Professional Decisions: The Central Role of Models

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Engineering is largely concerned with models and modelling. Models provide a context in which decisions are made. Here the modelling process is considered in a general sense and then the relationship with engineering models is developed. For understanding, a first step is to differentiate and categorize. Thus ten types of engineering model are proposed and their purposes with respect to professional decision making are discussed. The role of models in engineering failures is also considered.

Keywords: decisions, models, errors, failures, design, analysis.

1. Introduction

Arguably, the essence of engineering is the development and use of models, and particularly those that arise regarding actual or proposed changes to some technical reality. The engineer works with and develops models that are intended to provide a bridge to the essence of the perceived as well as the intended reality. Some of the problems that arise in the making of engineering decisions stem from a faulty understanding of both the role and the limitations of the modeling process. Here the nature and use of models in engineering are examined. Although the ideas considered are general, the discussion is narrowed and simplified by addressing structural engineering decisions by which the development and design process leads to the production of final working drawings and specifications for the construction of a substantial structure such as building or a bridge.

Fifty years ago much of the engineer's time was spent in calculations for which the education had provided an effective preparation. That has changed and computers carry out the details of analysis. However, then and now, appropriate use of models is necessary. Then models provided structural features that are considered critical and are often simplistic. For instance plane representations of structures, line members with assigned constitutive properties and geometries, homogeneous boundary conditions, fixed connections and prescribed loading states were used to represent the reality of structures. Now computers carry out the details of analysis and engineers engage in the pattern recognition tasks of identifying relevant programs and verifying the appropriateness of that selected. Structures will exist which cannot be so analysed such as shell roofs with non-analytic geometries, for which individual programs will be needed. However, all these arrangements will involve models that purport to represent perceived realities and yet cannot be complete. The various model types and purposes are here considered. These indicate what can, and to a certain extent what cannot, be included.

The paper is in two parts with a consequent discussion. The modelling process is first considered with a study of the nature of models and the manner in which they are generated and used. Concepts, labels and constructed expectations provide a basis for frameworks that incorporate a view of perceived reality. The second part is concerned with engineering models. As a first step towards deeper understanding of models and their processes it is necessary to move beyond general concepts and develop a categorization of models into different types. A taxonomy is required.

1. The modelling process

The engineer's output can include a set of drawings and specifications. The set of drawings; contains the information from which a required artefact can be constructed. This is a type of model: there is a mapping between the information contained in the documents and the actual or proposed reality. There are also important relationships between decisions and models. Certainly all decisions in an engineering context involve models, but the choice and development of models also involve decisions. More broadly, it can be said that all engineering activities involve the development and use of models (Elms and Brown 2010).

The engineering model can be viewed as a representation of reality. This statement requires the consideration of two consequential questions: In what sense does a model represent reality? What "reality" is meant?

If the idea of representation is generalized then there is a sense in which "model" stands for some reality. Once on this track of thinking it is evident that representations in many forms exist in the mind of the engineer. These can involve some presupposed reality "out there" as well as additional models and representations. There is a hierarchy of representations with different levels of meaning and information.

One representation of reality is typified by a model aircraft that has the appearance of a full-scale aircraft. The shape could be the same and it could be used in wind tunnel tests to obtain data regarding the pressure on the wings in different modes of flying. But air pressure data could also be obtained from a mathematical model idealizing the geometry and the relevant fluid dynamics. Another form of a model aircraft might not be a scaled form of a particular real aircraft but simply have the generic form, with wings, tail and fin, which could be used for enjoyment by a model aircraft enthusiast. This is a model too, but in the sense of a representation of the general nature of an aircraft. There is a general similarity relation. The mathematical model of the aircraft is similar to the working drawings produced by the structural engineer. Both contain information relating to the final result, with a remaining problem of translating or transcribing the information by some process into the intended real artefact. There is a sense that the conveying of information is an important aspect of modeling.

The second question concerns the meaning of “reality”. The reality may be actual, posed or possible. It may not be something that actually exists except in the mind’s eye.

At the most basic level mental concepts such as “reinforcing bar”, “transistor” or “wheel” exist. These, in a broad sense of the use of the word, are primitive forms of model. The next step in the hierarchy is to attach labels to these basic concepts. These labels are the words themselves such as “reinforcing bar”, and can also be thought of as models. They are representations of the basic underlying concepts and are signifiers, much discussed and categorized in semiotics (Chandler 2002).

