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Ethical Considerations in Engineering Design Processes

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Engineering ethics is usually seen as the field of study that focuses on the ethical aspects of the actions and decisions of engineers, both individually and collectively. Interest in engineering ethics, especially in the context of engineering education, has been rapidly increasing during the last few decades. As existing textbooks and other publications demonstrate, engineering ethics involves a broad range of (ethical) issues.

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Here we focus on the specific area of engineering ethics pertaining to engineering design. We believe that engineering design constitutes an interesting starting point for ethical issues in engineering, both for educational and research purposes.

As far as we know, there has not been much systematic research on ethical aspects in engineering design and on how engineers deal with such aspects. Engineering design is also an interesting topic to research from the point of view of engineering ethics because design is one of the main activities in which engineers are involved. Moreover, technology has social

0278-0079/01/$10.00©2001IEEE

and ethical implications mainly because of the kinds of products produced, which are the eventual outcomes of design processes.

We will focus here on two ethical aspects of design processes: the formulation of design requirements and criteria, and the acceptance of trade-offs between different design criteria. When calling an aspect of the design process "ethical" or "moral" - in this article these terms are used interchangeably - we have used the following criteria:

The aspect of the design process is connected to, or brings about possible negative consequences, for people other than the designers involved;

More or less generally accepted values or norms, such as safety or privacy, are at stake;

The norms and values of the different engineers involved in the design clash with each other.

The *Herald of Free Enterprise* Disaster

On March 6, 1987 the roll-on/roll-off passenger and freight ferry the *Herald of Free Enterprise* capsized just outside the Zeebrugge harbor. Water rapidly filled the ship. The capsizing of the *Herald of Free Enterprise* led to the death of 150 passengers and 38 crewmembers. The main cause of the disaster was the fact that the inner and outer bow doors were open when the ship set sail.

The assistant bosun should have closed the doors, but he had fallen asleep. The absence of warning lights made it impossible to see from the bridge whether the bow doors were closed. On at least two previous occasions, similar negligence with sister ships owned by the same company had led to ships setting sail with their bow doors open but without disastrous results [1]. In the case of the *Herald*, as is often the case, it was human error that preceded the disaster, but the ship's design contributed to the occurrence of the disaster in the first place.

Although other contributing factors were important in the *Herald of Free Enterprise* disaster, it was the inherent instability of roll-on/roll-off ships encountered when water enters a deck that played an important role. It might be expected that while designing the *Herald* and her sister ships, the designers were aware that if water were to seep into the decks the ship might quickly become unstable. After the disaster with the *Herald*, there was a similar disaster with the *Estonia.* Water filled one of the decks and the ship capsized killing nearly 800 people.

One moral question that arises in relation to the design of the *Herald* of Free Enterprise, and other roll-on/roll-off ferries, is whether it should have been safer given the fact that it was known that the process of water entering the deck might result in rapid capsizing. This is a moral problem because probable negative consequences are imposed on the passengers (e.g., criterion 1 of the moral problems mentioned in the introduction). There were, and are, simple technical solutions if one wants to prevent rapid capsizing when water enters a deck [2]. The fact that a simple solution designed to lower the risk considerably was available could mean that the way in which this issue was handled conflicted with generally shared norms and values or with the values of the designers involved.

When we look at this moral problem in relation to the design of the *Herald* and comparable ships, ethical aspects became relevant at two different stages of the design process: during the formulation of criteria and requirements for the design and in the acceptance of trade-offs between requirements. We shall focus below on the formulation of safety requirements for a roll-on/roll-off passenger or freight ferry, and on the trade-offs which exist between safety and economic requirements.

Safety Requirements

The International Maritime Organization (IMO) plays an important role in formulating legal safety requirements. This international organization is responsible for adopting legislation for ships. IMO's safety legislation has to do with the ship as well as the passengers. The SOLAS (Safety of Life at Sea) convention is especially concerned with passenger safety and with lifesaving equipment on passenger ships.

IMO knew as early as 1981 that if water entered the car decks of roll-on/roll-off ships, they could be lost in a rapid capsize [3, p 52]. This is regarded as common knowledge in the maritime world, at least since that time. IMO did not adjust its regulations to solve this problem, while a simple solution was available. Bulkheads created on the decks could easily impede the water and prevent rapid capsizing [2].

