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Engineering decisions: Information, knowledge and understanding

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ABSTRACT

The success of engineering outcomes largely depends on the quality of decisions made in the engineering process. The likelihood of poor decisions leading to unsatisfactory results, including safety issues, can be reduced by identifying potential problems in the associated decision processes. This paper concentrates on one aspect of decision making – on the knowledge an engineer requires for making a decision. The first section develops ideas as to how the necessary knowledge and understanding can be acquired, and how, importantly, its quality or dependability can be assured and maintained. These ideas are then considered in four contexts: the initial decision on structural form, structural design, construction, and finally, use and maintenance. As the discussion develops, a number of recommendations emerge. These are distilled into a series of "lessons". While they are principally intended for the practicing engineer, there are also significant implications for engineering education.

1. Introduction

The observed failure rate of engineering structures has been consistently shown to be several orders of magnitude greater than the failure rate predicted by probabilistic structural analysis [1]. The reason generally given for the difference is that most actual failures are to do with matters other than those taken into account in analysis. Thus to improve structural safety, the incidence and effects of these other matters, such as human error, must be reduced. Quality control helps, and so does the work by Reason [2], Turner and Pidgeon [3] and others in understanding the nature and sources of error. Here, we take a different approach and propose that engineering failures, human error notwithstanding, are almost inevitably the result of bad decisions. It follows that the likelihood of structural failure can be reduced by reducing the incidence of poor decisions. Poor decision-making is also the cause of other engineering problems such as serious cost overruns. How, then, can engineering decision-making be improved? An obvious first step is to study engineering decision-making in detail to understand it better – to break it down into component parts or aspects. Deeper understanding of the detail can lead to better and more sure-footed decisions.

Decision-making is surprisingly complex [4]. An earlier paper by us [5] lists a selection of aspects needing to be addressed as: models (defined broadly) and their use; responsibilities; heuristics (their power and danger); methodological issues; evaluation (i.e. putting values on decision consequences); information and knowledge; communication; quality; complexity; creativity. We discuss the first three items elsewhere [6–8]. The present paper focusses on the part that information and knowledge play in the decision process – on the nature of the knowledge that a decision-maker must have in order to make a good decision. Though the discussion is broadly applicable, it emphasises decisions typically made by structural engineers.

The key issue is this: a decision of any complexity must be based on a body of knowledge – knowledge known to the decision-maker and relevant to that particular decision. The different components of this body of knowledge will not in general be independent. They are interconnected in various ways, so the whole can be thought of as a system. We call this the *Relevant Knowledge System* (RKS) for the decision. The paper focusses on two issues: how the RKS is obtained, and how its quality or dependability can be estimated and assured.

The argument has several underlying assumptions and viewpoints providing an underlying foundation for the discussion. They are as follows. First, the nature of a decision is that it does not simply happen by itself, but is made by a decision-maker. It is assumed for convenience that the decision-maker is a single

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person. In practice the decision-maker could be a group, but as the issues are virtually the same we adopt the convention that it is one person. The role of the decision-maker and the associated responsibilities are discussed elsewhere [7]. Secondly, the paper leans towards decisions where the problem and context are complex. Complex situations are not always easily framed, so the decision-maker must tread carefully. Thirdly, we assume that we inevitably, and only, see reality through the interpretation of models of different types and levels. We have found this a helpful point of view, and it is a fundamental stance underpinning the discussion as it develops [6]. Fourthly, we make a distinction between knowledge and information. We define *knowledge* to be what the decision-maker knows, while *information* refers to all those pieces of information which might be available, actually and potentially. Most information will not be known directly by the decision-maker, whose knowledge as we define it here will only be a small subset. Thus a fact would be information, but in our usage it would only be knowledge if it is known to the decision-maker. Even though a piece of information might be known widely by others and be seen by them as *their* knowledge, if the decision-maker does not know it, it is not knowledge as the word is used here. We do not claim that our terminology is correct, but only that it is a point of view helpful if not essential to the subsequent discussion. The underlying point of view is that a decision is a subjective act, a standpoint at odds with the normal engineering view habitually focussing on an objective world and on objective and analytic processes. These issues, too, are elaborated elsewhere [5,8] – see also the discussions of references [6] and [7] and our response thereto [9].

