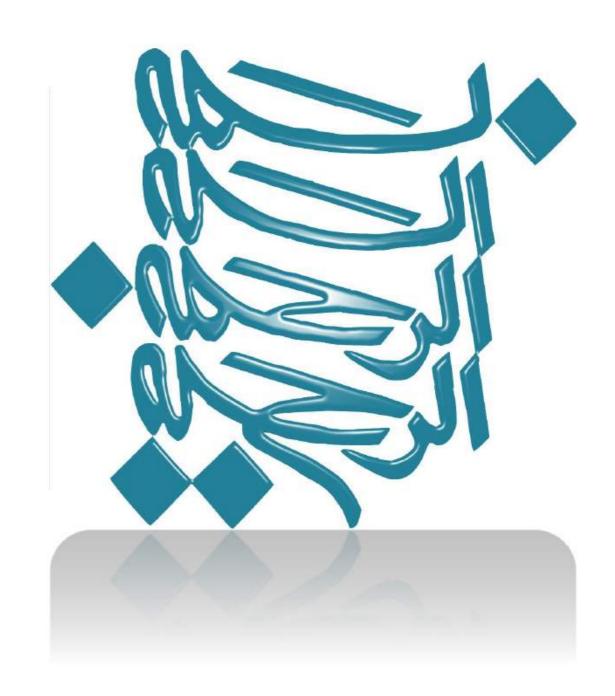
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A Philosophy of Technology

From Technical Artefacts to Sociotechnical Systems



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Introduction

Technology is not just a collection of technological products, but it is also about how people, more in particular engineers, develop these products, about how people use them to meet their specific ends, and about how this all changes the world as we know it. Ultimately, technology is an expression of our endeavours to adapt the world in which we live to meet our needs and desires. Technological action may therefore be termed a form of goal-oriented human behaviour aimed at primarily resolving practical problems. Yet, the most tangible results of such efforts are the material products of technology, and we shall call them technical artefacts. Technical artefacts are physical objects such as nails, aeroplanes and skyscrapers, but they are also the tools, machines and factories that are used to fabricate those objects. But practical problems are not just resolved by introducing a bunch of technical artefacts into the world. With these artefacts come instructions for their use. And with these technical artefacts come also social roles for people and social institutions for enabling the use of the artefacts. In this book, we shall present a philosophical analysis of this

Technical Artefacts

We shall start by focussing on what exactly it is that distinguishes technical artefacts from other physical objects, such as those found, for instance, in the natural world that are not made by human beings. We shall also contemplate how technical artefacts are made, how they are designed by engineers, and what kind of knowledge this entails. Technical artefacts are used by humans to achieve all kinds of goals and that immediately gives rise to issues that involve more than just the artefacts. Through technology, people are able to change the world around them, and those changes, together with the accompanying goals, can be morally good or bad. In other words, technological questions are also ethical questions. Does technology help to make the world a better place or does it make the world more dangerous? To what extent can engineers be held responsible for all the good and bad consequences of technological developments? These are also issues that will be addressed.

Use Plan

In this book, we shall make use of two main tools to guide the reader through this spectrum of issues. The first tool involves the concept of *use plan*. In short, use plans describe the ways in which we manipulate technical artefacts to achieve our different goals. One need only think of the can be used to, for instance, cut a hedge or listen to music. That, then, is the appliance's use plan. This first tool makes it possible for us to analyse how technical artefacts can become means to ends and allows us to see how there is a link between technology as a collection of tangible objects and technology as a collection of actions, by which people achieve their goals. In the first four chapters

Sociotechnical System

tool of use plans. In the chapters five to seven, the perspective will broaden out to include more social and societal technological issues, and for that purpose, we shall introduce a second tool in the form of the concept of sociotechnical system. Naturally, all technical artefacts, are embedded in human action, but in the case of many technical artefacts, they are also allied to wider systems where the proper functioning of the artefacts not only depends on the technology in question but also on social factors. Those kinds of systems are sociotechnical systems. An aeroplane factory and the civil aviation sector are examples of two sociotechnical systems, the first for producing planes and the second for the safe transporting of people by air. Such systems are composed of different kinds of elements including technical artefacts, people and also legislation which, together, form one cohesive system. For the individual user, technical artefacts embedded in sociotechnical systems are often difficult or impossible to use. However, with the help of all the individuals and legislation that constitute parts of such sociotechnical systems, users are often able to achieve their desired goals with these particular technical artefacts. With our two tools, we shall present what amounts to a modern view

Technology ... Not-Technology

to fulfil various human needs and desires. Scientists intervene in the world in order to find better ways to observe and study matters and phenomena. As such, they are essentially world observers with an interest in knowledge. Similarly, in this book, political, economic or artistic actions are not considered to be part of technology. Government, for example, endeavours to directly influence the behaviour of people by drawing up and introducing different laws. Such laws have an impact on people's behaviour. Indeed, they change the legal landscape. In much the same way newly established companies alter the economic reality, and music, film and fashion all serve to enrich our cultural universe. In the very broadest sense of the word, one could say that all of these factors touch on technology, but that is not an area we shall be exploring here. Instead, the technology dealt with here

Philosophical Conceptualization

Here philosophical questions are seen very much as questions that are posited in order to clarify concepts. In the case of technology, these are concepts such as: technical artefact, design, function, responsibility and, of course, the concept of technology itself. They are all central to the way we think about technology and its relationship to humans, but the meaning of these concepts is not always clear. In much the same way that engineers design material tools – technical artefacts – to get a better hold on the physical world, so we, philosophers of technology, need to develop conceptual tools in the form of concepts and conceptual frameworks, in order to get a better grasp on the way in which we think about technology.

CHAPTER 1

Technical Artefacts

We start in this chapter by analysing the nature of technical artefacts. What sorts of objects are they? What are the typical characteristics of technical artefacts? Given that technical artefacts play such a predominant role in our modern world, these are all important questions. The way in which

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Technical Artefacts ... natural ... artistic ... distinction

materials, et cetera. What all of these things have in common is that they are material objects that have been deliberately produced by humans in order to fulfil some kind of practical function. They are often described as technical *artefacts* in order to emphasise that they are not naturally occurring objects. Here, we do not classify artistic works as *technical* artefacts because they do not fulfil any practical kind of function (the producing of art typically also draws on different creative skills and qualities than those demanded of an engineer).

up.³ The distinction between artificial and natural objects is also problematic. It may be taken to be an artificial distinction in itself in the sense of being 'unreal', since one could point out that people themselves are natural organisms and that everything that a human being, as an integral part of nature, produces is inevitably natural (in much the same way that a beaver's dam may be termed a natural object). By attributing fundamental significance to the natural-artificial distinction, it is almost as though we humans are inclined to somehow view ourselves as external to nature. That, in turn, instantly gives rise to the question of how precisely humans may be viewed as non-natural beings.

3 Aspects of Technical Artefacts

Question 1: What is it for?

Question 2: What does it consist of?

Question 3: How must it be used?

The answers to these questions will describe the following respective matters:

Aspect 1: The technical function of the technical artefact.

Aspect 2: The physical composition of the technical artefact.

Aspect 3: The instructions for use accompanying the technical artefact.

These three aspects are not independent of each other because the physical composition must be such that the technical function can be fulfilled, and if that function is to be realised, the user will have to carry out certain actions as described in the instructions for use as laid down in, say, the user manual. A technical artefact cannot therefore be considered in isolation of the accompanying instructions for use. These instructions specify a certain use plan, a series of goal-directed actions to be met by the user with respect to the technical artefact to ensure that the function is realised, presuming that the technical artefact is not broken. Each technical artefact is, as it were, embedded in a use plan that is closely attuned to the relevant function.

Technical Artefact ... Technical Object ... Natural Object

In the light of what has been stated above, we may therefore define a technical artefact as a physical object with a technical function and use plan designed and made by human beings. The requirement that the object must be designed and made by humans is added to ensure that any natural objects that happen to be used for practical purposes are not also termed technical artefacts. For instance, a shell can be used for the purpose of drinking water. In such a case, it has a function and a use plan. Nevertheless, since it does not also meet the requirement of being human-made, it is not termed a technical artefact.

The most obvious difference between natural objects and technical artefacts is the fact that the latter result from purposeful human action whilst the same cannot be said of natural objects; a natural forest is one that has spontaneously evolved, without any kind of human intervention. Nature is that which has in no way been subjected to or disrupted by any kind of human intervention. The essence

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Aristotelian and Modern Concept of Nature

For Aristotle, not only living (biological) objects have a nature, but physical objects also have a nature; it is their intrinsic principle of motion that endeavours to realise the ends of physical objects. The motion principle of a heavy stone, for instance, is to gravitate to its natural place, and the natural place for all heavy bodies is in the centre of the universe. Whenever one throws a stone up into the air, one forces it to make an unnatural upward motion when, in fact, the intrinsic principle of motion of any heavy stone is to perform a downward motion towards its natural place in the centre of the universe.

It is not easy to relate the Aristotelian concept of nature with the notion of nature that lies at the basis of our modern natural sciences. That is mainly because the idea that physical objects may conceivably have an intrinsic end is one that has been abandoned. Yet curiously enough, a core element of the Aristotelian notion is still present in the natural sciences. The natural sciences are devoted to the study of natural objects and phenomena, in other words, objects and phenomena whose properties are not human-made but are rather determined by physical, chemical and biological laws. Those laws may be seen as the intrinsic principles of change for those objects and phenomena and thus as their nature (or as the natural laws governing them). Examples of such natural objects

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Technical Artefacts ... Physical Objects

objects. The most striking difference between an aeroplane and an electron is that the first has a function and use plan whilst the second does not. Physical objects, such as an electron, have no function or use plan; there is no place for functions and use plans in the description of physical reality. This does not mean that electrons may not perform functions in technological equipment. It just means that from a physical point of view, such a function is irrelevant because that function has no consequences whatsoever for the properties and behaviour of an electron as a physical object. The function fulfilled by a plane, by contrast, is an essential property of that thing as a technical artefact: if we ignore the relevant function and the use plan, then we are merely left with a physical and thus natural object and not a technical artefact.

A second important difference between technical artefacts and physical objects, and one that is closely allied to the first, is that technical artefacts, unlike physical objects, lend themselves to normative claims.' This is a good/bad aeroplane' or 'This aeroplane should be in good working order' are sensible assertions, but the same cannot be said of assertions such as 'This is a good/bad electron' or 'This electron should work'. Normative assertions about technical artefacts indicate that they function to a greater or lesser degree or that they simply fail to fulfil their function. Normative

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Technical Artefacts ... Biological Objects

Let us now consider biological objects. How can an aeroplane be said to differ from a bird 'in the wild'? Here, too, the answer seems obvious: a plane has a function, a bird does not. Yet the differences are more subtle and complex than in the case of physical objects. As a rule, it is true to say that biologists do not indeed attribute functions to plants and animals. What they do is to attribute functions to parts of plants, to organs of animal or to specific behavioural patterns. This is where we encounter natural objects and phenomena with a biological function. In a number of aspects, though, biological functions are clearly different from technical functions. In the first place, biological functions are usually ascribed to the component parts and behavioural patterns of biological organisms, not to the organism itself.⁷ Technical functions are ascribed to the parts of technical artefacts but also to the technical artefacts in question as a whole. In the second place, the biological functions of organs, for instance, are not related to use plans as in the case of technical functions: a bird does not use its wings or have a use plan for its wings. A third point of departure (linking up to the first point) lies in the fact that it is impossible to make normative assertions about organisms as a whole. The wing of a bird may be said to be malfunctioning but not the bird itself, as a biological organism. To conclude, insofar as functions do arise in nature, these functions would appear to be different from technical functions.

Technical Artefacts ... Social Objects 1

In this section, we shall compare technical artefacts with social objects. Such a comparison is not simple because of the wealth and variety of different kinds of social objects. A law, government, state, marriage, border, road user, driving licence, driving offence, traffic policeman, organisation, contract, and so on, are all part of social reality. Roughly speaking, all these things play a role in ruling the behaviour of humans, their mutual cooperation and the relationships between humans and social institutions. All of that is done by a fabric of formal and informal rules. Here the main focus will be on a certain kind of social objects, namely objects such as money, driving licences or passports. From a technological perspective, they are interesting because usually technology tends to play a prominent part in the producing of these objects. At a first glance, one might thus be tempted to categorise them as technical artefacts. But, as we shall see, they are not 'real' technical artefacts but rather social objects. We shall take as our example the ten-euro banknote. Its social function is that it constitutes legal tender - everyone can pay with it.

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Technical Artefacts ... Social Objects 2

and 'properly' meaning: according to specifications). Then just imagine that you and your fellow passengers suddenly become convinced that the plane no longer works, that it is not fulfilling its function (without the good functioning specifications/criteria having in any way changed). What will be the consequences of that for the functioning of the aeroplane? Will it instantly no longer operate? Will it suddenly break down? Such conclusions seem absurd. Whether or not aeroplanes function (meet the specifications) is not something that depends on what the users or any other parties might happen to think but rather on the plane's physical properties since it is its physical structures that have a bearing on the aircraft's functioning.

In the case of the ten-euro note, matters are quite different. With that note, precisely the same fate could befall it as that which befell the Dutch ten-guilder bank note on 1st January 2002 (and the German ten-mark note, or the Italian 10.000 lira note, et cetera) when it lost its status as legal tender. Despite the fact that the physical properties of the note had remained unchanged, it simply lost its power to serve as legal tender from one day to the next (indeed, much the same may be said of a driving licence or passport that expires; without undergoing any physical change, it loses its function). Evidently, such means of payment do not depend, for the fulfilling of their function

Social Objects ... Collective Acceptance

so vital when it comes to the producing of such monetary units. Nevertheless, the physical features which, from a practical point of view, are *necessary* if forgery is to be prevented are not in themselves *sufficient* to realise the function of legal tender.