Because legislation adopted by IMO needs to be implemented by governments, only governments accepting an IMO convention have to implement it. When writing a convention it is therefore important to make it acceptable to as many governments as possible, otherwise only a small percentage of all fleets will be obliged to abide by the convention. A shipping company can decide to sail under the flag of another country which has not ratified an IMO convention, if complying with the convention costs a lot of money. So there is a certain amount of pressure on IMO not to issue safety requirements that are too tight.

Most IMO conventions legislate new ships but do not affect the fleet that is already asail. This is known as the grandfather clause. The grandfather clause protects the poorer states, because for them it would cost a lot of money to adapt their older fleets to new legislation. Legislation may thus be said to be weak, and roll-on/roll-off vessels complying with legislation are still prone to rapid capsizing.

Apart from IMO, insurance and classification companies also have a part to play in the formulation of safety requirements. For hull insurance bought by operating companies from insurance companies such as Lloyd's of London, a ship needs to be classified. Classification organizations are private organizations that have to monitor compliance with legislation during construction and the certification of sea worthiness during a ship's lifetime. Only the equipment and the construction are taken into account by the classification organizations, not passenger safety [3].

There is little incentive for shipping companies to ask for, or for shipyards to design ships, that are even safer than required by IMO conventions and hull insurance regulations. When disasters occur, the investigation that follows usually concludes that it was a human error that led to the disaster. Little attention is given to the design of the ship as long as on completion it complies with regulations.

The Trade-Off between Safety and Economic Requirements

We have mentioned five actors that play a part in the formulation of safety requirements for roll-on/roll-off ferries. These actors are IMO, insurance companies, classification companies, shipyards and shipping companies. To understand why these five actors have not formulated tighter safety requirements, it is important to understand that in formulating safety requirements a trade-off with economic requirements is made.

Economic considerations are important for insurance and classification companies because they depend on shipyards and shipping companies for their customers. When the safety requirements imposed are more costly than those of their competitors they will lose customers. Insurance companies want the requirements to be tight enough to prevent them from frequently having to pay for hull loss. But usually they do not want to impose more or tighter requirements than their competitors.

Shipyards do not have regular customers. To be competitive the price needs to be kept as low as possible or at least lower than that of the competitors. Safety measures are usually only built in when there is a legal obligation to do so. Shipyards may not be held liable if their ships complied with the relevant legislation.

Shipping companies in Northwest Europe are in sharp competition with trains and planes, therefore they do not want to face increasing costs or longer loading times. In the case of roll-on/roll-off ferries, shipping companies do not want to have bulkheads on the decks because it takes time to put them in place while loading the ferry. So shipping companies also trade off safety against economic considerations.

Finally, IMO and individual countries also trade off safety considerations against economic ones. As we saw earlier, for IMO conventions to be effective, as many countries as possible have to support them. For many countries, however, economic considerations will play an important part when it comes to deciding which safety requirements they consider acceptable. This is reinforced by the fact that shipping companies can choose which flag they sail under. This, in turn, reinforces competition between countries when it comes to devising attractive rules for shipping companies. Such competition may well water down safety requirements.[1]

[1] *Countries might compete on aspects other than safety (i.e., on taxes), but to be attractive they at least have to compensate for expensive safety measures.*

Ethical Aspects of Design Processes: Requirements and Trade-offs

The *Herald of Free Enterprise* case shows that ethical aspects can be of significance in design processes. In particular, it shows two ways in which ethical issues may emerge in engineering design processes, i.e., 1) in formulating requirements, specifications, and design criteria and 2) in assessing trade-offs between criteria and in making decisions on what constitute acceptable trade-offs. We will elaborate on those two aspects in general terms in order to show that there is good reason to expect that these ethical aspects will play a part in almost any design process. By focusing on those two aspects, we do not want to suggest that these are the only ethical aspects involved in design. In fact, a host of other ethical issues may arise in design processes, for example in relation to the unforeseen consequences of a design or in relation to the way in which design invites certain forms of use [4].

