yards, slipways, launching pads, just to mention a few), manufacturing, construction, testing, and commissioning. From a very general point of view, the engineering component involved in this work can be considered to be a conversion of a concept design into something (the plant) that will deliver a required service, whether this service is that of the purpose of the project or an intermediate service, such as providing test results. A special case is decommissioning, where the "service" is that there should (ideally) be no trace left of the decommissioned plant.

8. *Operation and maintenance*. This component of engineering, which encompasses manufacturing and production, will generally be closely related to the activities in the corresponding project life cycle phase, but the engineering activities in this component, which are mainly related to engineering management (planning, scheduling, staffing, organising, supervising, inspecting) will be found in various forms in the other life cycle phases also.

**Survey Question 1: How would you rate the relative importance, or weighting, of a project to the three groups within society (i.e. excluding the engineers)?**

You may use any scale that you find convenient (e.g. 0 – 1, or 1 – 10, {1,2,3,4,5}), but please indicate which scale you are using:

Scale:

| Group | Weighting |
|---|---|
| Users | |
| Industry | |
| Environment | |

This will, of course, vary greatly from project to project, so that this will have to be understood as some form of weighted average over all projects.

**Survey Question 2: How would you rate the importance of the engineering components to the value of projects to the three groups within society (i.e. excluding the engineers)?**

You may use any scale that you find convenient (e.g. 0 – 1, or 1 – 10, {1,2,3,4,5}), but please indicate which scale you are using:

Scale:

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| **Users** | | | | |
| **Industry** | | | | |
| **Environment** | | | | |

**Survey Question 3: How would you rate the relative importance, or weighting, of the five value aspects to the average engineer?**

You may use any scale that you find convenient (e.g. 0 – 1, or 1 – 10, {1,2,3,4,5}), but please indicate which scale you are using:

Scale:

| Engineers' value aspect | Weighting |
|---|---|
| Remuneration | |
| Job security | |
| Work environment | |
| Self-esteem | |
| Self-actualisation | |

**Survey Question 4: For each of the five value aspects, how would you rate its importance to engineers involved in the four engineering components?**

You may use any scale that you find convenient (e.g. 0 – 1, or 1 – 10, {1,2,3,4,5}), but please indicate which scale you are using:

Scale:

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| **Remuneration** | | | | |
| **Job security** | | | | |
| **Work environment** | | | | |
| **Self-esteem** | | | | |
| **Self-actualisation** | | | | |

## 2 Result

The parameter values returned by the six respondents resulted in the following average values and standard deviation for the parameters in each of the four questions;

**Question 1**

| Group | Average | Std. deviation |
|---|---|---|
| Users | 0.38 | 0.113 |
| Industry | 0.32 | 0.083 |
| Environment | 0.30 | 0.111 |

**Question 2**

**Average:**

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| **Users** | 0.23 | 0.22 | 0.27 | 0.29 |
| **Industry** | 0.27 | 0.23 | 0.25 | 0.24 |
| **Environment** | 0.28 | 0.24 | 0.20 | 0.28 |

**Standard deviation:**

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| **Users** | 0.063 | 0.046 | 0.110 | 0.023 |
| **Industry** | 0.103 | 0.032 | 0.054 | 0.078 |
| **Environment** | 0.052 | 0.051 | 0.037 | 0.041 |

**Question 3**

| Engineers' value aspect | Average | Std. deviation |
|---|---|---|
| Remuneration | 0.18 | 0.016 |
| Job security | 0.21 | 0.033 |
| Work environment | 0.16 | 0.031 |
| Self-esteem | 0.19 | 0.060 |
| Self-actualisation | 0.26 | 0.054 |

**Question 4**

**Average:**

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| **Remuneration** | 0.24 | 0.24 | 0.26 | 0.26 |
| **Job security** | 0.24 | 0.26 | 0.24 | 0.26 |
| **Work environment** | 0.25 | 0.26 | 0.24 | 0.25 |
| **Self-esteem** | 0.24 | 0.27 | 0.25 | 0.24 |
| **Self-actualisation** | 0.25 | 0.27 | 0.24 | 0.24 |

**Standard deviation:**

| | Problem development | Solution development | Solution implementation | Operation and maintenance |
|---|---|---|---|---|
| **Remuneration** | 0.040 | 0.040 | 0.063 | 0.033 |
| **Job security** | 0.038 | 0.025 | 0.014 | 0.050 |
| **Work environment** | 0.014 | 0.012 | 0.059 | 0.052 |
| **Self-esteem** | 0.017 | 0.027 | 0.035 | 0.022 |
| **Self-actualisation** | 0.020 | 0.021 | 0.032 | 0.034 |

## 3 Evaluation

a. *The economic importance factors.* The survey resulted in $e_j$ = (0.20, 0.18, 0.36, 0.26), which means that the survey group saw the importance of engineering weighted towards the implementation end of the life cycle, in contradistinction to my personal view.
b. The engineers importance factors. The survey resulted in $a_j$ = (0.24, 0.26, 0.25, 0.25), which is no different to the view presented earlier.
c. The overlap, Γ, is now 0.96, which means that the survey group thought that the value of the engineering activity to engineers and to society are very much aligned.

These results illuminate two problems with the survey (but not necessarily with the model). The first is that while Questions 3 and 4 relate (primarily) to engineers, Questions 1 and 2 should be asked of a wide cross-section of society, as they relate mainly to the recipients of engineering services. The second problem is that while the outcome of this micro-survey is that the value if engineering, both to society and to engineers, is weighted towards what I would consider the “bread and butter”, or less intellectual, side of the engineering activities, this probably represents the participants’ view of the current situation; not what they believe it should be. The current design of the survey does not allow this differentiation.