Words are used to convey the intended meaning and these meanings may be peculiar to the engineering profession. One group of words with unambiguous professional meaning are the human constructs such as energy, force, entropy and stress. Their use in causative arguments is clear; but outside the profession, for the lay public and other professions and disciplines, the meanings can be different. Any effort to use these words in expert legal testimony before a jury requires considerable care. The labeling of a real article can be construed in different ways depending on the viewer. An example of yesteryear is “reinforcing bar”. In England it meant a circular steel solid cylinder. If an inch bar then it was of that diameter. In another place it referred to a solid circular steel cylinder with surface protrusions. If a #8, then it was, for design purposes, of 1 inch nominal diameter. The same words representing real engineering artifacts can have different meanings to professional engineers.

It is doubtful if thought can exist without words, and certainly not at any depth without using words. The words themselves are embedded in language through which ideas are shared with others, and for that matter, with ourselves. The trouble is that different groups and individuals have different languages. Even amongst structural engineers “reinforcing bar” was variously interpreted. In a broader sense, most engineers know the misunderstandings arising when dealing with architects, lawyers and other professionals where both language and world view can be subtly different. Language is developed to suit what a group, whether professional or more general, does. It is not in some sense absolute and independent of the user. Sociologists maintain that all language is socially constructed.

A central role of models is their use for developing, storing and conveying information. Generally speaking the information must be seen as an interconnected whole and not as a collection of fragmented pieces. In a sense it reflects Kant’s view that people take the mass of information reaching them and operate on it with their understanding to produce knowledge (Kant 1781). Knowledge can be thought of as selected and integrated information: a system view, so to speak. However, the interesting points here are what is meant by “understanding”, how it might be achieved, and what use understanding might be.

Even at the most fundamental levels we cannot escape from models. They are how we relate to the world, and represent it to ourselves and to each other. It is not a new idea. Wittgenstein, after stating that the world is a totality of facts, says “we make pictures of facts to ourselves.” And also “The limits of my language mean the limits of my world.” (Wittgenstein 1920). This is not to deny the reality of the world, but rather to express that our consciousness and perception do not relate to it directly, but through the intermediary of representations. In this format Wittgenstein was drawing on his experience and thinking as a philosopher. His statement relates to our knowledge, what we know about the world and in a subjective sense, beyond. This is ***what*** is known. If he had called on his previous experience as an engineer he might have stated that "We know about ***how*** to go about doing things." If he had been wearing both the combined engineering and philosophical hats he might have stated that "We know ***how*** as well as ***what***." The combination is especially important for engineers.

Models have to be employed building on and going beyond these primitive ideas of concepts and labels. However, models at all levels have limits with respect to decision making which have to be understood. Kelly (1955, 1963) provides a richer understanding of our perceptual interface with the world. He states "Man looks at his world through transparent patterns or templates which he creates and then attempts to fit over the realities of which the world is composed." He sets out a fundamental postulate, namely, "A person's processes are psychologically characterized by the ways in which he anticipates events." This is followed by eleven corollaries (Bannister and Fransella 1971). Kelly goes further than the idea of our seeing single signifiers. Rather, he argues that we have a set of constructed expectations or anticipations by means of which we establish filters through which we make sense of the world. In a way he is moving from individual elements to systems. His patterns and templates are more complex generic models constructed partly from experience and partly from education. Existing professional paradigms will also be involved in such filter construction in engineering. Kelly was in part anticipated by Heidegger who wrote (1927) "Inquiry, as a kind of seeking, must be guided beforehand by what is sought." Certainly such filters not only admit acceptable ideas but also exclude others. They provide a basis for the existence of surprise events that may be overlooked in decision making.

These primitive models – concepts, labels and constructed expectations – are fundamental to all our activities. They can be termed perceptual models that lie behind all of our decisions. They are always present and may lead us astray. They are a set of presuppositions; filters through which we see the world. If we mistake them for reality, both existing and potential, we can limit creative opportunities and introduce distortions that lead to errors of omission and commission in engineering decision making. Because the perceptual models are usually unconscious – they are taken for granted and seldom evaluated or judged – the distortions and limitations remain largely unnoticed. These are preconditions for a state of professional hubris.