Design Requirements

Formulating design requirements is often seen as a first step in the design process. Other actors, besides engineers, usually play a part in the formulation of design requirements or criteria, either by being involved in the formulation of requirements for a specific design or by formulating generic requirements through, for example, legislation. In the case of the *Herald*, for example, governments and IMO formulated safety requirements. In the formulation of economic requirements, the management and the (anticipated) customers of the shipyard had an important role.

Some authors even maintain that engineers do not and should not be involved in the formulation of design requirements, criteria, or goals [5]. The task of engineers is to discover what is technologically

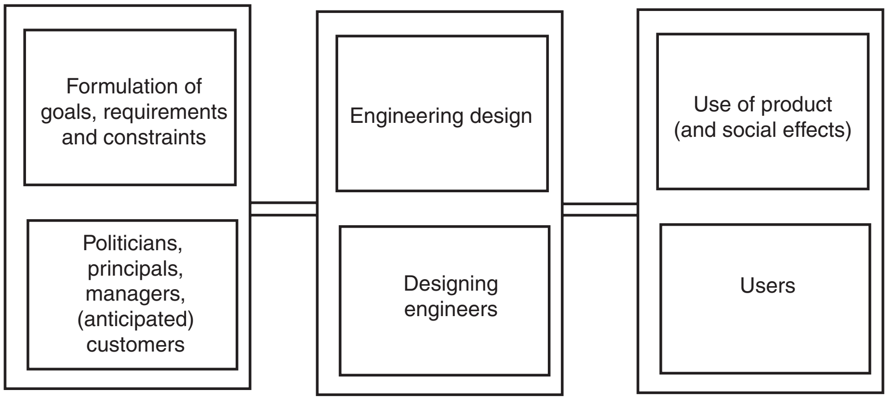

Fig. 1. Division of labor with respect to engineering design.

the best solution *given* certain goals, requirements, and criteria. This idea presupposes a division of labor as illustrated in Fig. 1. Politicians, managers, principals and customers formulate the goals, requirements, and criteria a technology has to meet in this division of labor. The task of engineers is to find the best possible technological solution given these goals and requirements. This task is seen as morally neutral. Moral questions may again arise in the user phase when technologies are being used for certain purposes and produce certain (social) effects.

In this model, the sole responsibility of engineers is to carry out in a competent way a task formulated by others. There are a number of reasons, however, why this model is unsatisfactory. One is that the design of products often invites certain forms of use and discourages others (cf. [6]). Therefore, the way a technology is designed is also relevant to how it will be used and what kinds of effects it will produce. Another reason is that engineers might in some cases have good (moral) reasons to suspect that, for example, on the matter of safety, the legal requirements are not adequate. The case of the *Herald* exemplifies this very point. Engineers usually see safety as an important (professional) responsibility [7]. Many codes of ethics state that "engineers should hold paramount the safety, health, and welfare of the public," implying that engineers have a responsibility for safety that goes further than what the law requires.[2]

Another, more fundamental reason why the described division of labor is not satisfactory is that design problems are usually ill-structured or ill-defined problems [8], [9]. Cross [9, p. 11-12] gives the following characteristics of ill-defined problems:

1) There is no definite formulation of the problem;
2) Any problem formulation may embody inconsistencies;
3) Formulations of the problem are solution-dependent;
4) Proposing solutions is a means to understanding the problem;
5) There is no definitive solution to the problem.

One important point here is that in the case of ill-defined problems, design requirements cannot simply be formulated before the development of potential solutions starts. Rather, the formulation of design requirements is an ongoing activity during the design process. Consequently, design requirements will be adjusted, reformulated, and added during the design process and engineers will play an important part in this process.

[2]*Another question is whether engineers are also able to live up to such expectations or obligations. So if one wants to take codes of ethics seriously, changes in the organizational structure and in the legal rights of engineers as employees might be required.*

In the following section, we will give examples taken from a case study done by one of us that illustrates that design requirements are reconsidered and reformulated during the designing process. We will also illustrate that design requirements or criteria themselves may also be ill-defined, at least in the early design process phases and are in need of further operationalization. During such operationalization, ethically relevant choices may be made.

