Modelling infrastructures as socio-technical systems

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Abstract: The conceptualization of the notion of a system in systems engineering, as exemplified in, for instance, the engineering standard IEEE Std 1220-1998, is problematic when applied to the design of socio-technical systems. This is argued using Intelligent Transportation Systems as an example. A preliminary conceptualization of socio-technical systems is introduced which includes technical and social elements and actors, as well as four kinds of relations. Current systems engineering practice incorporates technical elements and actors in the system but sees social elements exclusively as contextual. When designing socio-technical systems, however, social elements and the corresponding relations must also be considered as belonging to the system.

Keywords: System, socio-technical system, philosophy, systems engineering, large-scale system, complex system, IEEE.

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1 Introduction

Infrastructures are a primary example of complex engineering systems, but they are complicated in ways different from such engineering systems as, for example, satellites or computer processor chips. The complexity of infrastructures is closely related to their being engineering *systems*. Although the notion of system in its broadest sense, as an entity in which various separately identifiable but interrelated subentities can be distinguished, applies to both satellites and infrastructures, as well as to almost everything else for that matter, the notion of system typically implies a certain heterogeneity among the subentities. In view of this, infrastructures are paradigmatic systems and, in fact, paradigmatic *complex* systems. Infrastructures contain many hardware elements, and these are (still) the main reason why infrastructures are *engineering* systems, but they 'contain' or 'involve' people as well – people in different roles and involvement in many different ways, going far beyond the way people are 'involved' with satellites and computer processor chips.

In this paper we adopt the point of view that infrastructures are a special sort of complex engineering systems, namely socio-technical systems. We will argue that the modelling and design of this sort of system poses special problems, problems that current approaches to engineering design are insufficiently capable of recognizing and addressing. This applies even to the approaches, summarily referred to as systems engineering, that explicitly take the systemic nature of their subject into account.

The inverted commas in the above statement that infrastructures 'contain' or 'involve' people far beyond the way people are 'involved' with satellites and computer processor chips point to the fact that a precise analysis of the various ways in which non-technical elements participate in socio-technical systems is still lacking. We will argue that this situation is related to an ambiguity in the application of the notion of system in the field of systems engineering. The ambiguity testifies to a lack of clarity on the various ways that intentional human action affects the functioning of an engineering system other than the way by which the system's designers, operators and direct users affect its functioning. What characterizes socio-technical systems is a much more variegated and penetrating involvement of human action, which, in all its forms, is able to affect, even critically to affect, the functioning of the system.

Exploring the status of actors and social factors with regard to engineering systems, in our opinion at least three different types of systems can be distinguished (see Table 1) (Kroes et al., forthcoming): (1) engineering systems that perform their function without either actors or social institutions performing a subfunction within the system, (2) engineering systems in which some actors perform subfunctions but social institutions play no role, and (3) engineering systems that need actors and some social/institutional infrastructure to be in place in order to perform their function. In the last case it seems appropriate to speak of socio-technical systems, and in our view most large-scale infrastructures are of this kind.

Table 1 *Types of engineering systems*

	without actors	with actors
without social institutions	1) landing gear	2) airplane
with social institutions	—	3) civil aviation system

In this paper we will argue that from a systems-theoretic point of view engineering systems of the second and especially of the third type raise fundamental problems as compared to systems of the first type, since they are hybrid systems, in that they consist partly of elements that are conceptualized and described using the vocabulary of the natural sciences and partly 'consist of' – in a sense to be made precise – 'elements' – in a sense equally to be made more precise – for which a completely different description, employing the vocabulary of intentionality, is considered necessary.

In the next section we will investigate to what extent socio-technical systems fit the notion of system as it is articulated in systems engineering. In section 3 we will present intelligent transport systems as examples of socio-technical systems. In section 4 we will develop a preliminary characterization of the elements and relations that need to be distinguished in socio-technical systems. In the final section, some problematic issues regarding this characterization and some issues related to the modelling of socio-technical systems in general will be addressed.

2 Socio-technical systems and systems engineering

When different definitions of the field of systems engineering, as given by systems-engineering researchers and groups, are compared, an ambiguity in the notion of system becomes apparent. According to information that the Systems Engineering Departments of Brunel University and University College of London give on their websites, systems engineering is about the design, development and maintenance of large, complex, multidisciplinary systems. According to the Institute for Systems Research from the University of Maryland and also according to such books as Andrew Sage's Systems Engineering (Sage, 1992), systems engineering concerns a systemic approach to the design, development and maintenance of technological products. So 'system' applies in the first perspective to the product of engineering, in the second to the engineering process. The original focus of systems engineering was the increasing complexity of the design task (see e.g. Goode and Machol, 1957). We now see that two ways in which the complexity of engineering design tasks have increased must be distinguished. Figure 1 is a schematic representation of these two ways, presented as two dimensions.