Unlike an aeroplane then, a ten-euro bank note does not fulfil its function on the basis of its physical properties. On the basis of what does it perform its function? In a broad outline, the answer amounts to the following. If a ten-euro bank note is to fulfil its function as legal tender, it has to be generally accepted as legal tender. Exactly whether the latter actually holds is all a matter of whether or not people see it is being legal and official. In other words, it is all down to their believing that it is legal tender. If they do not view it as such, then the ten-euro note is unable to fulfil its legal tender function and becomes relegated to the status of being merely a valueless piece of 'paper'. It is therefore only on the grounds of collective acceptance that a ten-euro bank note is able to fulfil its function of legal tender. As soon as such collective acceptance disappears, it is no longer able to fulfil its function (as was seen to occur in the case of the Dutch ten guilder note when the euro was adopted).

Technical ... Social ... Mixture

on poles and positioned at junctions with red, amber and green colour filters sections. The switch boxes have to ensure that the lamps situated in the three different compartments go on and off in the correct sequence. Even if that technological system works perfectly well, one still cannot guarantee that the traffic light is really fulfilling its function. For the whole system to work perfectly well, road users also have to adhere to traffic regulations in which such matters as the significance of the red, amber and green lights are legally fixed. The function of the traffic light system may therefore only be said to have been fulfilled when both the technological and the social processes in question operate in the correct way (and are properly attuned to each other).

If one asks whether traffic lights, together with the rules concerning the behaviour of road users in response to the different colours, are essentially a technical artefact or a social object, there is no clear cut answer to that question. It is not entirely a technical artefact but by the same token it is not a straightforward social object either. It is a mixture of the two; traffics lights are an example of a sociotechnical system (see Chapter 5). Given that a solution to the regulation of traffic at crossroads

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to be subsequently produced.

Describing Technical Artefacts: Technological Practice

We have described technical artefacts as physical objects that have been designed and made by human beings and that have both a function and a use plan. Moreover, we have noted that the function bears some relationship to the physical structure of the technical artefact and to the use plan. Now

In technological practice, there are two particular ways of describing technical artefacts that are important. Those ways are descriptions from a structural point of view and from a functional point of view. A structural description of a technical artefact simply describes it in terms of physicalchemical and geometrical properties. That is how a physical scientist, who knows nothing about the technical artefact's function, would describe the thing after having analysed it in detail (in answer to Question 2 in Section 1.1). A functional description looks, in contrast to a structural description, at what the technical artefact is intended for without saying anything about the physical-chemical properties (in answer to Question 1 above). A typical example of a structural description would, technical artefacts. Schematically speaking, the designing of a technical artefact commences with a functional description of the object to be designed and ends with a structural description of that same object (see Chapter 2). A complete structural description has to be given if the technical artefact is

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Technical Function: User's View (intentional)

Regarding the question as to what a technical function is, two interpretations can be broadly distinguished. The first interpretation closely links functions to the objectives of human actions, to what a technical artefact is expected to do, to 'the goal served'. If one goes into more detail, functions are then described in terms of 'black boxes,' for which only the input and the output is described (see Figure 1.1). The function of the technical artefact, of the black box, is thus to transform input into output. One looks, as it were, at the technical artefact merely from the 'outside' and describes what precisely it should do. The function of the technical artefact can only be said to have been realised at the moment the goal is achieved. This is typically a user's view of technical artefacts and one in which functions are closely allied to use plans and the related reported goals that users have in mind. It is a view of functions that actually plays a crucial role in the early phases of the design process when all the functional requirements of the artefact that is to be designed are established. This is a thoroughly normative characterisation of a function; if the technical artefact, represented as a black box, fails to transform the input into output, then it may be said to function badly or not at all.

Technical Function: Designer's View (structural)

The black box representation is insufficient for the designing, making, maintaining or repairing of technical artefacts, all of which belong to the engineer's central task. To that end, the black box must be opened and viewed from the inside. In designing, the black box still needs to be given content. What then comes to the fore is the link between functions and the physical properties and capacities of the technical artefact as a whole together with all its component parts. In these activities, we see that engineers often interpret a function as a desired physical property or capacity of the technical artefact. While functions are viewed from this internal perspective, the goals of users disappear from sight, and the emphasis comes to lie on the structural aspects of the technical artefact in question. As long as a technical artefact has a desired capacity, it fulfils its function regardless of whether the aims of human actions are realised (see also Section 2.1). Take note that although this second

Technical Function: Moral Status...

Just like the structural and functional descriptive methods, both interpretations of functions are indispensable in technological practice. A technical function is inextricably intertwined with the physical qualities and capacities of a technical artefact; these qualities and capacities ensure that a function is realised in practice. And the function of a technical artefact and the artefact itself, cannot be detached from the use plans and from the goals of human actions. It is only in relation to those goals that technical artefacts have functions and that normative claims, pertaining, for example, to the good or bad functioning of technical artefacts, make any sense.

Since the functions of technical artefacts cannot be contemplated in isolation of the goals of human action and if one presumes that from the moral angle those goals can be evaluated as good or bad, one may well wonder whether technical artefacts can, in themselves, be seen as morally good or bad. We are not talking here about technical artefacts being good or bad in an instrumental sense, that is, about technical artefacts realising their technical function; we are bringing up the question of whether it is meaningful to assert that they are good or bad in a moral respect. This is where we come up against the problem of the moral status of technical artefacts.

Neutrality Thesis: Dual Use

'Guns don't kill people, people kill people.' This slogan, once produced by the American National Rifle Association, is perhaps the most succinct way of summarising what is known as the neutrality thesis of technical artefacts. What this thesis asserts is that from a moral point of view a technical artefact is a neutral instrument that can only be put to good or bad use, that is to say, used for morally good or bad ends, when it falls into the hands of human beings. People can use weapons to defend themselves from robberies but also to mount armed robberies. The weapon in itself can never be qualified as either good or bad in the moral sense of the word. The way in which the neutrality thesis specifically comes to the fore is in the notion of the 'dual use' of technical artefacts. It is a term that is used to indicate that technologies that can be used for peaceful ends, can often equally be deployed for military purposes. A case in point is radar systems that can be used to follow aeroplanes. On the one hand, radar can be used to make civil aviation safer, but they can equally be used in times of war to track and shoot down enemy aircraft.

Neutrality Thesis: Non-responsible Engineers

The neutrality thesis has direct consequences for our views about the moral responsibility of engineers as designers and as makers of technical artefacts. The thesis asserts that technical artefacts do not in themselves have any moral implications, thus implying that engineers are involved in merely designing or making morally neutral instruments or means. As engineers can generally bring no influence to bear upon the way in which the technical artefacts they design are actually put to use, they cannot therefore be held morally responsible for the way in which their artefacts are ultimately used.

Against the Neutrality Thesis (1)

we shall briefly examine. In the first place, it may be remarked that in the design phase, engineers already anticipate not only what form their product might take but also how it may be used. In other words, they do not just design something that can be randomly put to good or bad use, but they design rather for a specific use. The whole idea that during the design phase engineers anticipate use is something that, for instance, emerges from the use plan notion. Whenever engineers design any artefact, they simultaneously contemplate the goals of the kind of user they have in mind, who will subsequently have to be able to fit that artefact into a certain use plan. Such use plans are invariably not morally neutral. A macabre example of a morally reprehensible use plan is that of

In reply to that kind of argument, one might claim that whilst engineers are perhaps able to anticipate certain kinds of uses, they cannot in fact *determine* them. An artefact can always be put to different use to that which was originally intended, be misused or simply not used at all. Though this may be true, this does not mean to say that a designed artefact is always suitable for any given form of use. A radar system that has been designed for civil aviation purposes has to meet other requirements and will possess other technical features to one designed for military ends. Not all

Against the Neutrality Thesis (2)

A second argument against the neutrality thesis lies in the fact that the phases of designing and using cannot always be clearly differentiated. This applies especially to situations in which sociotechnical systems, such as the civil aviation system, come into play. The functioning of sociotechnical systems is not only dependent upon the proper operating of technological systems but also upon properly functioning social systems (see Chapter 5). A company such as Airbus designs a component of this system, namely the aeroplanes, whilst the existing civil aviation system is fully in use, and this system is one of the elements that determine the constraints for the planes that are to be designed. Sometimes sociotechnical systems can be so all-embracing that the 'use' thereof becomes almost unavoidable, like, for instance, in the case of the electricity system. The built-up environment or a city, which may also be seen as a sociotechnical system, has become so commonly accepted in everyday life that it would be strange to speak in such cases of 'use'. Likewise, in the case of sociotechnical systems, the notion of design can sometimes also be problematic; all kinds of components of sociotechnical systems are designed, but often, there is no single organisation that is responsible for designing the system as a whole. On top of everything else, the way in which use is

Against the Neutrality Thesis (3)

A third argument that can be levelled against the neutrality thesis resides in the fact that new technical artefacts invariably lead to new options for acting, in other words, to ways of acting that did not previously exist and which could give rise to ethical questions. For instance, the invention of the aeroplane made it possible to speedily transport goods to distant destinations and that, in turn, gave rise to new moral obligations when it came to the matter of dealing with disasters and famine in distant regions. From time to time, new options for acting that are opened up by technology can be very controversial, precisely because of the inherent moral considerations - like in the case of the cloning of animals and people – and can therefore constitute grounds for wishing to oppose certain technologies.

In such cases, supporters of the neutrality thesis could argue that it is up to the users to either avail themselves of the new options for acting or not. However, in certain situations, the mere existence of new options to act is, in itself, something that is morally relevant. A good example of this is prenatal testing of the sort that can indicate whether an embryo has some kind of defect.

Against the Neutrality Thesis (4)

In our final argument against the neutrality thesis, we might point out that technical artefacts do not just fulfil functions but that they also bring with them a whole host of undesired side-effects and risks. The use of aeroplanes leads, for example, to noise hindrance, environmental pollution and sometimes even to accidents in which people are killed. Such kinds of side effects and risks clearly have moral significance. Adherents to the neutrality thesis could assert that also these side effects primarily depend upon the manner of use. That is not, however, always the case. The amount of noise hindrance created by an aeroplane does not, for instance, only depend on how it is used but also upon how it is designed. The occurrence of side effects also indicates that the designing of technical artefacts is not only about their efficacy and efficiency. One should also bear in mind that it is not just through being used for a certain purpose that technical artefacts influence the world but also through their side-effects. Such side-effects have to be accounted for in the design phase. The sorts of issues one may think of in this connection are safety, health, sustainability and privacy. These are all moral values that can already, as it were, be built into technical artefacts in the design phase. If such moral values are already inherent to technical artefacts, then one could level this as yet another argument against the neutrality thesis.

Neutrality Thesis: Function as Structure

All in all, proponents of the neutrality thesis are very much inclined to detach the functions of technical artefacts from the specific aims and objectives of human dealings and to conceive of technical artefacts as objects with particular physical properties or capacities. In other words, they conceive of technical artefacts as physical objects. Though it is true to say that these physical objects are designed and made by people with a view to their particular physical properties, it is also true to assert that just like the physical properties of a natural pebble or electron these particular physical properties cannot be evaluated as good or bad in a moral sense. In other words, technical artefacts in themselves cannot be seen as either good or bad. Given such a view of technical artefacts, the neutrality thesis may be said to be applicable to them. However, if we think of technical artefacts as physical objects that have been designed and made by human beings and that have both a function and a use plan, as we propose, then the neutrality thesis can no longer be said to hold. The function and the use plan link technical artefacts inextricably to human goals, and since such goals have moral significance, the same has to be said of the technical artefacts to which they are related.

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Dual Nature

by the arrows with continuous lines). We have furthermore established that the function of a technical artefact is, on the one hand, related to the physical object and, on the other hand, to the use plan (symbolised by the arrows with dotted lines). We have also concluded that technical artefacts are

artefacts are different from physical (natural) objects and social objects. According to the interpretation given above, technical artefacts are hybrid objects that incorporate characteristics of both physical and social objects. An aeroplane is, on the one hand, a physical object with all kinds of physical features and capacities required for fulfilling its function. On the other hand, though, the function of a plane may not be termed a purely physical feature because it also pertains to a use plan or, in more general terms, to a context of human action. In that context of human action, goals have a crucial role to play, and it is only in relation to those goals that physical objects can be said to have functions. Just like the functions of social objects, the functions of technical artefacts are related to the purposeful (intentional) actions of people, but they cannot be termed social objects because the realisation of technical functions is something that comes about in a completely different way. To conclude, it may be asserted that technical artefacts have a dual nature: 9 they are objects that belong both in the world of physical (i.e., natural) objects and in the world of social objects.

CHAPTER 2

Technical Designing

In Chapter 1, a technical artefact was defined as a physical object designed and made by humans with a technical function and a use plan. In this chapter, we focus on the question of what technical designing actually is. There is consensus amongst engineers about two main features:

- the core activity of technical designing is describing a physical object that is able to fulfil a technical function effectively and efficiently;
- in a broad sense, technical designing is an activity aimed at achieving the goals of people, companies or society as a whole.