The fact that design problems are often ill-defined also means that there is usually no definitive or optimal solution. This also means that design does not simply involve finding the (optimal) solution given particular goals and requirements. In fact, during design processes, decisions are made that go beyond the (originally) formulated requirements and goals. This is also corroborated by empirical studies of design processes [10].

Trade-offs

In many cases, not all requirements or criteria for a design can be met at once [11]. Therefore, compromises or trade-offs between the various design requirements have to be accepted. The decision as to which trade-offs between design requirements are acceptable or desirable is a normative one and it is ethically relevant if ethically relevant criteria, like safety or sustainability, are involved in the trade-offs.

Designers can deal with trade-offs in design in different ways. One thing they can do is to look for new technical options that meet all design criteria or minimize the trade-offs between the various design criteria. Often, however, certain trade-offs eventually have to be accepted and a decision has to be made.

One way to decide about the acceptability of particular trade-offs is to formulate threshold values for certain requirements beyond which the design will be considered unacceptable. This design strategy is related to a more general strategy in design that is known as "satisficing" [12], [13]. Satisficing means that a designer is satisfied with any solution that is "good enough" given the design requirements and will not look for optimal solutions. Empirical studies seem to corroborate the fact that engineers use a satificing principle in design [13]. More generally, empirical studies suggest that engineers start with one possible solution concept that will only be abandoned if it becomes clear that a number of minimal requirements cannot be met [9], [13], [14]. While satisficing is understandable given the complex and ill-defined character of design problems, it does not lead to "optimal" solutions to design problems.[3]

While satisficing does not seem morally objectionable as long as "acceptable" thresholds are formulated with respect to ethically relevant requirements, like safety, it probably does not lead to the most ethically desirable solutions. Another point is that satisficing, and especially the tendency to fix on one (initial) solution, may lead to pressure to lower threshold values with respect to, for example, safety because otherwise no design seems possible. Occasionally, this may result in threshold values below what is generally considered acceptable.

Engineers may also use more formal methods, like multi-criteria analysis, to decide about what constitute acceptable, or desirable, trade-offs in design. From a methodological point of view, such methods are often problematic because they suppose — often implicitly — that the degree to which a design meets often quite different criteria can be measured on one common scale. Even if such methodological problems could be solved, there is the normative (ethical) question of how to decide what weight different criteria should have vis-à-vis each other. How should one decide, for example, on the relative importance of safety versus costs? Who is to make this decision? The engineers, the manager or principle of the project, the portrayed users, the people possibly affected, the general public? And how is this decision to be made in an ethically acceptable way?

There will be differences between actual design processes as to the degree to which trade-offs occur and the way in which such trade-offs are handled; there may also well be significant differences in this respect between the different engineering disciplines. Nevertheless, the arguments above suggest that trade-offs will often play a part in design and that in decisions about what are acceptable trade-offs, ethical aspects are significant.

Research Project at Delft University of Technology

For about five years, our department at Delft University of Technology (DUT) has been involved in providing engineering ethics education for engineering students [15]. In most of the curricula at DUT, engineering ethics is now a compulsory subject. At DUT, design and design methodology are important research issues. It is this combination that makes DUT a good place to do research into the ethical aspects of design processes. As part of the engineering ethics research program, a Ph.D. project on the ethical aspects of design processes has been outlined.

The objective of the Ph.D. project[4] is to find out how designers deal with the ethical aspects of the design process. By referring to case studies, the aim is to find out whether designers recognize ethical aspects in the design process and, if so, how they deal with them. For every case study a list of design subjects that have ethical aspects is made. This list, which can be adjusted as the cases proceed, is not meant to be complete or definitive; it aids, however, the data collection. From the field of philosophical and engineering ethics, ideas will be drawn about how designers should deal with ethical aspects of the design process.

In Table I, the research questions are summed up and the methods used to answer these questions are given.