After this exercise in personal construct theory the next step in model construction and complexity is the development of frameworks that provide characteristic ways of viewing and examining the world. These prejudicial guides or templates for thinking and action may be acquired unconsciously and can result in useful expectations. These expectations relate to Kelly's ideas, but they also could take the form of unwarranted prejudices and expectations. However the filters and templates can be selected by individuals and indicate personal prejudices. These are characteristic ways of looking at the world –world views or *Weltansschaungen*: guides, rules or templates for thinking and action. They could be quasi-religious dogma, such as the view that private enterprise and ownership are in all cases more efficient than state ownership. Ethical frameworks are an interesting instance. It could be argued that any ethical position consists of a framework and a set of contents (Wareham, et al. 2006). Two possible ethical frameworks are utilitarianism (seek the greatest overall good, or least harm) or a rule-based system (one shall not kill). These are incompatible. If two people staunchly hold the frameworks and they argue then there is no possibility of compromise. The frameworks are ethically neutral; it is the content that sets the tone. Christ and Hitler might both have had a teleological ends-based framework, but the contents would have been very different. Obviously, this issue and the distinction between framework and content can have important implications for an engineer.

2. Engineering models

The idea that model frameworks provide both a constraint and a guide for the use of models in decision-making is of significance to engineers. In particular, a great many engineering failures arise from models that are faulty in some way. Therefore, a clear understanding of the nature of engineering models and of characteristics that can arise in using them will be a useful contribution to improving engineering safety. A first step to understanding the complex models used by engineers is to break them down into categories. Without this, any understanding would be limited to generalities.

There are various approaches for the establishment of such a taxonomy; in other words various possible bases for categorization. Frigg and Hartmann (2009) for instance, speaking from the point of view of philosophy, give a formidable list of model types, though the basis of their categorization is not clear. Their examples include: probing models, phenomenological models, computational models, developmental models, explanatory models, impoverished models, testing models, idealised models, theoretical models, scale models, heuristic models, caricature models, didactic models, fantasy models, toy models, imaginary models, mathematical models, substitute models, iconic models, formal models, analogue models and instrumental models. At first glance this abundance of model types seems overwhelming but it can be bought under control by recognizing that these notions pertain to different problems that arise in connection with models. For example Frigg and Hartmann show that models raise questions in

a. semantics (what is the representational function that models perform?),
b. ontology (what kind of things are models?),
c. epistemology (how do we learn with models?), and
d. the philosophy of science (how do models relate to theory? what are the implications of a model-based approach to science for the debates over scientific realism, reductionism, explanation and laws of nature?).

From the engineering point of view, the most important razor with which to categorise models is purpose. Bammer (2008) addresses purpose in the statement “The primary tasks of models are description, explanation, prediction, imputation, integration and evaluation.”

The authors propose ten classes of models shown in Table 1, based on their intended purpose. There is no particular order of priority or importance but the taxonomy is intended to be complete. The categories might overlap in particular situations; this circumstance would need some caution as models with more than one purpose can easily mislead the user.

Table 1 Types of engineering model: names and purpose

	Model Type	Purpose
1	Perceptual	Seeing, understanding and communicating
2	Framing	Fundamental framing
3	Learning	Developing understanding
4	Prediction	Predicting outcomes
5	Comparison	Comparison of alternatives
6	Conceptual	Developing ideas and understanding
7	Analytic	Checking
8	Blueprint	Specifying what is to be constructed
9	Communication	Communicating between actors
10	Organisational	Ensuring the correct and efficient functioning of an organization

By itself Table 1 is inadequate. It is too stark. But it rests on a number of underlying ides and qualifications that require expansion and explanation. These are given in the following commentary on the ten types. However, the comments are restricted for the sake of brevity and further material will be included in future work.

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1. *Perceptual models.* These have been discussed previously. They are filters between the received input and what is perceived. What is received is raw sensory data, or communication from others. What is perceived is what is expected. Difficulties arise when the filters are inappropriate for the task (decision), leading to limitations or distortions in what is perceived. Usually the distortions are unconscious. These incorrect perceptual models are the cause of many failures.

Warning signs are not perceived as important and are missed, as in the pre-failure decisions with respect to the Tacoma Narrows Bridge in 1940 (Andrews 1952, Brown 1986).

2. *Framing models.* These are basic underlying rules guiding and constraining the development of more detailed models. An example is the free body diagram in structural mechanics where a piece of structure floating in space is acted on by a set of forces that, in the absence of accelerations, must be in static equilibrium. Framing models require imagining a structure in a mechanistic form, a concept that can be elusive. The walkway failure at the 1981 Hyatt Regency Hotel in Kansas City can be largely attributed to the incorrect static model developed for construction changes (Marshall et al. 1982). Another example of an imaginary concept is the control volume in fluid mechanics. An equivalent idea is the central concept in any system analysis. The laws of nature, concepts such as conservation of energy and mass, the laws of logic and the choice of geometry can be regarded as framing models. The Kuhn-Tucker conditions provide rules for the existence of certain dualities in the variables in optimisation problems. All this is public knowledge and the output is usually a constraint in the development of more detailed models.