Technical Design in Engineering

In the engineering literature, technical designing is characterised as an activity in which engineers describe a physical object that is capable of effectively and efficiently fulfilling a technical function. That technical function originates from a requesting party, the 'customer', which is typically a company but can also be a private individual or a government organisation. This customer may determine the required function himself or herself, or the function is deduced by the designing engineer from the goals, problems or wishes the customer presents. The physical object that is described is frequently an object that does not as yet exist but still has to be designed and made. Such an object is then, by definition, a technical artefact. A customer may, for instance, wish to transport people over

Designing an Effective and Efficient Artefact

function. The artefact must be effective, meaning that the engineer should be able to justify that it actually fulfils the function in question. Furthermore, the artefact must be efficient in the sense that no reasonable better or cheaper alternatives can be found that meet the needs of the customer as well.

Let us formulate this characterisation of technical designing as follows: technical designing is an activity in which for a technical function F a description D_S of a technical artefact with a physical structure S is established that can effectively and efficiently fulfil F. There are at least two

Before ... Core Activity ... After

the objectives of the customer correspond with what is technically possible. A designing engineer is not only a service provider who satisfies customers' requests but also an advisor who interprets, adapts and even sometimes rejects customer demands. A customer who wants to transport people

Technical designing thus extends to a phase that precedes the core activity of establishing a description D_S of an artefact that can fulfil a function F. It also extends to the phase that follows. The description D_S is a description of an artefact for which the designer is able to technically justify that it can fulfil F. This justification may sometimes exist of giving a demonstration that a prototype artefact with structure S indeed is able to perform the desired function F. Yet, in cases where the artefact then has to be produced in great numbers – think of car manufacture – the design process can further extend to, for instance, the necessary manufacturing facilities, including the technological infrastructure required for maintenance and repair.

Designing is an Iterative Activity

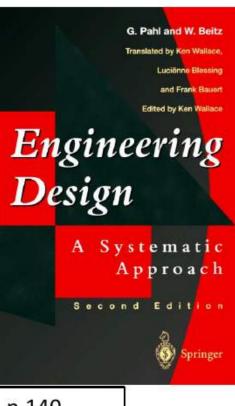
Methodologically, and in terms of timeframes, the core activity of designing is not, moreover, isolated but rather intertwined through all kinds of feedback loops with the preceding and ensuing phases. If the description D_S of an artefact with function F is impossible or too complex, the designing engineer can return to the customer and ask if he or she can adapt his or her goals. But also after the description D_S of an artefact has been laid down or after it has been proved that the prototype works, it is still possible for the engineer to go back to the customer and modify the goals. The artefact can be difficult to manufacture, or it can turn out that the fabrication costs are too high. In some cases, it is only once an aeroplane has been manufactured or has even entered into service that a clear view of the production costs emerges; one need only think in this context of the new problems that continuously surface during Space Shuttle flights. Designing is therefore an iterative activity or, in other words, an activity in which, step by step, engineers translate the goals of customers into functions F, convert those functions into descriptions D_S of artefacts, construct those same artefacts, test them and ultimately produce them, while at every new stage being able to return to previous steps.

Design: Commercial and Social Aspects

chapter. The customers are frequently commercial companies - many engineers are traditionally employed by such companies - which means that the vested interests of those companies, in the form of commercial success and economic continuation, become integral aspects of the goals that have to be achieved during the design process. Technical designing thus also becomes, in part, a form of product design for economic markets; the designing engineer must create artefacts that can be marketed and must innovate technologically so that companies and national economies can grow. As well as this commercial aspect of technical designing, there is also a social aspect that needs to be considered. Governments also commission projects: for instance, in order to serve society engineers design airports, air traffic control systems and military aircraft. Engineers are service providers who set out to help people, companies and society to realise their goals and to resolve their problems.

3 Phases of Designing

there are three main phases that can be distinguished: a conceptual phase in which the configuration of the artefact and the most important components are described in general functional terms, a materialisation phase in which technical solutions in terms of existing technical components are selected for the various components and a detailing phase in which the physical description of the chosen components is adapted so that all the demands can be met. Especially the last two phases are rounded off with necessary but time-consuming analyses to determine whether or not the results achieved are adequate. The time and means demanded by these analyses are all at the expense of the time and means that the engineer is able to devote to designing in the conceptual phase. This



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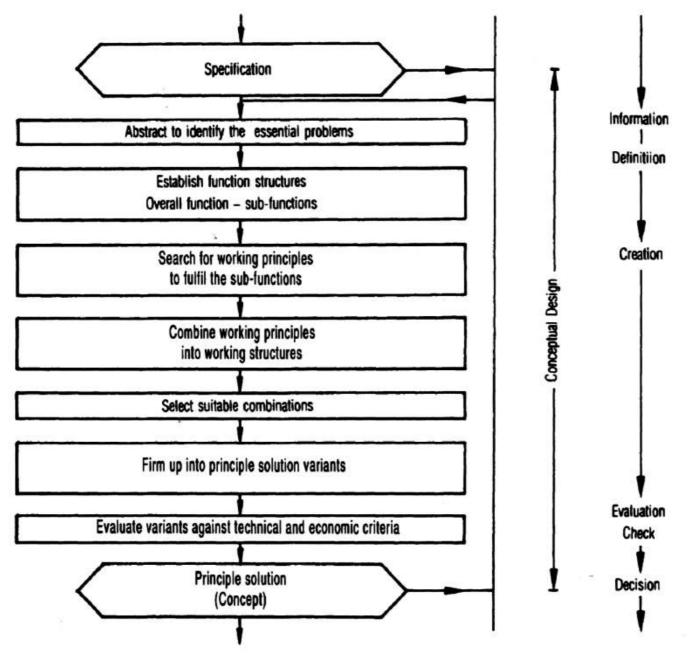


Figure 6.1. Steps of conceptual design

G. Pahl and W. Beitz Translated by Ken Wallace, Lucienne Blessing and Frank Bauert Edited by Ken Wallace Engineering Design A Systematic Approach Second Edition pringer

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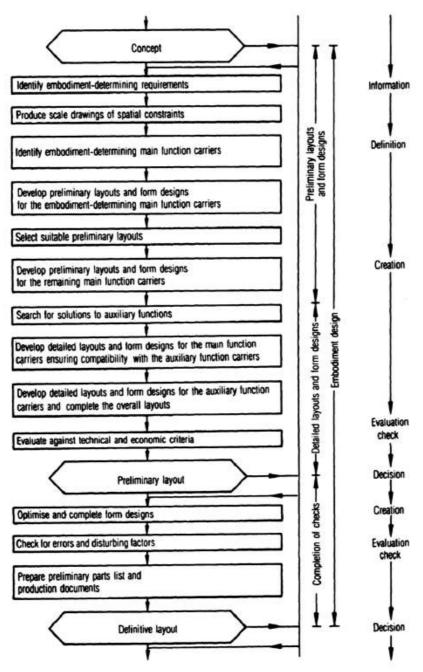


Figure 7.1. Steps of embodiment design.

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Design: Two Interpretations

function' has not been fully defined. In Section 1.4, we distinguished two interpretations: one in which functions are closely related to the goals of human actions and one in which functions are interpreted as the desired physical properties or capacities of technical artefacts. The two interpretations are different, which can be established if one questions under what circumstances the artefact has fulfilled its function. In the case of a plane, for instance, the first interpretation leads to take the goal of transporting people by air from point a to point b as the plane's function. In the second interpretation, the function of the plane may be described as that of having the capacity to transport people through the air. With the first interpretation, the aeroplane may be said to have fulfilled its function as soon as the goal is achieved, that is, once the aircraft has landed and the passengers have arrived at their destination; in the second case, the plane's function is fulfilled as soon as it becomes airborne with passengers on board (regardless of whether it ever reaches its destination). It is precisely this ambiguity in the concept of function that extends to ambiguity in the characterisation of technical designing. With the first interpretation, the core activity describes an artefact that is able to attain a possible goal whereas in the second interpretation, it is an artefact that has certain desired physical properties or capacities. In some cases, the difference between these two specifications of

2 Interpretations ... 1 Choice (2nd one returns...)

function. We, as philosophers, can adopt an unequivocal meaning by deciding how we are going to define the term 'technical function'. We shall opt for the second interpretation, and we shall systematically take technical functions to be the desired capacities of artefacts. By making this choice, we obviously disregard that part of the engineering literature in which functions are taken to denote goals. Engineers who conceive of functions as goals may therefore view the remaining analysis of designing given here as strongly biased. There are two reasons for supporting the choice that we propose. To start off with, a philosophical analysis requires that concepts have a clear and unambiguous meaning. We therefore have to make a choice, even if that means estranging ourselves, in part, from the discipline that we set out to describe. In the second place, our choice enables us to examine technical designing in more detail. For engineers who maintain that functions are closely related to

2nd Interpretation returns through Use Plan (aeroplane example)

With our decision to regard functions as the desired physical properties and capacities of artefacts, we thus identify a step in technical designing in which objectives are converted into functions (as desired physical properties and capacities). We shall now describe the relationship between these goals and functions with the aid of a use plan, as outlined in Section 1.1. A use plan consists of the actions that the user of an artefact has to fulfil with the artefact in order to realise the goal associated with that particular artefact. Such a use plan is fairly clear for light aircraft and

plan to be effective. The use plan for a small plane amounts to a series of consecutive actions aimed at transporting people by air from a to b, and the function of the aircraft lies in the capacity to carry people in the air, since this is the capacity of the aircraft which ensures that the execution of the use plan realises the goal of the plan.

Technical Design Steps (Use Plan Analsis)

In the use plan analysis, the core activity of technical designing consists of four steps:

- 1. the designing engineer commences with fixing the customer's goal,
- 2. (s)he then develops a set of actions with the artefact-to-be-designed by which this goal can be realised,
- 3. (s)he determines which function F, that is, which capacity F, the artefact must have if the plan with the artefact is to indeed realise the customer's goal, and
- 4. (s) he finally describes the physical structure D_S of the artefact so that it has that capacity F.

Technical Design: Restrictions ... Success

Because of the broader contexts in which the core activity of technical designing is embedded, it is not so that every description D_S of an artefact that is able to fulfil a function F is automatically a case of successful technical designing. Those contexts impose all other kinds of further restrictions. The function F must derive from the goals of a customer and that same customer can have further demands, such as physical and financial requirements and demands linked to the use of the artefact that is to be designed. The social context also brings with it limitations. When being produced, used and disposed of, artefacts must comply with various safety and environmental norms and stipulations. These restrictions must all be taken into consideration when describing D_S of the artefact that is to be designed. The designing engineer must furthermore complete the assignment within a given

"Design" Restrictions Lead to Redesigning

to doing more explorative research into new technological possibilities. When it comes to technical designing, it is necessary to be sufficiently certain that the description D_S of an artefact that is able to fulfil the relevant function F can actually be produced within a limited span of time, with the resources available and on the basis of the available technological means. The designing of an aeroplane must be feasible. By contrast, scientific and technological research may remain uncertain in terms of expense and success. When formulating a new chemical theory, doing archaeological excavations or carrying out research into nuclear fusion, one is not, in principle, expected to prove beforehand that success is guaranteed and that results can speedily be produced.

This is the reason why, to a large extent, technical designing remains a process of redesigning: the technical designing of a plane, for instance, often amounts to introducing a variation in existing designs so that, in that way, success may be guaranteed within the permitted design period. Walter Vincenti, an aeronautical researcher, calls such redesigning normal designing, and he contrasts it with radical designing. In normal designing, engineers adopt the operational principle and the normal configuration of an artefact from existing designs. According to Vincenti, the operational principle

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Operational Principle ... Normal Configuration

configuration of an artefact from existing designs.¹¹ According to Vincenti, the operational principle is the physical and technological principle that enables the artefact to fulfil the required function.

✓ Refers to how a device works.

The normal configuration, by contrast, is the way in which the salient components of the artefact are ordered. For present generations of commercial aircraft, the operational principle resides in the

- ✓ Refers to kind of material.
- ✓ General shape and arrangement that are commonly agreed to best embody the operational principle.

Radical Designing

tail stabiliser. Radical designing is any kind of designing where engineers deviate from the operational principle, from the normal configuration or from both. In many cases, technical designing amounts to normal designing; radical designing is often confined to just several components of an artefact such as when introducing new materials or making various engine innovations.

Within normal designing, the main task of the engineer is to focus on the materialisation and detailing phases; within radical designing, the conceptual phase is also of importance. There can also

Function Decomposition, Component Selection, Description Refinement

The conceptual phase is sometimes described as a phase in which the designing engineer 'decomposes' the intended function F in an ordered series of subfunctions $f_1, f_2, \dots f_n$ without at the same time immediately opting for existing components for fulfilling those subfunctions. In that way, the engineer is able to dissect and analyse the intended function without immediately committing himself to existing operational principles and normal configurations. The function 'transporting people by air,' can thus be broken down into the subfunctions 'giving people a seat' and 'conveying by air' without immediately having to envisage seats in a circular tube-like structure with wings, engines and landing gear. Alternative solutions – a helicopter, a zeppelin, a flying saucer? – are thus not, by definition, ruled out. The selection of components is something that then takes place in the materialisation phase, when it becomes clear whether the existing components suffice and whether some new components have to be designed. In the detailing phase, the descriptions of the selected and newly defined components are refined so that all the original requirements can be met.