The first elaborate case study is being performed within the framework of the DutchEVO project at DUT. Within an interfaculty research program, known as Smart Product Systems, the DutchEVO project is designing a lightweight, sustainable family city car. The design team comprises Ph.D. students, students, and staff. The list of subjects with ethical aspects related to this case study includes, for instance: safety for users as well as behavior of the car in collisions with cyclists and pedestrians, sustainability and user-friendliness (which persons are physically able to drive the car, comfort). Below, some examples will be given of how designers deal with some of these ethical aspects.[5]

Since the design process is so

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[3] *An optimal solution is in fact a normative (ethical) question on which no agreement may exist. It may, however, be clear that satisficing generally results in solutions that are considered less than optimal. Even if there is not one "optimal" solution, satisficing may lead to an option that is considered worse than what otherwise might have been achieved.*

[4] *The Ph.D. project is carried out by one of the authors*

[5] *We thus pay attention to aspects that are ethical according to our list of ethical subjects, based on the criteria mentioned in the introduction. In this article, we do not pay attention to the question of whether these aspects are also seen as "ethical" by the engineers involved in the project.*

dynamic, everything is at this moment still open-ended. Conclusions reached today can be modified again tomorrow. The car ultimately designed might differ from what the discussions mentioned here suggest. What is described is not the design itself but the way ethical aspects are dealt with during the design. The observations made and described here are interpretations of what happened; we do not attempt to give a full and literal account of what happened, although some remarks will be quoted literally.

In the examples given, safety and sustainability will be central. Sustainability is an ethical aspect because non-sustainable development can cause negative consequences for others, so the first criterion for ethical problems mentioned in the introduction is met. In society there are also regulations and norms about the environmental impact of products, which means that the second criterion is also met. For the same reasons, safety is an ethical aspect.

Table I
Research questions and methods

How and when do ethical aspects manifest themselves during design processes?	case studies literature, concepts of ethical aspects
How do designers deal with ethical aspects?	case studies
How could/ should designers deal with the ethical aspects of their design	case studies normative part of the question: philosophical and engineering ethics process?

The Operationalization of Sustainability

The definition of sustainability that is used by the DutchEVO project is the definition given in the Brundtland report. According to this definition [16 p. 8], sustainable development is kind of a development that ensures

> "that it meets the needs of the present without compromising the ability of future generations to meet their own needs."

It is not clear from the definition laid down by the Brundtland commission how sustainability should be operationalized with regard to transportation. There are, however, some aspects that are clearly relevant to sustainability in transport: energy consumption, emissions, recycling of the materials used. But what is not clear is whether these are the only relevant aspects and, if they are, how they should be weighted against each other. The operationalization of sustainability is an ethically relevant choice.

One frequently used method when it comes to operationalizing sustainability is that of performing a Life Cycle Analysis (LCA), but although there are norms on how to do a LCA, these norms are not without their problems. For example, there are discussions on how to draw the boundaries and on which aspects should be discounted and which should not [17].

At the moment, the DutchEVO project operationalizes sustainability mainly as "lightweight" and "emotional sustainability". Lightweight as a parameter for obtaining a more sustainable car is chosen because reducing car mass could well lead to large fuel consumption decreases.[6] In the car industry it is quite usual to focus on fuel consumption when a (more) sustainable car is designed.[7]

The concept of emotional sustainability is introduced on the basis of the assumption that "A technological solution will not in itself yield more sustainable product use. This needs to be accompanied by a change in the relationship between the user and the product"[18]. The requirement that the car should be "emotionally sustainable" means that there is a bond between the driver and the car. In this case the interaction between user and product should involve the following interaction terms: aging, caring, and exploring. The designers want the users to feel "pleasure to age with your product." The emotional sustainability concept implies therefore that people should enjoy their car and not feel guilty about using it. The interior should be flexible so that a user can change the car and make it his or her car.

The operationalization of sustainability as lightweight can clash with other operationalizations of sustainability that are, for instance, based on a LCA study. Lightweight materials can be difficult to recycle and often consume a lot of energy during production; the energy gain is concentrated in the using phase. Comments have been offered on this

[6] *Whether the lightweight or fuel consumption criterion is the most important criterion may well be questioned. These two criterions partly overlap but they are not completely equivalent.*

[7] *Fuel cell cars are another sustainable alternative explored in industry, but it will likely take some years before these become commercially interesting.*

from within the interfaculty research center. At one project meeting a member of the project team stated that it is not possible to do an LCA on only the user phase, so it is not possible to determine whether the car is sustainable by only looking at fuel consumption. Recycling and LCA are being focused on within the interfaculty research center which will probably mean that more attention is paid to recycling and LCA when selecting materials and combining methods. Such increasing attention to LCA and recyclability is indeed observed and the designers acknowledge that recyclability and lightweight can be conflicting aspects. At this moment, lightweight is still the most important criterion.