The present paper is in two main sections. The first, *Information, knowledge and decision*, considers in general terms the nature of the knowledge a decision-maker needs for making a decision and how this relates to his or her wider knowledge base and to the mass of information actually or potentially available. The second, *Structural engineering decisions*, shows how the ideas of the first section apply in the context of structural engineering, particularly addressing four aspects: decisions on overall structural form; decisions in structural design; decisions in the construction phase; and decisions related to the use and maintenance of structures. As the discussion proceeds, a number of ideas or ''lessons'' are identified, primarily aimed at practicing engineers.

2. Information, knowledge and decision

Fig. 1 outlines the relationships between information, knowledge and decision, giving a framework for subsequent discussion. Working from left to right, information (the left-hand box) flows into the box labelled ''knowledge'' by a process of communication after the decision-maker has located and selected what is required. It is then integrated into the decision-maker's broader knowledge base (''internalisation''). The subset of the knowledge base relevant to the decision is the relevant knowledge system or RKS, with the word ''system'' implying that the RKS must be seen as an integrated whole. The RKS is then used in a processing activity resulting in a decision. The overall process is controlled by the decision-maker, shown at the top, where ''control'' refers both to what is done and also to assurance of quality. A full understanding of Fig. 1 requires discussion of its elements individually, keeping in mind the distinction being made between information and knowledge. We start with ''information''.

2.1. Information

We are afloat in an ocean of information, with chancy instruments of navigation. Knowing what is and is not there is impossibly demanding, in the sense that it is impossible to know the whole. It is not only that there is so much information, but also that despite all the library and other catalogues in the world, it is not possible to know how to reach it all. This needs to be understood. Thoreau said, ''To know that we know what we know, and that we do not know what we do not know, that is true knowledge'' [10]. Borges explores some of the implications in his short story ''The Library of Babel'' concerning a library with an infinity of uncatalogued and unindexed books [11]. All possible written information is there, true or false, but there is no knowing either its location or its dependability. The issues of selection, location and dependability are serious, and we consider them later. Meanwhile, we need to understand the nature of information. There is not just one type, but many, with different characteristics.

We do not use the word ''information'' in the sense used by Shannon and Weaver in developing information theory, where information is considered as a flow of independent and meaning-free bits [12]. In contrast we regard it as a total though ever-changing body containing a degree of coherence – it comes in chunked form as a book, a report, legislation or the sight or site of a bridge. It is the coherence that produces meaning, as an emergent property.

Information is available to the decision-maker in many forms. At the most primitive level, it is available as photons, sound waves and tactile impressions, but it is not perceived at that level of detail. Rather, we perceive a table, a tree. It is analogous to using a word processor on a computer: we do not interact directly with the operating system or the compiler, but only with the word processor itself. Regarding coherence or ''chunking'' of information, there is a difference between correlation within a body of information and the act of perception, which seeks and perceives patterns. They are two different issues, one concerning what is there, and the other concerning what we do. More generally, both perception and understanding depend on expectations [6,8]. We see what we expect to see. There are dangers here for professional engineers.

Lesson: We make assumptions as to what we see, hear and believe. This helps as a short cut to understanding and action. Yet our assumptions may be very wrong. It pays to be wary, and aware of the need to be careful.

There are many types of information, and many possible sources. The left-hand box of Fig. 1 suggests a set of information types as: facts; values; limits; analogies; and techniques. The list is incomplete. How, for instance, could music and art be included? However, the list aligns with the present topic of engineering decisions.

At first sight *facts* seem obvious. By ''facts'' here, we mean states of affairs believed to be true, within limits. Generally they are identified by statements: ''It is a fact that ...''. Examples are the maximum expected flood level of a river, the compressive strength of a concrete mix or the significant stakeholders of a project. They could come from many sources such as books, analysis, specifications, observations, codes of practice, the internet or communication with others. Facts could be direct (the strength of steel) or indirect (where to go to obtain some required information).

However, there is an issue regarding the *quality* of a fact, its reliability or dependability. This is important. It is neither true nor helpful to follow Churchland [13] and say that ''A fact is a fact is a fact.'' If a fact is seen as a statement of belief, it could be true, it could be false, or its status could be uncertain. We can be pretty sure that Henry VIII came to the throne of England in 1509, on the basis of evidence, but less certain that all the required design checks were done on a structure. Blockley gives a useful discussion of problems relating to truth and uncertainty [14].