Design Methodology: Functional Modelling

that is known as functional modelling. 12 In this particular method, functions and subfunctions are presented as operations on flows of material, energy and signals. The function F that is to be analysed is represented as an operation that the customer wishes to see carried out upon such flows. Here the aeroplane example is not so suitable. We shall therefore consider a hairdryer. The function of such an artefact is to be represented as an operation by which incoming air, electrical energy and a signal from an on-off signal is transformed into a flow of warm air (see Figure 2.1). The subfunctions f_1 , $f_2, \dots f_n$ are represented by means of well-defined elementary technical operations, working on flows of material, energy and signals such as 'transport electrical energy', 'convert electrical energy to rotational energy', and 'stop acoustic energy'. In the conceptual phase, the engineer then has to select a network of such elementary subfunctions $f_1, f_2, \dots f_n$ that, together, exert the same net operation on the flows as the overall function F. For the hairdryer, these subfunctions are 'transport electrical energy in accordance with an on-off signal', 'separate electrical energy into two flows of electrical energy', 'convert electrical energy to kinetic energy' and 'convert electrical energy to thermal energy' (see Figure 2.2).

Functional Modelling... (Stone, Wood)

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Development of a Functional Basis for Design

Functional models represent a form independent blueprint of a product. As with any blueprint or schematic, a consistent language or coding system is required to ensure others can read it. This paper introduces such a design language, called a functional basis, where product function is characterized in a verb-object (function-flow) format. The set of functions and flows is intended to comprehensively describe the mechanical design space. Clear definitions are provided for each function and flow. The functional basis is compared to previous functional representations and is shown to subsume these attempts as well as offer a more consistent classification scheme. Applications to the areas of product architecture development, function structure generation, and design information archival and transmittal are discussed. [S1050-0472(00)00704-2]

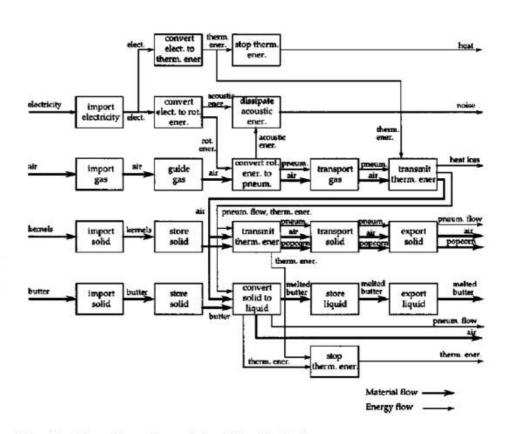
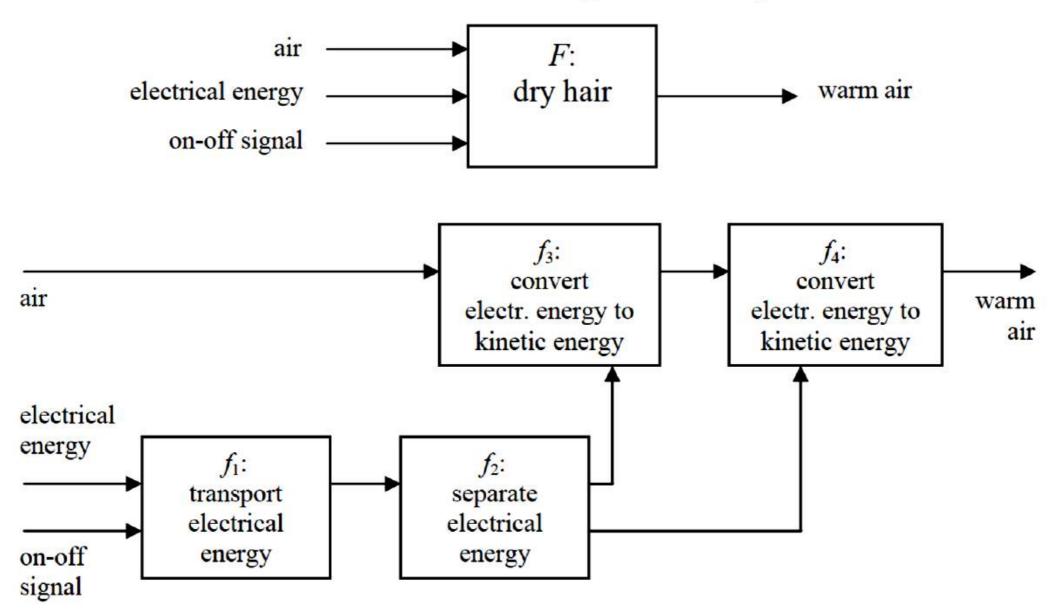


Fig. 7 Functional model of the hot air popcorn popper generated using the functional basis (FM B)

Functional Modelling: a Hairdryer



Engineering Reasoning: Decision, not Deduction

The conversion of a technical function F into a physical description D_S of an artefact is not perceived by engineers as a logical derivation. Engineers presume that for every function F, there exist different physical structures S, S', \ldots for artefacts that can fulfil F. So, then there are also numerous possible descriptions D_S , $D_{S'}$, ... Conversely, it is also presumed that an artefact with a given physical structure S can fulfil a number of functions F, F', \dots Both presumptions can be covered by the slogans Function doesn't follow form and Form doesn't follow function. The consequence of this is that reasoning in technical designing is not a deduction of the description D_S from the given function F. This reasoning has more the character of a decision: the designing engineer analyses possible descriptions D_S , $D_{S'}$, ... of artefacts that can fulfil F and then takes a technologically supported decision to subsequently select one as the most effective and efficient description.

Description (D_s) : Experience, not Theoretical Knowledge

a whole cluster of subfunctions. In more general terms, it is presumed in many design methods that engineers have a whole repertoire of existing components at their disposal - through experience, manuals and, more recently, computer data files - of which the subfunction are known. This repertoire is then plundered in the materialisation phase when determining which components can best meet the subfunctions $f_1, f_2, \dots f_n$. In that way, designers are able to create different combinations of components that are able to fulfil the function F and thus also generate and assess a number of possible descriptions D_S for the artefact that is to be designed. One conclusion that can be drawn from this using and reusing of knowledge and experience, is that the description D_S is typically not derived from the function F on the basis of theoretical knowledge. Engineers do not, for instance, calculate the description D_S by filling in the function F in a theoretical or mathematical formula. It is rather the case that engineers make use of the knowledge and experience they have of the functions and physical properties of existing artefacts and components and so determine the descriptions D_S .

Engineer Decision: Suitable not Optimal

meets the requirements as well as possible. Due to the size of the range of possible values for the design variables and due to the fact that engineers have to come up with a design under the pressure of limited resources and time, it is generally impossible to consider all the possible values. Therefore, an aeroplane characterised by certain values n, w, and p, for which the fuel consumption level per passenger and per kilometre lies below the x litre requirement level, will be deemed suitable, provided that small variations in the chosen n, w and p, values do not prove to leading to a more economical plane. Not all the n, w and p values will, however, be checked; precisely when it is a good time to stop searching for better alternatives is not something that can be unequivocally determined but which must be decided by the engineer. Simon called this search for a suitable, rather than an optimal, match for the design values 'satisficing'.

Reflective Practice

that is to be designed. This influence of the decisions of engineers and the way they formulate the design problem is central to the reflective practice design method of Donald Schön. 14 According to that method, technical designing starts with an unstructured problem. The designing engineer then imposes order on this problem by 'naming' and 'framing' the problem in a certain way. In naming the problem, the engineer selects the elements he thinks are most important in the design problem, and through framing, he interprets that problem in a particular way. The vague problem of wanting to transport people quickly is, for instance, named as a problem about transporting people by air, and it is framed as the problem of needing to create an aircraft that can take off vertically, that can fly horizontally and can descend vertically. After that, the engineer takes the next step in the technical designing process by exploring solutions to the more structured problem he created, and then evaluates the results together with the adequacy of the chosen way of labelling and interpreting the problem. The engineer might perhaps choose a gas balloon as a means of providing upward force for the aircraft and then go on to establish whether that decision helps to simplify the remaining design problems. This evaluation will lead to new insights about the original design problem and the chosen solution. The design problem provides 'feedback' - Schön's term is 'back talk' - to which the

Proper and Improper Use

This information conveyance from engineer to user has a very obvious normative side to it that is inevitably linked to any discussion surrounding the *proper* and *improper use* of artefacts. Commercial aeroplanes are designed to transport people from one place to another and may not be used to attack people and structures in the way demonstrated on 11th September 2001. This latter example makes it clear that the *improper* use of artefacts can be deeply reprehensible, but that is not always the case. Many of us sometimes use screwdrivers improperly, for instance, to ease open the lids on paint tins or to poke holes in materials. This certainly is not in line with the purposes for which screwdrivers were originally designed, but in many cases the alternative use is handy and rational.

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Social Recognition of Use Plan

of the use plan can be realised. Someone has a goal and via information obtained from others - like parents (for everyday information such as how to prepare a meal), friends, advertising and schooling (for more advanced goals like internetting and flying) - is already familiar with a whole host of use plans for the purpose of realising goals. One puts those plans into practice, all depending on the available means such as time, experience and, of course, the artefacts themselves. What amounts to the proper use of an artefact is the execution of a use plan for that artefact that is socially recognised. Use plans are socially recognised if they have, for example, been developed by engineers because those are the people recognised as the relevant experts, as people who have been educated as experts in the field of use planning. Use plans for aeroplanes that have been developed by engineers are thus socially recognised. But there are also other ways in which use plans can gain social recognition. More everyday artefacts, such as kitchen utensils, have use plans that have existed for a long time and which have been passed on from generation to generation. Undoubtedly, such plans came into being without the intervention of engineers or other experts. Nevertheless, because of the widespread knowledge of these use plans, they have become just as socially recognised as the use plans developed by engineers. By contrast, improperly using an artefact has to do with the executing of a use plan that is either not recognised or not yet socially recognised. Transporting people by plane by manipulating

Can You be a Designer?

designer. In more general terms, any individual who comes up with a use plan for a newly thought up artefact, for an existing artefact or for a natural object, may be perceived as a designer. If you mock up a new kind of kite for a child or help a fellow camper by fastening a loose guy rope with a screwdriver, then you become involved in technical designing. Such kinds of designing could be labelled amateur designing or, where they involve existing artefacts and objects, innovative using. Such kinds of designing differ from technical designing by engineers in that amateur designers or innovative users do not develop their new use plans and the accompanying artefacts with professional knowledge drawn from modern technology but rather, perhaps, on the basis of everyday experience. In the Middle Ages and before that, these forms of designing constituted the only possible way of arriving at new use plans; in our modern technological age, non-engineers gain less recognition. If, in

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Do Engineers Have A Monopoly?

engineers and non-technical, unschooled designers. Proper use of modern artefacts amounts to uses according to use plans that are developed on the basis of professional technological knowledge – with all the guarantees of success in the case of uses that engineers can give – and improper use consists of uses of the same artefacts according to use plans developed by non-engineers on the basis of other types of knowledge – with all the possible dangers that that might entail. With modern technical artefacts it would appear that thanks to the above-mentioned division of labour, engineers have a monopoly on use plans and on the describing of technical artefacts, so that innovative use of such artefacts or unintended use is quickly branded by engineers as 'improper use' with 'unintended consequences'. Civil aeroplanes are incorrectly used as projectiles. Low-energy light bulbs, designed

more positive description of the role of improper use of artefacts can also be given. Non-engineers have always had the capacity to develop new ways of using artefacts and that also applies to modern technical artefacts. Engineers do not have a monopoly on technical designing and thus on the determining of what constitutes the proper use of such artefacts, but they can improve their work by anticipating how users will manipulate modern artefacts by taking that aspect into account during the technical design phase.

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CHAPTER 3

Ethics and Designing

the technical design process. We learned that technology is directed at changing the world and that engineers contribute to that by designing artefacts. The changes brought about by technology can be both for the good and for the bad. In this chapter, we shall therefore consider some of the ethical questions related to technical artefacts and designing. Ethics has to do with good and bad and right and wrong behaviour. Ethics is about how the world should be and not about how it actually is. Given that engineers are concerned with changing the world when they design technical artefacts, one might say that they are doing ethics. An important question about ethics in engineering is then: how can and should engineers change the world for the better by the designing of artefacts? The

Values vs. Interests

Three central notions in the area of ethics are values, norms and virtues. Values are enduring convictions about what is good; values can pertain to a good life, to a good or just society but also to what constitutes a good work of art. Values have to be differentiated from interests or preferences. Preferences or interests indicate what someone considers important for himself or herself; when it comes to values though an appeal always is made – at least implicitly – to something that applies to everyone. If we state that freedom is a value, then we do not merely mean to say 'I like to be free,' but we mean rather that is important for everyone to be and feel free. You can like floral wallpaper without having to believe that others should share the same view; in such a case, we speak about a preference rather than a value. Values are, moreover, enduring convictions. They do not change from one day to the next. That does not mean to say that values cannot change or that we cannot arrive at new insights about values; however, in such cases, more is at stake than just a change in our preferences. Rather than stating that we now like something else, we will, for instance, put forward arguments for why a value has become or is no longer of importance, or has to be differently understood.

Moral/Non-Moral ... Intrinsic/Instrumental

Not all values are of a moral nature. Instances of non-moral values that are also important in the design process are beauty and simplicity. Alongside the distinction between moral and nonmoral values, a distinction is often made between intrinsic and instrumental values. Intrinsic values are values that are valuable for their own sake. Instrumental values are those which are, by contrast, pursued for the sake of another value. Typical examples of instrumental values are effectivity and efficiency. Both values assume that there is a goal, to which effectivity and efficiency are directed, so that they are not strived for for their own sake. A typical example of an intrinsic value is the good life. There are also values that do not fit so neatly into these two categories. Many important moral values that play a part in the designing of technical artefacts are indeed of such an intermediate nature. One might think for example of values such as safety, sustainability, health, privacy and justice. Health is something that might be seen as an instrumental value leading to a good life, but it is also, to a certain degree, a value in itself; it not only leads to a good life but is also itself part of a good life.