Difficulty may also arise in the area of emotional sustainability. If people really enjoy their car they might use it more often. If the car is used in preference to cycling or walking the total energy consumption for transportation might rise instead of fall. In this way a sustainable product might lead to unsustainable behavior. The designers do not seem to realize this; at least they have not discussed this so far.

Safety Requirements and Trade-Offs

The safety requirement was initially operationalized to meet European standards and legislation. The designers, however, also felt a need to discuss these standards and legislation themselves. These discussions were probably triggered by the lightweight requirement because including all the existing safety devices would lead to a car certainly being heavier than 400 kg.[8]

As things now stand, the DutchEVO will not, for example, contain airbags or Anti-Lock Braking System (ABS). The general idea discussed within the group is that all those kinds of safety measures just make people feel very safe which leads to more speeding and reckless driving not to fewer accidents. When a member of the design team said that airbags will be obligatory in the future, the response of some of the other members was that such an obligation should be challenged. This leads to conflict between the different requirements, because one requirement is that the maximum weight is 400 kg and another is that the car has to meet European legislation and standards.

In other discussions the challenging of safety regulations or testing methods was also observed. Triggered by mass restrictions, some ethical aspects of car safety are acknowledged by the designers. Some designers find some requirements too low (rear impact) or irrelevant (door testing with a cylinder), and so after discussion the design team can decide, if it wishes, not to meet certain safety standards or to define stricter safety norms than legally required.

Ethical Issues in Design

Ethical issues do play a part in engineering design and engineering design is an interesting starting point for research into engineering ethics. In this article we have tried to show this by discussing two (potential) ethical aspects of engineering design: the formulation of design requirements and the acceptance of trade-offs between requirements. While these are not the only ethical aspects in design, they will probably play a part in many design processes

While the data available do not make it possible to draw final conclusions, some propositions and questions for further research into how engineers deal, or should deal, with ethical aspects of design, in particular in relation to requirements and trade-offs, can be formulated. With respect to requirements (and their ethical aspects) it seems that engineers often feel little need to reflect on those requirements if they are clear-cut and can be directly implemented in the design process [4], [19]. If requirements need to be further operationalized, which is regularly the case, or if requirements cannot all be met at once, which is also regularly the case, this seems to trigger off reflections on and discussions relating to requirements. Ethical aspects can, but do not necessarily, play a part in these discussions.

In terms of trade-offs between requirements, engineers often seem to want to meet certain minimal threshold values for the requirements ("satisficing"). While this may result in ethically acceptable designs, it probably does not lead to the most desirable design from an ethical point of view. Another possible problem is that trade-offs between requirements may cause requirement levels to be lowered, because otherwise no design is possible. In both the cases described, the *Herald of Free Enterprise* and DutchEVO, it could be seen that there was a tendency to rethink or water down safety requirements because they conflicted with other requirements. We do not want to suggest that trading off safety against other requirements is never ethically acceptable, but there is clearly an important ethical issue at stake here.

Despite the fact that many engineers still seem to believe that engineering design is an ethically neutral task, the above discussion shows that individual designers and design teams often do have to make ethically-related decisions during design processes. This also raises important normative questions that remain beyond the scope of this paper, like how can engineers make such decisions in an ethically acceptable way, and should other people — such as

[8] *We do not want to imply hereby that the design team wishes to design a light 'unsafe' car; they only need to critically reflect on safety norms and regulations given the lightweight criterion.*

managers, users, or those possibly affected by a design — be involved in such decisions?

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Myths About Engineering Ethics

(continued from p. 14.)

The basics of interpretation are not hard to learn. I have had no trouble teaching undergraduates to interpret codes of ethics. Indeed, I have had some of these students, those with engineering jobs, point out the similarity between what we were doing with codes in class and what they had to do at work with specifications (and municipal, state, and federal regulations). Engineering is, in fact, a profession in which interpreting rules is important. Why then not explicitly teach the interpretation of rules as part of engineering ethics? Why not understand codes before finding fault with them?

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