Transgressions occur in framework modelling when the rules are ignored. An intellectual environment can exist where the rules are so taken for granted that the they are hidden, and largely relegated to the unconscious.

3. *Learning models.* The aim of learning models is to achieve an improved understanding of a problem or situation. An actual, proposed or possible reality is modelled in some way. Examples are a drawing, where the engineer sketches the stress flow due to an imposed load, a computer model that reveals a scenario, and system dynamics models where the engineer can probe the influence of parameter changes. In one instance the torsional seismic behaviour of structures was clarified by the use of a simple physical model. Learning models do not require great precision; it is sufficient that they reveal some broad aspect of behaviour. However a model's simplification must not exclude any significant aspect of behaviour. For instance a model based on linear partial differential equations cannot be expected to exhibit non-linear forms such as occur in unstable behaviour. What is required is that the *form* of the behaviour is modelled, but a precise simulation or representation is not necessary. Though not precise, this type of model must be accurately focused.

Four problems that might arise are:

a. There is insufficient understanding of the nature of the problem when the model is being initially developed. Essential issues can then be missed.

b. The model is not representative of the critical aspects of reality of the problem.

c. Marginal probing may miss correlated effects. This relates more to the operation of the model rather than the selection.

d. There is confusion in the use of the model that results in it being used as a prediction rather than a learning scheme. As an example, evidence was presented at a hearing in New Zealand regarding a proposed power station. The evidence was in the form of scenarios showing future demand for electricity based on assumptions such as growth. At the beginning it was explained that the scenario results were not predictions. Later, after some discussion, the arguments began to incorrectly refer to the scenarios as predictions, so causing confusion in subsequent legal arguments.

4. *Prediction models*. These models predict events in the future; they are dynamic models. Prediction models range from conceptual ones where, based on a set of premises, observations and even metaphors, certain situations are predicted, to ones involving computer based numerical system dynamics. Where precise results are required then great care is needed to understand and manage uncertainty.

A distinction must be drawn between prediction and learning models. Prediction models seek to produce a specific forecast of what will happen, when it will occur and the magnitude of any effects. Learning models concentrate on why and how something might happen, and also, in general terms, what might happen. The limitation of scenario models is that they produce possibilities and not forecasts. To transform them into forecasts and hence predictions requires a further and often difficult step. Confidence in the data, knowledge, information and model must be much higher than necessary for the construction of scenarios.

5. *Comparison models.* These models are intended to compare the results of alternative courses of action, all other circumstances being the same. The models can be either static or dynamic. An example of the former would be an engineer assessing the effect of geometry changes on the serviceability of a structure. A dynamic model could assess the effect of a change in road alignment on traffic behaviour over time. Precision is not required and in fact the measures used may be surrogates for actual values. The intention is to obtain a sense of preferment of one scheme over another as to which is better and then to determine the best course of action. Uncertainty must be understood but it does not have to be as tightly controlled as in prediction models. Scenario models are useful here. The main requirement is to have models of sufficient detail or degree of disaggregation that they contain the necessary information to allow comparisons to be made. They must encapsulate the essence of the situation. They provide the essential basis on which decisions are made.

6. *Conceptual models.* These models are employed for the development of ideas and schemes that will be considered in a decision process. They could as well be termed *schematic models*. The idea of playing with arrangements and schemes to attain the

best solution is dominant. It is essentially a creative time and playing is very much a part of creative human activity. Huizinga (1955) coined the term *Homo ludens* as an alternative to *Homo sapiens*. An example is the engineer playing with the possible forms of a bridge until he is satisfied that a concept is feasible and elegant. This playing might involve trying different forms and subsequent modifications such as sketching out different ways in which the elements might fit together. Billington (1983) emphasizes this aspect of structural engineering.

A conceptual model deals with ideas and possibilities. The Millennium Bridge in London began with a rough sketch showing a thin ribbon crossing the Thames (Wise 2000). Such a model often evolves over time, in which case it can be termed a *developmental model*. Its form could change and it could grow in detail.

A possible problem with such modelling exists that reflects Kelly's ideas about the essential role of expectations. These could be limited by the modeller's background and experience. How are broad expectations constructed? This relates to creativity in general. An extensive literature on the subject is available. Suffice it to note that conceptual models are pervasive within engineering for establishing alternatives for decision.