Norms

Norms are prescriptions for action. They are usually more concrete than values; they are, in fact, often directed at the realising of values. One might, for example, associate the value of traffic safety with a whole range of norms such as 'drive carefully' and 'give way to traffic from the right'. Norms can also be based on conventions. In the Netherlands, for instance, we have the convention that traffic coming from the right and not from the left has right of way on cross roads. Abiding by that convention is something that contributes to the realising of the value of road safety.

In their professional practice, engineers are inevitably involved with a vast number of norms. One need only think of all the technical norms that prescribe how an artefact must be designed. Another example is professional codes of conduct. In most countries, professional associations of

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Virtues

Alongside norms and values, also *virtues* can be distinguished. Virtues may be described as positive character traits such as courage, restraint and empathy. Virtues do not directly prescribe actions, but they are expressed in people's actions. A brave individual behaves differently from a coward. In addition to general virtues, professional virtues may be distinguished. These are those virtues that contribute to the proper exercising of one's profession. Examples of professional virtues, in the case of engineers, are competence, accuracy, creativity, perseverance and honesty.

Responsibility

If we hold someone responsible for something that happened, we usually mean that we expect that person to account for what happened. One can hold people accountable for actions or for the consequences of actions, such as when a bridge collapses. Responsibility is not only relevant in retrospect, i.e., if something went wrong, but also prospectively. If someone is responsible for something in a prospective sense, then that same person is expected to act in such a way that undesirable consequences are, as far as reasonably possible, prevented. An important question in

Designing the Norms

If it is indeed true that engineers not only design artefacts but also use plans, then what are the implications for their responsibility? When engineers design use plans, they do not only come up with an artefact but also with a set of stipulated actions intended to achieve a certain goal. One might assert that engineers therefore prescribe certain actions to the users and thereby design the norms for proper use of the artefact in question. Depending upon the exact nature of their content, these norms can also have moral relevance. The goal realised by the execution of a use plan is often morally relevant. A goal can be morally praiseworthy (for instance, if a road bump is introduced to enhance road safety), morally neutral (if one travels from a to b) but also morally reprehensible (if a person murders someone).

Morally Acceptable Use Plan (Conditions 1, 2, 3)

What are the conditions that a use plan has to satisfy if it is to be morally acceptable? A morally acceptable use plan will not at any rate be based on a morally reprehensible objective. That, though, is not the only requirement that we should pose for a use plan. Another requirement is that the execution of the use plan is actually conductive to attaining the stated goal or, in other words, that the plan is effective. The use plan must furthermore be realistic for the users. For example, a use plan that demands of users that they carry more weight than is physically possible is not a good use plan. Indeed, different users will invariably have different skills, strength and statures. The elderly, for instance, often lack the strength to use traditional tin openers, which means that they are excluded from using such artefacts and from benefiting from the advantages that they bring. Such exclusion does not have to be a moral issue if, for instance, alternative adapted tin openers are available at a reasonable price. The situation only becomes problematic when certain groups are excluded from vital social services. One might think, for example, of train ticket-dispensing machines that old

Morally Acceptable Use Plan (Conditions 4, 5)

One might also wish to demand that a use plan can be executed and can realise its aim without producing any unacceptable side-effects. If electric sawing machine users run a substantial risk of sawing off their fingers when they use the device according to the use plan, the use plan in question cannot be termed a good one. Finally, the use plan also has to be properly communicated to the users. This can be done via a manual but also by means of instructions printed on the appliance itself or, for more complicated appliances, through special courses. The last two requirements are described

Who Is Responsible?

Imagine that an engineer designs a technical artefact and provides a use plan that conforms to all the above-mentioned requirements. If something then still goes wrong with the artefact, or if unintended and undesirable side-effects materialise, is that then the responsibility of the user rather than the designer? There seems to be some sense in this. If users deviate from the use plan, surely, it is they who should be blamed and not the designer, certainly if the plan was feasible and met all the other listed requirements. If a person drives too fast in his car and causes an accident, then we are inclined to blame that person and not the designer of the car in question. Clearly, the designer cannot control the behaviour of users, and therefore designers can hardly be held responsible for the behaviour of drivers. However, matters change if the undesirable consequences can be traced back to a deficiency in the use plan or to a deficient communication of the use plan.

Does Use Plan Release the Designers from Responsibility?

for such weapons. Just imagine that the use plan communicated confines itself to the use of such a weapon for purely professional military ends, for the purposes of proportional violence, that is to say, violence that is proportional to that which it endeavours to combat, for instance, because it is necessary to reach legitimate military targets or in order to guarantee security. Does such a use plan release the designers from responsibility? One good reason for doubting this is because studies conducted since the Second World War have proved that machine guns considerably lower the violence threshold. When eye-to-eye with the enemy, soldiers are much sooner inclined to shoot with a machine-gun than with a traditional gun. Apart from anything else, largely thanks to the number of bullets that can be dispensed in a short space of time, automatic firearms are much more effective when it comes to killing the enemy. More so than with traditional guns, these weapons therefore encourage excessive acts of violence. Even if this was not part of the original use plan, it seems reasonable to assert that the designers are partly responsible for the consequences, especially if one thinks that such potential effects could be known from existing studies. Regarding the use of such weapons in civil war situations and by child soldiers, the matter is somewhat more complex.

Further than the Use Plan

Script: Designing the Behavioral Norms

were developed. Nevertheless, it can be concluded that the responsibility of engineers sometimes extends further than the use plan.

The argumentation above indicates that we need a term that denotes various forms of use that may not literally be seen as part of the use plan but which the technical artefact in question does invite. A term that Madeleine Akrich and Bruno Latour, two sociologists of technology, have come up with is 'script'. A script may be described as the behavioural norms which – intentionally or not – are built into a certain technical artefact. A nice example of this is the automatic seatbelt. In the case of automatic seatbelts, the car simply will not start if the seatbelt is not used. That therefore forces the driver to fasten his seatbelt. The inbuilt norm is thus 'do not drive your car without a seatbelt.' With the help of this norm, the value 'safety for the car driver' is promoted.

Values and Design Requirements: Whose Values?

of design requirements. One need only think of the design requirement that a certain appliance may not use more than a stipulated amount of energy or that the chance of a certain component breaking down should be below a certain probability. At the same time, values can be translated into design requirements in different ways. For instance, the matter of whether the value of safety, in the case of vehicles, is translated into safety for passengers or safety for other road users, such as cyclists and pedestrians, makes quite a difference. Cars that are safe for their passengers will not necessarily also be safe for other road users.

Apart from being translated into design requirements, values also have a part to play in the choices that are made between different concept designs. It is frequently the case that during a design process, different options are compared with the aim to select ultimately the 'best' alternative. Values can inform such decision-making. Different potential choices can be compared from the point of view of the extent to which they realise certain values. Often, as part of the process, the values are first translated into different criteria.

Value Sensitive Design (VSD)

A third way of coping with values during design processes is by adopting a value sensitive design approach. The idea behind this approach is that at the start of a design process one establishes which values are morally of importance when it comes to designing a technical artefact. Subsequently to the content of these values, one establishes why the values are of moral significance and then they are translated into certain design requirements. These values can also come to play a part when choosing between various alternatives. When engineers design in a value sensitive way, they seek technical solutions that help them to realise as well as possible all the relevant values. Values that may conflict in one particular design do not need to conflict in another innovative design. Values are thus able to steer the design process possibly leading to socially better technologies.

Vast Number of Values in Aeroplane Design

design requirements. Some of the design requirements have to do with the reliability and safety of the engines. The moral value that is of relevance here is safety, both for passengers and people on the ground. Aeroplane engines also have to be capable of fulfilling certain performance demands like, for instance, a certain thrust or speed. Here the underlying moral value is human well-being; the underlying conviction being that the ability to enjoy air travel (and the faster, the better) is something that serves human well-being. One can, of course, debate whether this is really the case. Aircraft engines also have to comply with certain environmental norms with respect to, for example, fuel consumption or the emission of various substances. The underlying value 'environment' can be justified in terms of the moral obligations that we have towards future generations but also in terms of the intrinsic value of nature. Finally, aeroplane engines also have to observe various noise level requirements; again, the value at stake is human well-being, both for passengers and people on the ground.

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Dilemma

It is definitely not easy to simultaneously respect all these different values when developing aeroplane engines. With the advent of jet propulsion in the post World War II era, it became possible to fly at much higher speeds, but the new jet engines consumed much more fuel than the old propeller-driven aircraft. The use of jet propulsion also led to much more noise hindrance on the ground, though it must be admitted that for passengers jet engines were, and are, much more silent than traditional propeller engines. The introduction of jet propulsion therefore gives rise to a number of moral questions. One question one might ask is whether the speed gain derived from jet power can justify the higher consumption of fuel. The values of human well-being and the environment seem to clash when one poses this question in this way. The dilemma may be formulated in terms of the well-being of present generations against that of future generations or in terms of the well-being of people who fly and those who do not. The last two formulations foreground the fair distribution of burdens and benefits. Another moral question linked to the jet engine is to just what extent the noise hindrance for plane passengers weighs up against hindrance for those living in the vicinity of airports; the jet engine is quieter than the propeller engine for passengers but noisier for people on the ground.

Codes ... Standards ... Regulative Frameworks

with these issues. As far as most artefacts are concerned, there are usually laws and regulations that have been promulgated by governments. Furthermore, for many technical artefacts, there are often technical codes and standards that can be quite detailed [Hunter, T., 1997]. Technical codes are legal requirements that are enforced by a governmental body to protect safety, health and other relevant values. Technical standards are usually recommendations, rather than legal requirements, that are written by engineering experts in standardisation committees. Some artefacts have to be certified before they can be used. Aeroplanes, for example, are only allowed to fly if they have been certified. One of the aspects covered by certification is airworthiness; another is noise reduction.

Although some of the rules mentioned apply to all engineering areas, a great many are product-specific or dependent on the type of artefact developed. All rules that apply to a specific kind of technical artefacts form together what may be called a *regulative framework*. We briefly discuss

Regulative Framework: Reified Morality

A regulative framework may be seen as a kind of reified morality. It lays down prescriptions for right action in rules. Such rules are usually based on past experience, like certain kinds of accidents that have occurred with a given type of technology, or the discovery of certain negative side-effects. Often a regulative framework is established in the wake of public unrest or public debate. In the case of legislation, the rules laid down result from democratic decision-making.

A regulative framework can support engineers when confronted with ethical questions in their professional practice. Insofar as the framework is democratically legitimised, it also provides a solution for the previously mentioned matter of when and whether engineers are allowed to regulate the moral behaviour of users and others. Nevertheless, one cannot blindly follow a regulative framework. Even

Regulative Framework: Conditions

- The framework must be *complete*, which means to say, that it must provide an answer to the question of how to act in specific situations without leaving relevant aspects of the situation out of the picture.
- The framework must not contain any contradictions or inconsistencies.
- The framework must *not be ambiguous*, that means to say, there must be consensus on how the framework applies in a specific situation.
- The framework must be morally acceptable.
- The framework must be observed and not just paid lip service.

Regulative Framework: Conceivable Situations

All in all, there are three conceivable situations as far as the availability of a regulative framework is concerned. In the first place, there might be a framework available that fulfils all the mentioned conditions. In these kinds of situations, engineers can be guided by this framework when making their ethical choices during the design process. In the second place, there may not be a framework that is applicable to the relevant design. This kind of a situation is quite thinkable in radical designing. In such cases, the engineers have to make their ethical choices either individually or in collaboration with others such as the users, regulatory bodies or other stakeholders. In this situation, the engineers have more own responsibility for the artefact they design because they are less able to rely on already socially sanctioned rules. In the third place, it might be possible that a framework does exist but that it does not satisfy one or more of the mentioned conditions. Precisely what is the most sensible strategy in such a case will partly depend on the condition that has not been met. We shall confine ourselves here below to the question of what engineers can do if the existing framework is morally unacceptable or morally disputable.

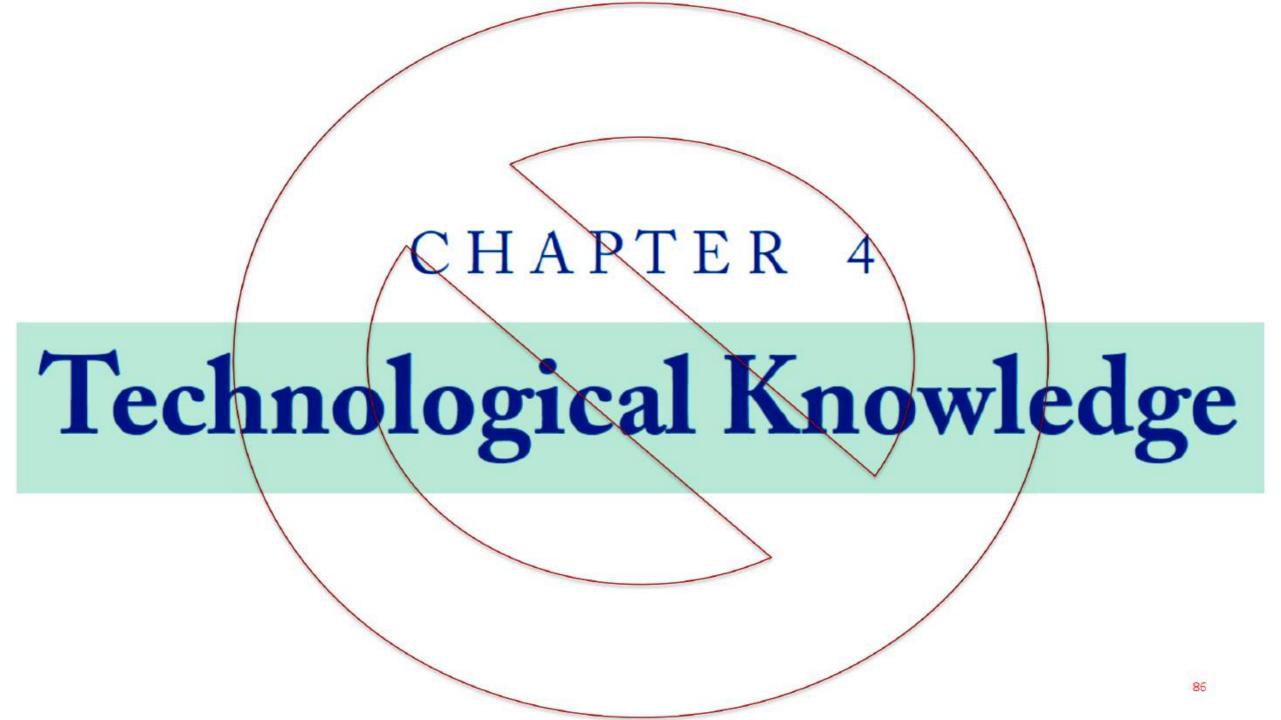
If A Regulative Framework Is Not Acceptable ...