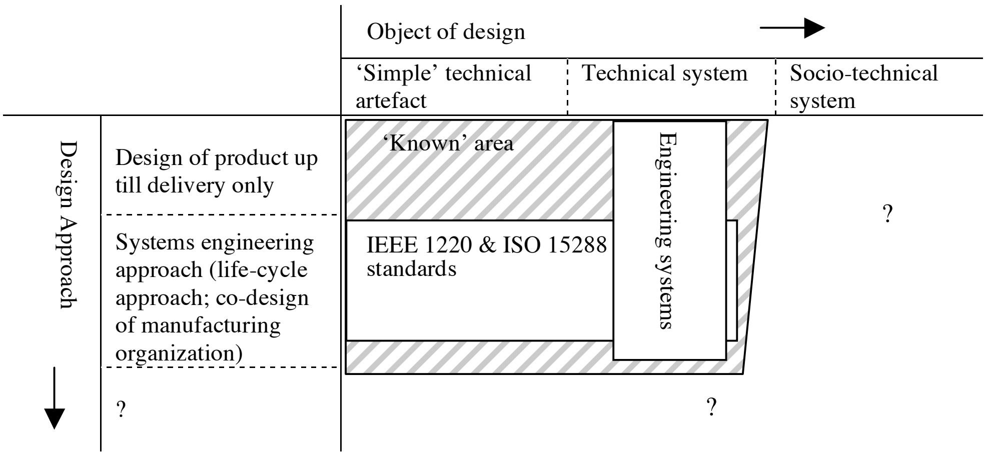

Figure 1 *Two forms of complexity*

The first complexity is in the object of design. Whereas engineers started out designing relatively simple artefacts like paperclips, bicycles and bridges, the objects of design have become more complex over the years, involving more and more disciplines, eventually even disciplines from outside the engineering domain.

The second way complexity has increased is in the design approach. Initially (whenever that was), the design task was limited to the design of the object itself, and was considered finished as soon as the object complied with the specifications agreed to. With the increase of multidisciplinary design tasks, the organization of the work process became an element of the design approach, since ignoring it would impede a successful completion of the design task. Additionally, with the ongoing development of technology, it was increasingly acknowledged that the responsibilities of the engineer did not end with the creation of the artefact as such, but must also address the production, operation, maintenance, and disposal of the artefact.

The development of the field of systems engineering has recently resulted in a number of documents in which the field's general outlook is presented and its basic concepts are defined. One of these is the *IEEE Standard for application and management of the systems engineering process* (IEEE Std 1220-1998), and we will take this document as a starting point for our enquiry concerning the way the particular characteristics of socio-technical systems are dealt with in systems engineering. IEEE Std 1220-1998 and the way the notion of a system is construed therein clearly belong to the second of the two perspectives sketched above. In this standard, 'system' seems to denote the totality consisting of an enterprise's product and the associated processes directed at developing, manufacturing, maintaining and disposing of that product and at training people for the competences they use in these processes. However, the noted ambiguity in the meaning of system raises a number of questions for the scope of the standard. First there is the question of whether the standard itself construes the system concept unambiguously and coherently. Second, what if the standard is applied to cases where the engineering product is itself of a systemic nature? Does the system concept from the standard match engineering products with a systems character? And third, even if the answer to the second question were a 'yes' in general, is the standard applicable to the special category of socio-technical systems? These questions are especially urgent since nowadays the importance of the societal context to the functioning of technical artefacts is widely recognized and engineering is increasingly focused on system level solutions.

In our view, the standard IEEE Std 1220-1998 suffers from a weakness that affects many applications of systems theory. The standard is vague concerning how to characterize the various 'elements' or 'components' of a system and the relations between them, and also vague concerning what is counted as part of the system and what as the system's environment. The standard adopts the perspective that engineering systems are, generally, human-machine systems: systems are said to be "composed of hardware, software and/or humans", and these system "elements" can themselves again be analyzed as (sub)systems consisting of the same types of elements (p. 2). But at the same time, the "building blocks of a system" are said to be either "products" or "processes" (pp. 3-4). It is unclear from the text how the relation between the elements and the building blocks, that each in one form or other make up the system, must be seen.

The relations between the various elements, moreover, are not specified further than as being “interfaces”. Further, the involvement of the ‘human element’ (in the design approach) is conceived exclusively in terms of individual people, “required to develop, produce, test, distribute, operate, support, or dispose of the (system’s) element’s products” (p. 2). In the concept of a system (as a product of design) as used in IEEE Std 1220-1998, humans are taken into account exclusively as fulfilling subfunctions within the system. The relation with the technical elements is found in a man-machine interface.