The final form of a conceptual model may provide the input for further detailed work before the proposed artefact can be constructed. Sketch plans in the making of decisions about structures are models of this type. Once it is decided to accept the sketch plans, or the basic concept, the project can proceed to the next stage.

7. *Analytic models.* Models of this type are used to ensure that various requirements have been satisfied. Often the models are encoded onto complex computer programs. The three requirements that are critical for structural engineers are safety, serviceability and functionality. A fourth requirement of economy, although important in the final decision, is of secondary significance in these models. The result or output of the checking process is the belief that scheme modelled is

a. correct, or
b. optimal. or
c. satisficing.

The two major ways in which things can go wrong are

a. errors, slips and lapses in the forms discussed by Reason (1990) and others, and
b. the engineer can confuse the model with reality and not appreciate its limitations. Of particular importance are the uncertainties introduced into the model by the underlying assumptions and simplifications. This is sometimes called epistemic uncertainty, but here it is meant in a broad and not necessarily quantitative sense.

The engineer must understand the range of applicability of analytic models. The focus must be on knowing how good the model is from an engineering viewpoint. A mathematician and an engineer might employ the same mathematical technique but their outlooks are necessarily different. The mathematician's focus is on the validity of proof, the engineer's on the range of applicability.

8. *Blueprint models.* A blueprint is a particular form of a communication model where the aim is to provide sufficient information from which a specific structure or artefact can be constructed. In a sense the blueprint model is a template. In structural engineering it is the complete set of working drawings and specifications setting down every detail and dimension of an intended structure. Such models are usually works in progress and will normally change during construction as variations are agreed upon.

The entire set of construction documents can be thought of as a complete system. To be effective the system has to be "healthy". To ensure this state Elms (1998) has proposed criteria that must be met, namely, balance, completeness, cohesion, consistency and clarity. These provide a good guide for the development of blueprint models.

There is an overriding need for both precision and accuracy. This means that processes such as quality control must be in place to catch the otherwise inevitable errors.

9. *Communication models.* As noted earlier, all models involve information and communication. Here, however, models are discussed whose primary aim is to enable and facilitate communication that mediates between two parties. It conveys and also conserves information. The communication could be between members of the design team or other actors in the construction process, and with other parties like the general public. The engineers have also to convey and conserve their ideas and hence communicate them to themselves, as they are developed contemporaneously or over a period of time. The communication model could be a drawing of a technical arrangement or just an explanation. In structural engineering it is important to maintain a record of the as-built structure as well as the design notes and analyses. The checking models could also have a role in communications inasmuch as the various classes of models proposed here are not mutually exclusive and there could be situations where a model fulfils different purposes.

Difficulties may arise in these models if the basic ideas of communication are not addressed. In information theoretic terms a source, a receiver and a channel between them are required. The channel might be used for transmitting more than one message at the same time. The source and receiver must employ the same language, and noise and distortion must be taken into account. The point about a common language is not trivial. Even the communication between professionals can be faulty because of confusions in the use of terms and conflicts in their views of the world. The random uncertainties of "noise" can be dealt with by introducing redundancy. Distortion demands more careful thought and systematic analysis and attention.

It is emphasized that the communication model conveys and conserves information, but, as noted above, information is not the same as knowledge.

10. *Organisational models.* Like most professions engineering usually requires the interaction of diverse parties over a period of time. An organizational model that takes into account the needed teamwork defines or describe the interested parties, tasks and processes involved, and specifies responsibilities.

A particular point of difficulty arises when the model selected and agreed on for a project does not prove to be appropriate. Failures can often be associated with violations of the five criteria that should be satisfied in healthy systems (Elms 1998). A report on the Clapham Junction disaster provides a number of deficiencies of this nature (Hidden 1989).

A problem can arise when there is a difference between the specified organizational system and reality. In this case specified tasks that are critical for the success of the venture may not be completed. Often participants are not aware of or do not clearly understand their responsibilities. Examples are the checking of the design changes in the Kansas City Hyatt Regency project (Marshall et al. 1982) and the absence of a required wire count in the Clapham Junction disaster.

In the evaluation of organizational systems three distinctly different systems are possible: the ideal system that is appropriate for the project, the specified system that is believed to be in place, and the actual system that exists in reality. The degree of coincidence of these is a critical part of the evaluation.