As an engineer, there are different courses of action one can take if a regulative framework is not acceptable. To start off with, you can try to alter the framework. Engineers may be involved in committees that draw up technical codes and standards or think up test procedures, and they are thus able to have an influence on these aspects of the regulative framework. In the second place, complaints can be lodged with bodies that are able to influence other aspects of the framework like, for instance, the government, the parliament or a professional organisation. In the third place, one can choose to deviate in the design process from certain elements of the regulative framework. Existing frameworks often provide a certain margin of flexibility for such deviation, but with legal rules, the engineer does, of course, have less room for manoeuvre. Finally, you can opt for radical designing where the existing framework will not be applicable.

Regulative Framework: Normal/Radical Design

on the kind of design process. Empirical research suggests that regulative frameworks are more common in the case of normal designing than with radical designing. This is understandable. A number of the rules of regulative frameworks are founded on the operational principle and the normal configuration of an artefact. This applies especially to more detailed rules. Very general rules

previously. That, in turn, led to metal fatigue and ultimately to disaster. What this proves is that existing frameworks designed to safeguard certain moral values – in this case safety –cannot be automatically transferred to radical designs. When choosing between normal and radical designs there are also, therefore, moral considerations alongside the technical considerations. Such moral considerations include the moral acceptability of the existing regulative framework, the degree to which a radical design can probably better satisfy important moral values and the level of risk that is introduced with radical designing.



CHAPTER 5

Sociotechnical Systems

chapter, we show that to view technology as merely a 'collection' of technical artefacts would be an immense oversimplification. In so doing, we would completely fail to acknowledge the layeredness that is such an important feature of modern technology: the technical artefacts discussed so far are building blocks in wholes of a far greater complexity. Although one cannot build 'loose' technical

Aviation System: Tangible/Intangible Components

ingenuity, the actual aeroplane itself in which you will ultimately fly. However, alongside all these separate things you will also be making use of something much more encompassing, just as much created and maintained by human hands as the prototypical artefacts just mentioned, but at the same time, it is much more impalpable and harder to fathom. That 'thing' is the world civil aviation system. All the artefacts just mentioned constitute a part of it, but there is incredibly much more to it than that. Some of the components are concrete, like the buildings in which the passengers are subjected to a whole range of routine procedures before entering the plane or after stepping out of it,

there are also, in very divergent ways, numerous other components of a more abstract nature: the air corridors within which the aeroplanes fly, the airline companies responsible for the flights, the regulations that pilots and airline companies have to observe, the organisations that draw up and enforce these regulations, the treaties agreed to between countries that make it possible for planes to fly from one airspace zone to another, the companies that insure the system for the different ways in which it can fail, and so forth, and so forth. Each of these things contributes to the functioning of the world civil aviation system. Without this system, it would be impossible for you to travel by

Aeroplane System: Hard/Soft Components

aeroplane is itself a system. All of its components, however, are 'hard' things, the behaviour of which is governed by various natural laws. A thorough knowledge of these laws is required in order to comprehend how an aeroplane operates from the way in which its components work together and to design and connect the components in such a way that the resulting plane does precisely what is expected of it. Admittedly, in present-day aeroplanes, there are all kinds of control systems that are computer-steered, running on software systems that were designed in isolation of the computer and, in that respect, definitely not tangible. However, once downloaded, this software ensures that the onboard computers are set up in a specific physical state, which is essentially no different from the way in which a thermostat is adjusted to a specific setting for it to maintain a certain temperature.

The presence of software thus changes nothing whatsoever about the character of the aeroplane as a physical entity. What makes the aviation system a special sort of system is the fact that it includes all kinds of components – the organisations and institutions, the conditions and rules – that are not tangible things. For all of these components, no thorough knowledge of the natural sciences will do to understand how they work and to fit them into the system in an effective way. The relevant

pp.68-69

Employees: Biology/Psychology/Sociology

employees mentioned, in their capacities as human beings made of flesh and blood, are tangible, but that is hardly relevant to the position that they occupy within the system. One does not need to possess knowledge of biology to fit the staff working at the check-in desks into the system as a whole. The most basic everyday knowledge is sufficient to do justice to their character as physical-biological organisms that cannot walk on air or pass through walls, so that they need accessories like doors, seats and floors to be able to carry out their work. Which is not to deny that occasionally, specialised

weight, gender or stamina are not the issue at stake; what counts is the fact that they are persons, capable of understanding and carrying out instructions and also of understanding the purposes served by these instructions. The regulations and the organisations and institutions that contribute to the aviation system presuppose the status of human beings as persons. Rules and regulations are drawn up by people and can be observed or flouted by people. Organisations and institutions are created and maintained by people. In order to assess the way in which people function within the civil aviation system, we largely rely on a general picture of the way in which people go about doing the things they do in everyday life, supplemented with knowledge obtained from the fields of sociology and psychology. None of the natural sciences, however, has anything useful to say on the matter. We

Sociotechnical Systems: Hybrid Systems

This, thus, brings us to the heart of the matter of what makes the world civil aviation system such a special sort of system: it is a hybrid system. It consists of components which, as far as their scientific description goes, belong in very many different 'worlds'. This is what makes them essentially different from even the most complex of technical systems, like for instance civil aircraft. Even though the engineers who were involved in the designing and the manufacturing of the Airbus A380 had very different backgrounds - mechanical engineering, materials science, aerodynamics, electronic engineering and computer engineering - all these disciplines share a form of describing the world rooted in natural science. However, the aviation system into which such an Airbus A380 operates involves numerous other things - people, institutions, rules - about which the natural-scientific way of describing the world has little to say and for which a social-scientific way of formulating matters is therefore required.²⁶ Hybrid systems, in which certain components, are described and researched using the natural sciences and other components, are described by drawing on the social sciences are called sociotechnical systems.

Engineers and Sociotechnical Systems

Even though it is eminently this hybrid character – the presence of components requiring a physical description and components requiring a social description – that characterises sociotechnical systems, the designing, implementing and maintaining of these systems remains predominantly in the hands of engineers, who have been educated in pronouncedly natural-scientific ways. That is why these systems constitute a major challenge for the engineering sciences. All kinds of traditional notions about what constitutes the designing of a technical artefact, how the design process should be structured, what kind of knowledge is required and how one should assess the functioning of a designed artefact, become very problematic whenever they are literally transplanted to the context of designing sociotechnical systems. The reasons for this are presented in the following section.

Roles and Goals: User/Operator

physical interaction, we can have no use. What makes sociotechnical systems special is, first of all, that they have many users at any one moment and, secondly, that they involve people in two different ways, namely, not only in the role of user of the system but also in the role of operator. The word 'role' is apt because one and the same person can simultaneously be a user of and an operator in a system. If a pilot plans to spend some time at his or her destination for a holiday, after having flown the plane there, he or she is, on the one hand, performing the role of operator by flying the plane and, on the other hand, he or she is performing the role of user by using the aviation system to get to his or her holiday destination.

of time, but he or she is not doing so in order to realise his or her own goal of arriving in Singapore within a certain amount of time. It is the passengers who have this as a goal and by taking that plane they realise that goal. To do so they not only use the aeroplane but also the entire aviation system, which they 'operate' by purchasing a ticket. The pilot of the plane is a *component* of that system, a component that is necessary for the whole system to be able to fulfil its function, just as much as the plane that the pilot flies is. After all only few of us have at their disposal their own private air

Device/Operator

Pilots may be the most obvious indispensable human link in the civil aviation system, but they are certainly not the only ones. Just as indispensable are the air traffic controllers who sit in the control rooms at airports and supervise the taking off, landing, cruising and taxiing movements.

monitor, by means of their radar equipment, the position of all the aeroplanes. In much the same way, all the staff members mentioned above – the staff working at the check-in desks, those who operate the X-ray equipment, the passport controllers and the ones who load the baggage in and out of the holds – are components of the aviation system, each contributing a specific function to the operation of the entire system.

All sociotechnical systems have operators who fulfil such roles, because it is too difficult or even impossible to build a system consisting merely of interconnected technical artefacts – that is, machines or 'hardware' devices – and guarantee its adequate functioning. Every large chemical plant

Automation/Coordination ... Natural/Social Sciences

This should not, however, be taken to mean that large-scale systems involving human operators will be merely a temporary phenomenon. The complexity of sociotechnical systems, particularly large infrastructural systems, consists just as much in the fact that, unlike a typical technical artefact such as a coffee-maker, they have very many different users. The functioning of the system as a whole, as it appears to each of its users, not only requires coordination between the technical or hardware aspects of the system and the behaviour of the users - like the driving of the vehicles by their chauffeurs - but also, and especially, the mutual coordination of the behaviour of the many users. To achieve this coordination, it will not to do to implement one or another causal mechanism that is attuned to the physical characteristics of the users. Successful coordination comes about through agreements, rules, laws, habits, in short, precisely the sort of things that are studied in the social sciences and not in the natural sciences.

Rules ... Sanctions

want to 'direct' people, it is common to do this through rules or instructions and not through causal stimuli and signals.²⁸ A rule is a directive or norm that has the underlying intention of bringing about a behavioural pattern, irrespective of whether that pattern actually occurs. A rule can be observed or ignored, just adhered to from time to time or abided by depending on the circumstances. If a rule is not followed in a particular case, this indicates that it is apparently not in everyone's best interests to behave in the manner that the rule dictates.²⁹ Such deviations will not necessarily undermine the intended behavioural pattern, but they are likely to do so, especially if many people are tempted to breach a rule because acting according to the rule requires an effort or is costly in one form or another. What is especially characteristic of a rule is, therefore, the existence of sanctions relating to the breaching of the rule. As a result, rules also presuppose the existence of a social group in which the rules are considered to apply and through which sanctions can be enforced. After all, an individual cannot be expected to enforce sanctions upon himself if a rule is deviated from.

Sociotechnical Systems: 2 Problems

With this understanding, we come to the problems that confront those who are responsible for designing, implementing and maintaining sociotechnical systems, and we come to the challenges they pose for the way in which engineers are traditionally taught to tackle the designing of artefacts and systems. These problems will be dealt with from two angles. First, there is the problem of how to draw the system boundaries and, accordingly, to establish the extent of the design task. In the second place, there is the problem of the predictability of the system's behaviour and the extent to which this can be controlled.

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1 ... System Boundaries

As far as the designing of systems is concerned, the important question is not what boundaries can be drawn in an existing reality, but what place the new system is to occupy in the existing reality? As long as this is unclear, the design task with respect to the system is still undetermined. Imagine that, as an engineer, you are requested to design a new type of aeroplane engine. In order to be able to do that, you not only need to know of which technical system this engine is to be a component for what type of plane it is required – but also of which (socio)technical system the plane will be a component. If the aircraft is merely destined to fly in the private airspace above the land of a large estate owner (let us presume that something like that is possible), then the functional requirements can be limited to the exclusively technical requirements: power, thrust, weight, and so forth. If, on the other hand, the aeroplane in question is destined to fly as a component of the existing world aviation system, then an accordance with all kinds of legally stipulated norms and standards will also form part of the functional requirements for the engine. An aeroplane that does not meet these requirements cannot be integrated into the system, just as little as a bolt will fit into a nut with an incompatible screw thread. These norms and standards are preconditions to which you, as a designer, must conform in much the same way that designers, in general, have to accept the laws of nature, which they cannot change.

1 ... Example of a Sociotechnical System: TCAS (Paper)

In 2002, in the wake of previous mid-air collision incidents, aircraft making use of European airspace were all equipped with a TCAS, traffic collision avoidance system. In the nose of the cockpit, there is an instrument that sends out a signal but can, at the same time, pick up signals sent out by other aircraft. When the received signal, in combination with the plane's own position and cruising speed, indicates that unless one or both aeroplanes change course, they will collide, the TCAS equipment transmits coordinated instructions to the pilots: one of the crews is given a spoken instruction to descend and the other is instructed to ascend. The TCAS is intended as a last resort in an emergency: it is the task of the relevant air traffic controllers to notice, at a much earlier stage, that two aeroplanes are flying at the same altitude, on courses that will lead to disaster and to rectify the situation by directing one of the two to a different altitude. The TCAS was introduced for situations where air traffic controllers fail to do so. This was indeed the case in the Überlingen incident, but there is more to the story. The air traffic controller on duty in the area where the aeroplanes were flying had

1 ... TCAS (continued)

more to the story. The air traffic controller on duty in the area where the aeroplanes were flying had indeed failed to notice the impending accident in time and had thus not intervened when he should have. Eventually, however, he did notice the problem and intercepted by instructing the Russian aeroplane to reduce its altitude. But the air traffic controller's instructions came so late that by then, the TCAS on board both aeroplanes had been activated: on the basis of the signals that had been exchanged, the software had generated instructions to the effect that the captain of the American plane should descend while the Russian aeroplane had been instructed to ascend. There was just one second's difference between the Russian captain receiving the message generated by the TCAS to ascend and being instructed by the controller on the ground to descend. Of course, this led to great confusion and debate among the Russian pilots, but there was very little time available for finding out what to do, and after air traffic controller and TCAS had repeated their conflicting instructions, the captain of the Tupolev 154 decided to follow the instructions from the ground and not the message generated by the TCAS. As the Boeing 757 had only been instructed to descend by its own TCAS, this aircraft also started to drop altitude, with the result that shortly afterwards, the two planes collided, causing the death of everyone on board both aeroplanes.

2 ... Loss of Predictability & Control

This brings us to the second problem that sociotechnical systems pose for the traditional engineering approach to design, namely a loss of predictability and control. When developing technical artefacts, the external circumstances within which the system has to fulfil its function are explicitly included in the requirements. Traditionally, it is the task of the designer to produce an artefact that functions as long as the circumstances obtain as specified. Whether the circumstances within which the system is used or implemented, in fact, meet this specification is not so much the designer's problem but rather that of the customer or user, even though, as a designer, one should make certain that the functional requirements taken to define the design task are a correct translation of what the client or commissioner has in mind for the system. With sociotechnical systems, this is completely unattainable. The overarching social system within which every sociotechnical system functions as a component is in a perpetual state of flux. Even if we imagine that a particular large-scale sociotechnical system - say, the world civil aviation system - is developed all in one go, it would still be impossible to precisely specify the institutional context within which that system has to function. This problem that can hardly be resolved by broadening the definition of the design

2 ... Emergent Properties

is a matter of dispute. The fact remains that because of the very nature of the system, the global system controllers must always be uncertain about the degree to which their endeavours will succeed. Sociotechnical systems have unavoidable *emergent properties*, that is to say, properties that admittedly emanate from the properties of the components and from the way the system is structured but which are not predictable, for the simple reason that in order to predict them, one would need to have access to knowledge which, at least in practical terms, is unavailable or, if in principle available, cannot be accessed in the available time.

Global Control ... Local Coordination

There are many different schools of thought on what is the best way to design and manage these kinds of dynamic sociotechnical systems. On the one hand, there is the strong tendency to try to force the system in the direction of the aviation system by restricting the role of the individual user through various sorts of automatic vehicle control systems. In that way, the system would become more controllable in line with traditional engineering norms. On the other hand, there are also small-scale experiments where the task of successfully coordinating all vehicle movements is laid entirely with the road users by deliberately eradicating all the instruments that are customarily used to direct their behaviour, such as road signs, give-way road-marking, traffic lights and all the other paraphernalia. In cases where the global control possibilities of a sociotechnical system are fundamentally limited because for principled or for practical reasons the users of that system are granted a high degree of freedom to involve themselves in the system, it may well be advisable for authorities to resist the temptation to make maximum use of the possibilities for top-down control. Global control does not, of necessity, lead to better results than locally coordinated actions between individual users do.

Sociotechnical Systems vs. Traditional Artefacts Social vs. Natural Sciences

With the examples given in this chapter, we have shown that traditional engineering opinions about the designing of technical artefacts and about the knowledge that such designing requires is no longer adequate when the artefacts attain a form of complexity that leads us to introduce the notion of sociotechnical systems. The designers and operators of such systems are confronted with numerous aspects that are not easily or not at all describable within the traditional engineering approach, which is overwhelmingly oriented toward the natural sciences. This traditional approach and the accompanying conceptual frameworks, models and theories therefore need to be enriched with knowledge that has been and is being developed within the domain of the social sciences.

As we have seen, one of the features of sociotechnical systems is that they are less predictable than traditional technical artefacts; sociotechnical systems can display unexpected behaviour even if the end-users set out to use the system in a 'neat' or 'tidy' way. Although the notion of a use plan is

CHAPTER 6

The Role of Social Factors in Technological Development

CHAPTER 7

Ethics and Unintended Consequences of Technology

In Chapter 5, we have seen that technical artefacts are often part of larger sociotechnical systems and that those systems also contribute to determining the consequences of the use of such artefacts. We ended Chapter 6 with the conclusion that technology can result in unintended consequences. These two observations lead one to wonder to what extent engineers are able to predict the consequences of what they design during the actual design process. Those consequences provided an important basis for the ethical questions accompanying the design processes that were dealt with in Chapter 3.

Unintended Effects

Technologies have unintended effects. Aeroplanes crash with fatal consequences. Chemical plants pollute the environment. Security cameras diminish privacy. In other words, such technologies can be dangerous for humans, the natural environment and animals.

The various dangers and other unintended consequences are often not known beforehand, but that does not always mean to say that they are impossible to know. One strategy towards the unintended consequences and dangers of technologies, and addressing them in time, is therefore to try to predict the consequences as good as possible and to expressing the dangers in terms of risks. What are the possibilities and constraints of such a strategy?

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Risk

'Risk' is usually defined as the probability of an undesired event times the consequences of that event. If we want to express dangers of a technology in terms of risks, then we need to have reliable knowledge about what precisely the consequences of the technology can be, and we also need to know what the probabilities are that the consequences might materialise. For technologies that have been in use for a long time and where a number of incidents and accidents have occurred, we tend to have reliable information about both factors in the form of accident statistics. We are, for instance, able to estimate the probability of a passenger dying in an air crash in terms of the probability of being killed per kilometre flown. Much the same applies to most other forms of transport.

In the case of new innovations, such reliable information for calculating risk levels is usually lacking. We are often not aware of all the unintended consequences and dangers of a certain new technology. And even if we are aware of the possible undesired consequences, we do not always have enough knowledge about the failure modes: the possible ways in which a new kind of technology can fail. Apart from anything else, in the case of new and innovative technologies, we do not have accident statistics for calculating failure probabilities for the simple reason that no accidents have yet occurred. In such cases, engineers often employ fault trees or event trees in order to estimate

Event Tree ... Fault Tree

yet occurred. In such cases, engineers often employ fault trees or event trees in order to estimate the probability of failure. An event tree sketches possible sequences of events that can follow some kind of potential technical failure, like the failure of a plane's landing gear to properly operate. A fault tree sketches the possible series of events that can lead to an accident such as, for instance, the crashing of an aeroplane. By attributing probabilities to individual events in an event or fault tree, the probability of certain accidents can be calculated. Generally, speaking, predicting risks in such a way tends to be less reliable than making use of real accident statistics.

Risk ... Acceptability: Are Equivalent?

Although the magnitude of its risk says something about the acceptability of a technology, this magnitude does not tell the whole story. Also other considerations are relevant. To see this, suppose that you want to compare the acceptability of two very different types of technologies. Some engineers and scientists maintain that if according to given risk assessments the risks of these two technologies are roughly the same, then those technologies are also morally equally acceptable. This would, for instance, mean that if you accept one technology, then you would be obliged to also accept the other one with approximately the same risk level. However, this line of reasoning is incorrect for the following reasons. In the first place, not all risk assessments are equally reliable. It

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Risk/ Acceptability: Aren't Equivalent ... (1, 2, 3)

incorrect for the following reasons. In the first place, not all risk assessments are equally reliable. It is therefore not always appropriate to compare the outcomes of different risk assessments with each other. In the second place, risk assessments are often multi-dimensional whilst the risk comparisons are often one-dimensional, or at least confined to just a few aspects. A very commonly used risk measure is that of the number of fatalities per unit of time. In reality, though, two technologies that are equally dangerous in terms of the number of fatalities per unit of time, can be very different in terms of the danger they pose to human health, the damage to the ecosystem, their economic threat, et cetera. In the third place, the acceptability of risk does not only depend on how big a risk is but also on the question of whether the risk is voluntary and whether people have agreed to take the risk. The risks posed to people that take part in traffic thus tend to be more voluntary accepted than, for instance, the risks posed by a chemical plant near where they live, especially in view of the fact that chemical plants are frequently just built without first consulting the local inhabitants. On the other hand, the risks attached to skiing, for example, are more voluntary than those attached to participating in the road traffic system. On the whole, voluntarily accepted risks are seen as being more morally acceptable than those that are forced upon people. In the fourth place, risks are not

Risk/ Acceptability: Aren't Equivalent ... (4, 5, 6)

more morally acceptable than those that are forced upon people. In the fourth place, risks are not just inherently acceptable but are acceptable because they bring with them some kinds of advantages. That means that if the advantages are great, people have reason to accept higher levels of risk. In the fifth place, the acceptability of risks also depends on the availability of alternatives. If there is a possible alternative that carries fewer risks and has no other major disadvantages, then the very existence of that alternative might be grounds enough for viewing the risks of an existing type of technology as undesirable. Finally, the acceptability of a given risk depends on how fairly the risks and benefits are distributed. If there is a certain group in society that only has the disadvantages of the risks without being able to enjoy any of the benefits attached to such risky activities, then that can also make the risk in question morally unacceptable.

Considerations in Risk Acceptability

In the discussion provided above, there are four important considerations that come to the fore in judging risk acceptability. The first is the question of whether the advantages of the risk-bearing activity outweigh its disadvantages. The second is whether there are alternatives that would, in that respect, score better. The third consideration is that of whether the risk is voluntarily taken and whether or not those involved have agreed to the risk. In ethics, this agreement is often described as giving informed consent. The main idea is that a risk is only acceptable if individuals agree to it after having first been fully informed of the risks, advantages and technological alternatives. A fourth matter of consideration is whether all the possible advantages and disadvantages of the activity-bearing risks are fairly or justly distributed. The value at stake here is that of distributive justice.

Risk Assessment ... Risk Mitigation

Risk assessment may thus be useful when assessing the magnitude of risks. A second reason for possibly wanting to make use of risk assessment might be to limit the risk magnitude at the actual design stage. This is often viewed as an important moral responsibility of engineers. Many professional codes of conduct emphasise that engineers are responsible for designing safe installations. As is stated in the code of conduct of the NSPE, the National Society of Professional Engineers in the USA:³⁴

Engineers shall hold paramount the safety, health, and welfare of the public.

Risk Mitigation ... Pros and Cons

Although it would generally seem desirable to minimise the risks during the design process, it is not always possible or, for that matter, desirable to do so. It is not always possible because there is no such thing as artefacts or processes that are absolutely safe. It is not always desirable because reducing a certain risk often brings with it costs or other kinds of disadvantages. For example, a safe car or aeroplane is usually more expensive. If planes are made safer by being made heavier, that means that they will use more fuel which, in turn, will make flying more expensive and will further encumber the environment. In these sorts of cases the pros and cons have to be morally weighed up in order to determine whether it is worth reducing the risks. That is where the above-mentioned considerations play an important part.

Risk Mitigation Strategies (1)

A first strategy is *inherently safe designing*. This strategy aims at taking away dangers rather than managing them. That can, for instance, be done by substituting various dangerous substances, mechanisms or chemical reactions with less dangerous ones. In order to do that, one needs to have knowledge of the kinds of substances, mechanisms or reactions that constitute a danger. It is not, however, necessary to have details concerning the exact probabilities of the dangers arising. To follow this strategy you need to have some but not full knowledge about the risks of a given technology.

Risk Mitigation Strategies (2)

A second strategy that can be adopted is that of building in safety factors. This means creating a structure so that its expected strength exceeds the expected load with a certain factor, the safety factor. The risk of failure of that particular construction is thus reduced. It is also a way of coping with the possible uncertainties attached to the expected loads and the predicted strength of the construction. Indeed, there is a tendency to think more in terms of the expected probability of failure of a construction or of components - that may not exceed certain thresholds - than in terms of the safety factors since the former results in less over-dimensioning and thus cheaper constructions. This, however, requires reliable knowledge of both the expected loads and the actual strength of the construction, and it eliminates uncertainty margins which are incorporated in a design if it is based on safety factors.

Risk Mitigation Strategies (3)

A third strategy is that of incorporating *negative feedback*, which involves designing installations in such a way that if an installation fails or if a operator loses control, a mechanism will be activated that will automatically switch off the installation. A good example of this is the driver's safety device (DSD) in trains which ensures that the train comes to a standstill if the driver falls asleep or loses consciousness. Note that up to a certain point, this strategy can cover partially unknown risks: a mechanism can be triggered if, for instance, a certain poisonous substance is in danger of escaping from a chemical plant. One does not need to know beforehand what the probabilities of such an incident occurring are in order to be able to design an effective negative feedback mechanism.

Risk Mitigation Strategies (4)

A final strategy can be to design *multiple independent safety barriers*. In that way, one creates a chain of different independent safety barriers to ensure that if the first barrier fails, there will be others to back it up. In this way, the probability of danger arising is reduced. With this strategy, it is once again the case that one does not need to know beforehand what precisely the probabilities of an incident occurring are or what the exact causes might be. In order to be able to design safety barriers that are actually independent, one really needs to have insight into the possible failure modes; otherwise, there is always the danger of a failure mode simultaneously undermining different safety barriers.