A major reason for the proposed classification of models is to avoid the confusion that can exist between a model and the reality that it represents and also regarding the purpose for which it is intended. This became clear to one of the authors at the time of the early development of sophisticated structural analysis computer programs when a well-known engineer stated: “We now know more about this building than has ever been known about a building before.” At that stage the building was expressed by computer outputs, drawings and specifications but had not yet been built. The engineer knew about the model but not the reality.

4. Discussion.

The modelling process is formed in terms of models. The work of Kelly is still important fifty years after its formulation. Of primary significance here is the individual’s prejudiced selectivity when confronted with fresh realities. That which is accepted is personal and will vary from person to person in the light of the same evidence. Two people can practice the same profession over the same period of time and yet their reputations and others’ regard for their work may be very different. I.K.Brunel, when vice-president of the Institution of Civil

Engineers in 1856, entered the following note in the minutes on news of the death of a distinguished contemporary member:
“He was always considered a safe man - one who would seldom do anything that he had not, or others had not done before - and this is, strange to say, a recommendation with men of business, who do not understand engineering. But it is quite clear this quality is not the characteristic of a Smeaton, a Stephenson, or a Watt, or the world would make no progress.”

In the last fifty years neuroscience has explained many of the relations between the brain and the mind (Kandel 2006) and identifiable locations in the brain can be assigned for definite sensual inputs. An example is provided by Wood (2003) in describing the relationship of social cognition to locations in the brain. Of interest here is the extent that this knowledge enhances the understanding of modelling of professional matters and decision making. It is apparent that the terms of the mechanistic metaphor continue to have value in explaining personal characteristics.

The key to the successful use of models is matching the type of model to the purpose of the relevant act or decision. There are two forms of error that can arise when using a particular model type. The first is a mismatch between the type of model and its associated purpose while the second is the kind of error that can arise within an otherwise correctly focused model.

The ten categories of model proposed to support professional decisions are not independent. The possible interaction has a potential of being confusing. In this respect the use of a model will require care so that contradictions are avoided. To this extent the thinking of the responsible engineer has to be clear. However the possibility of overlap and absence of independence may avoid crucial matters falling between the cracks with disastrous results. There are many examples of errors of this type. In nearly all of these occasions the subsequent reviews characterized the reaction as surprise. The overlooked features had either not been considered or been treated as unimportant.

There are costs associated with the modelling necessary in professional engineering decision-making. The example in the Introduction of the use of computers in structural analysis indicates that as the geometric shape became less amenable to established programs the engineer had to construct special solutions with associated additional costs. The ability to make these individual analyses has removed a geometric constraint from architectural practice with unusual and surprising results. The high costs of constructing models that require these special purpose analyses are often connected to the special requirements and the unusual usage. Thus aircraft and off shore drilling structures make large demands on the engineer producing sophisticated analytic models.

Uncertainty is a state that exists in all of the ten model types proposed. Essentially engineers make decisions in a finite time in the face of uncertainty. The real world displays uncertain situations and the effort to include them into decisions is accomplished by modelling the uncertainty. The use of statistics is common in all branches of civil engineering. This type of modelling demands care. The relevance of the measured population to the intended population has always been difficult to establish and has led to misleading results. The size of the measured population is critical, and, in the case of rare events, difficult to attain. The use of probability methods has also been important in engineering decisions. Again questions about the measurements used arise in spite of the elegance of the theory. An incorporation of unspecific uncertainties into modelling has either been by comparisons to other events, verbal descriptions or by the use of logic that included yes, no and maybe, as opposed to the binary logic of probability logic. The Lukasiewicz logic was established in the 1920s and 30s and the use of fuzzy support measures for quantitative values of subjective features in the 60s. These methods allow such subjective uncertainties to be modelled and included into professional decision schemes with success. They are of particular importance in control systems.

5. Conclusion.

Modelling is an essential part of professional decision making. The orderly process of constructing models can help avoid errors and inadequacies in the engineering process, particularly related to omissions in the development or collection of the information or knowledge necessary to make valid decisions. However, the engineering decision maker has to ensure that the process is correct and complete. This requires the continual evaluation of reality and the inclusion into the models of all relevant aspects of the problem.

It is believed that a clear focus on the process of modelling will contribute to better engineering. Such a focus requires an understanding of the process, and to this end a categorization of models has been proposed according to their purpose. Each category has its uses and each also has characteristic errors – ways of going wrong.

Further work is necessary to elaborate on the characteristics of the model types and also as to appropriate principles that would be helpful for their use.

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