Unintended Consequences ... Technological Determinism

This brief overview of strategies shows that during designing, one can take measures to reduce possible dangers, even if one is not exactly aware of the dangers and one is not able to precisely quantify them in terms of risks. All the same, one must have some idea of what can go wrong and what unintended effects can occur if one is to successfully apply the referred to strategies. In other words, it is more or less impossible, during the design process, to account for unintended consequences which cannot possibly be foreseen beforehand. The unintended consequences variant of technological determinism discussed in Section 6.2 posits that such unintended and unforeseen consequences cannot be avoided in technological development. We concluded in the previous chapter that this assumption regarding the unintended consequences variant within technological determinism is indeed plausible. The conclusion must therefore be that during the design process, one cannot take into account all the possible unintended consequences of a technology because some of the consequences do not reveal themselves beforehand.

Not *All* the Consequences

One reason why one cannot account for all the consequences of technology beforehand is because there is a limit to the amount of time that can be spent on finding out about those consequences. Quite where one places that limit is also an ethical question because the decision to finishing a design process quickly, may have the consequence that the probability increases that users and others are burdened with the negative consequences of technology.

There is, however, another reason why one cannot always predict the unintended consequences of technology and that is this: during the design phase the consequences are indeterminate because they also partly depend on the actions of other *actors* besides the designers, like the users. This especially applies when we take sociotechnical systems into account, which – as we saw in Chapter 5 – depend for their proper functioning on all sorts of actors, such as operators.

Problem of Many Hands

If undesired consequences arise in a sociotechnical system it is, in many cases, not possible to simply trace the cause of those consequences back to one actor who might have been able to foresee and prevent such consequences and who can, thus, be held responsible for them. It is much more likely that the consequences will depend on the actions of a number of actors and on the constellation of the sociotechnical system as a whole. This was a point that clearly emerged from the discussion in Chapter 5 on the mid-air collision above Überlingen (see Section 5.5). The final upshot would appear to be that one often cannot indicate who is responsible for certain undesired consequences. This is also sometimes known as the problem of many hands: because there are so many people who play a small (and difficult to pinpoint) part in the chain of the events that it is difficult to establish who is responsible for what.³⁵

The problem of many hands is not just a problem because, in retrospect, no one can be held responsible but also because, apparently, no one feels the obligation to endeavour to prevent such consequences occurring, and so we do not learn from our mistakes. All the same, there are times

Hold Individuals Responsible (Aeroplane Accident, Brazil, 2007)

consequences occurring, and so we do not learn from our mistakes. All the same, there are times when it is possible to hold one or more individuals responsible for an accident. To illustrate this point, we shall now examine an aeroplane accident that took place in 2007, in Brazil.

On 17th July 2007, an Airbus A320 overshot the end of the runway when landing at Congonhas International Airport in São Paulo. It ploughed across a motorway and finally came to rest, next to a petrol station, in a warehouse belonging to the Brazilian airline company TAM. It then exploded. Some 199 people were killed in the incident, 12 of whom were on the ground.³⁶

Congonhas Accident Timeline



18:48:26	Flight 3054 lands on the runway.
18:48:30	The aircraft begins to veer left.
18:48:40	The aircraft over shoots the runway.
18:48:50	The aircraft crashes into the TAM Express building.

Accident Responsible: Airport?

The initial conclusion was that the accident was attributable to the relatively short runway and to wet weather. The runway in question had been resurfaced not long before, which meant that gullies had not yet been created to deal with excess water on the runway and thus prevent bydroplaning. Already airport safety there had previously been questioned, especially in wet weather. In February 2007, a Brazilian judge had imposed a flying ban at Congonhas for a number of aeroplane types, following complaints lodged by pilots about rainwater on the runways, which had negatively influenced the planes' breaking performance. The airport, the Brazilian airline company TAM and the Brazilian Civil Aviation Authority all contested the ban, and so within a day it was dropped following a higher court overruling. The A320 did not fall under the original ban because according to Airbus, its braking distance was shorter than that of the banned aircraft types.

Accident Responsible: Thrust Reverser?

When it became clear that during the landing of the fatal flight water accumulation on the runway was limited, the investigation focused on other possible causes. What soon emerged was that the thrust reverser of the right engine had not operated during the landing procedure. Thrust reversal is deployed during touchdown to aid deceleration. The authorities knew about the problem, but according to Airbus and TAM, the airline company, it was not unsafe to land with a defective thrust reverser. According to reports – that were vehemently repudiated by TAM – there had been landing problems with the same plane only a day before.

Accident Responsible: Pilots?

From analyses of the Flight Data Controller and the cockpit conversations, it became evident that the pilots had been aware of the problem with the inoperative thrust reverser in the right engine. During the landing roll, they had switched the right engine to 'climb', probably to prevent the defective reverser from starting to operate. Because of that, the spoilers on the wing did not work. During landing, those spoilers are used to increase the plane's air resistance or drag while at the same time reducing the lift factor so that the plane is forced down onto the runway and can brake more easily. With the Airbus A320, the spoilers only work properly if the engines are in the 'idle' position, but as the right engine was in the climb mode during that landing procedure, the spoilers did not come into play. Most probably, that was the cause of the accident or, at least, one of the major contributing factors. Interestingly, after the disaster, Airbus ordered that with that particular series of aircraft, all engines should be switched to the idle mode in readiness for touchdown.

Who Is Responsible?

Over the course of time, philosophers have given various answers to this very question. In many philosophical discussions, there are a number of conditions that recurrently arise. The following conditions are the ones that are most frequently mentioned: ³⁷

- 1. The action taken by somebody for which (s)he is held responsible must have been consciously undertaken;
- 2. There must be a causal connection between the action taken and the ensuing consequences for which someone is held responsible;
- 3. The person must have foreseen or at least have been able to foresee the consequences;
- 4. The person could have taken a different course of action;
- 5. The action taken was wrong or otherwise blameworthy, and that mistake or blameworthiness contributed to the negative consequences.

Apply Conditions to the Pilots (1, 2, 3)

In the light of this information, look once again at the actions of the pilots. The relevant actions of the pilots involved consciously adjusting the right engine to the 'climb' mode or, more precisely, leaving it in that position. In so doing, they fulfil the first condition. Thanks to this course of action, though, the spoilers did not function in the way that they should have done, so the plane failed to decelerate sufficiently, flew off the runway, crashed and went up in flames. Condition 2, concerning the existence of a causal connection, is also satisfied. Whether or not the pilots could have foreseen the disaster, which is the third condition, is less clear. One presumes that the pilots were not able to anticipate the consequences of their actions: they did not deliberately crash the plane. The real question is whether they could have or should have been able to anticipate the consequences. One argument that can be levelled is that according to the flying instructions for that particular type of Airbus, the engines should be in the 'idle' mode when landing; the onboard computer also backed up those instructions, but the pilots chose not to follow them. It could be argued that pilots should know

Apply Conditions to the Pilots (4, 5)

can lead to a disaster. The question as to whether the pilots could have done any differently, the fourth condition, is disputable. At first sight, it would seem obvious that the pilots could have done something differently: after all, they could have allowed the right engine to idle instead of climb. Nevertheless, one could argue that the pilots were forced to make a quick decision in what was not an everyday situation (with a malfunctioning thrust reverser in the right engine), and that it was perhaps not obvious that it would make a difference in that situation if the right engine was in the climb mode. On the other hand, one could argue that it is part of the pilot's job to be able to react quickly and appropriately in such situations. As far as the fifth condition is concerned, the pilots clearly breached a norm, which means that their actions could be labelled wrong. They failed to abide by the flying instructions given in the manual (see also Figure 7.1). On top of everything else, they ignored the directions given by the onboard computer. Still, one can argue that this was an unusual situation in which the pilots had to think and react fast, so they could not be blamed for what they did wrong.

Apply Conditions to the Engineers (1, 2)

Apart from looking at the pilots, one can also look at other actors that could possibly have borne some responsibility in this case such as the air traffic controllers, the aviation authorities, the plane's maintenance technicians and the engineers, who designed the aeroplane and drew up the flying instructions. Just think for a moment of the engineers and go once again down the list of the five conditions.

One may presume that the engineers did make the relevant technical decisions in a conscious fashion; they knew what they were doing or should at least have been aware of what they were doing. They therefore satisfied the first condition of responsibility. To what extent the second condition was also met – that of a causal connection between the actions of the engineers and the disaster – is not so clear. If the design had been different, the disaster may possibly have been averted. In addition, the manual could have stated that the aeroplane should only be allowed to take off if both thrust reversers are operating properly. That would probably have been sufficient to prevent the accident. To conclude, it would therefore seem that the engineers' manuals did have a causal connection with the accident. To what extent the engineers could have foreseen this – the third condition – is once more

Apply Conditions to the Engineers (3, 4)

accident. To what extent the engineers could have foreseen this – the third condition – is once more not so clear. When designing the aircraft, the engineers probably did not take into consideration a scenario like that which occurred during the Brazilian air disaster. One can really question whether the engineers should perhaps have borne in mind the possibility of something like that happening.

In this particular case, it would seem that the fourth condition was met: the engineers probably could have dealt with matters differently. There are, at any rate, no indications that they were forced to adhere to this design or were somehow pressured to do so by their superiors. The mention, in the flight manual, that aeroplanes can take off if one of the thrust reversers is out of order is probably dominated by commercial considerations because it means that a plane can put in more flying hours before requiring maintenance.

Apply Conditions to the Engineers (5)

The fifth condition would imply that the actions of the engineers might have been incorrect or blameworthy. In this connection, the following stipulation laid down in the NSPE code of conduct is of relevance³⁹:

(II.1.b) Engineers shall approve only those engineering documents that are in conformity with applicable standards.

As far as it is known, the aeroplane did satisfy all the safety regulations. It is possible, though, that the design endangered the well-being of society in a different way. In this light, the following

Influence: To What Extent?

Although there are no clear indications that the engineers violated any of those stipulations, there are a number of questions that could be asked. One might, for instance, query whether the engineers had sufficiently evaluated the safety of the system. As has already been suggested, one could ask whether the engineers might not have been able to anticipate events of the kind that took place in Brazil in 2007. If they had, then they probably would have designed the system slightly different. Regarding the second directive, directions for use had been drawn up that would also have made it possible for the pilot to land safely in these circumstances. As was suggested above, one might ask whether those instructions for use were not too complex; the pilots had to react in a very short space of time. From the point of view of safety, the manual should perhaps also have mentioned that planes should only be allowed to take off if both thrust reversers are in working order. Finally, one might wonder to what extent the engineers were involved in or were able to influence this particular aspect of the instructions for use.

Other Actors' Responsibility

responsible. It has to be acknowledged that there were many other actors involved who, directly or indirectly, may have contributed to the disaster. For instance, the Brazilian Civil Aviation Authority had been held responsible for previous accidents; some even spoke of a safety crisis within the Brazilian aviation sector. There had also been complaints about lack of safety at the airport where the accident happened. One might even go as far as to assert that the cause of the crash needed to be sought in the sociotechnical system as a whole. This was definitely so in the case of the accident discussed in Chapter 5 where there was a mid-air collision. In these kinds of situations, the matter of responsibility is more diffused. As we also saw in Chapter 5, it is not usually one actor that designs a given sociotechnical system; the system is much more often the - partly unintended - result of the actions of many actors.

Wait for the Consequences!

Letting the consequences of technology manifest themselves after the designing of a technology, also has a number of disadvantages. It is then not only the case that these undesired consequences will arise, but also the costs of preventing the consequences from arising again in the future will often be much higher than when matters are tackled in the design phase. Returning to the drawing board is not only expensive because something new has to be designed but also because - once the consequences manifest themselves - the relevant technology will already have become embedded in society. That means that users will already have become used to it and will have adapted their behaviour to that technology; it also means that regulations and other social institutions will have become adjusted to that particular technology. Breaking open such a level of embeddedness is often not only difficult (if indeed possible at all) but also expensive. Furthermore, as we saw in the last section, if negative effects are manifested in a sociotechnical system, it is often not very easy to determine who exactly is responsible for those effects. That, in turn, can lead to situations in which people avoid to address those undesired effects once they have manifested themselves.

Collingridge's Control Dilemma

When dealing with the possible unknown effects of technology, we are therefore confronted with a dilemma. On the one hand, we often do not know, in the design phase of a given type of technology, the possible future consequences that we have to take into account when designing. On the other hand, by the time those consequences become manifest, the technology in question is already operational and the costs of redesigning or making other adaptations within the sociotechnical system are often high and difficult to realise. This, in fact, is the Collingridge's control dilemma that was already described in Chapter 6.

Although there is no easy solution to the Collingridge's control dilemma, one might not conclude from the mere existence of the dilemma that responsible technological development during the design phase is impossible. In fact, in many cases one does, already in the design phase, really

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Acceptability of Social Experiments

From the ethical angle, one may question when such experiments are acceptable and when they cease to be acceptable. There are certain philosophers, like Hans Jonas, who put the case that extreme precautions should be exercised with all the kinds of technology that could conceivably threaten the survival of our species. 42 Another proposition is that such experiments are acceptable if those who possibly stand to suffer from their consequences agree to the experiments going ahead.⁴³ This notion is similar with the principle of 'informed consent' that is widely used in medical practice. It is the idea that whenever people have to undergo surgery or whenever they participate in a medical experiment, they are first informed as fully as possible of all the possible inherent risks and dangers so that they can decide if they want to undergo the surgery or participate in the experiment. In medical practice, informed consent tends to be implemented on an individual basis; in the case of technological development, that would seem to be more difficult because the relevant 'experiments' often involve large groups all at once. A question which then arises is whether all the members of the group in question have to agree or whether the consent of the majority is enough. Further problems arise in the case of technologies that have possible repercussions for future generations. People who have not yet been born cannot, of course, be asked for their informed consent.

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