The system concept from the IEEE standard completely ignores the social dimension of human involvement, which takes the form of regulations, laws, procedures, standards, and so on. Without these rule-like elements being in place, it would be impossible for large engineering systems, like infrastructures, to function, at any rate function as they currently do. How exactly such rule-like ‘elements’ must be thought of as ‘participating’ in such systems is of course not obvious. The IEEE standard incorporates a conceptualization of systems that treats social aspects as belonging to the system’s environment (p. 37: “6.1.3 Define external constraints”), forming constraints to the design and management tasks. This approach is likely to run into difficulties as soon as one takes a broader look at the kind of products that a development and manufacturing process is directed at. If we refer back to the distinction among fundamentally different kinds of systems summarized in Table 1, then the IEEE standard clearly focuses on systems of the first and second type (p. 3). Social issues are explicitly considered external constraints (p. 37). Since the interest of the IEEE, in particular its Systems, Man & Cybernetics Society, extends to large-scale systems like infrastructures and to the formulation of a general theory of systems, the standard should be applicable to systems of the third type as well.

In the next section we will introduce some examples of socio-technical systems and evaluate the extent to which the IEEE standard does justice to their specific socio-technical character.

3 ITS as socio-technical systems

Improving the intelligence of road transport systems in order to, for example, increase the efficient use of road infrastructures and improve safety, is currently high in the engineering agenda. Technologies that deal with this are called Intelligent Transportation Systems (ITS). In this paper we focus on two different ITS implementations. ITS in public and cargo transport and specific at systems that focus on automated vehicle guidance. Systems for cargo transport are widely implemented but mostly on a relatively small scale in, for example, warehouses. Large-scale cargo systems and systems that use or cross public roads are less widely implemented and the issues they give rise to are different from the ones raised by small systems.

Most automated systems for public transport use some kind of rail for guidance and are separated from public roads, like for example a subway. Some, however, cross public roads and use different kinds of guidance systems, which makes the system more flexible. We focus upon these systems and on the large-scale cargo systems because of the different kinds of elements necessary for the functioning of the system. In this section we will give a detailed description of some of these systems, in order see to assess the applicability of the IEEE standard. In the next section we use this description to illustrate a general model for socio-technical systems.

3.1 ITS for cargo transport

An example of a large-scale ITS for cargo transport is the Underground Logistic System (Dutch abbreviation OLS) Schiphol for which several feasibility studies were done. This system is to connect Amsterdam Airport Schiphol, the Aalsmeer Flower Auction, and a new high-speed terminal near Hoofddorp in the Netherlands (Versteegt & Verbraeck, 2001). The system focuses on handling time-critical cargo like newspapers, flowers and other perishables. When fully operational it will use around 400 automated vehicles, fully automated transshipment facilities and a fully automated control system. The system is planned to contain around 15 kilometers of 3.5 to 5 meter wide tubes (several variants were studied) and consists of several terminals on the different locations connected by the tubes. The ground-level area around the airport is highly congested and the flower auction (the largest flower auction in the world) puts a heavy load on this area. Currently the project is on hold because of uncertainties regarding the rail terminal and the availability of high speed cargo trains, uncertainties regarding the future of Schiphol and the rail companies involved (possible physical extension; organizational structure; possible future privatization) (Koppenjan & Ham, 2002). The OLS was developed as a Public-Private Partnership. Parties involved are Amsterdam Airport Schiphol, Flower Auction Aalsmeer, NS Cargo, the Ministry of Transport, Public Works and Water Management, Nederland Distributieland, ATAN, Center for Transport Technology, and participation is also expected from the province of North-Holland and the affected municipalities.

Feasibility studies show that the system is technically and economically feasible. The structure should be partly funded with public investments. Because of this the public/private discussion is important, but also because of the use of land of third parties. Only the government can use expropriation laws, and furthermore issues regarding different kinds of land use might be solved more easily by legal means. Because of the scale and complexity of the project such issues are very likely to arise. In all designs for example land of third parties will be crossed (although at 15 meters underground). So in the design phase the choice for a public-private partnership is recommended. In this, the project is not much different from other large infrastructure projects.

Several non-technical issues are of crucial importance in decisions regarding the design of the system, however. Of paramount importance are uncertainties regarding some of the main players. Other issues are the possibility to use the HSL (High Speed Train, currently under construction) for cargo transport and risks regarding cargo transport through tunnels. Also the decision to call the project public or private is of crucial importance, not only for financial reasons but also for legal and policy reasons. Since the system will come into existence as a result of public-private partnership, some form of legal code, regulating, for example, access, will be required. Additionally agreements between the involved parties are needed for its functioning. These agreements are quite intricate because of the uncertainties regarding the future of several involved parties.

Another example of ITS for cargo transport is the Chauffeur 2 project. This project is about the electronic coupling of trucks. Using this system two or three trucks can drive very close behind each other while only one driver is steering the trucks. An interesting difference with the OLS system is that this system is supposed to drive on public roads. Experiments showed the technical feasibility of the project, but the implementation is hampered by non-technical issues (Benz et al., 2003). By Dutch law, unmanned vehicles are not allowed on public roads and not only must the vehicles be manned, the 'drivers' should also be able to overrule the automatic system and have the time to do so. 'Solutions' to these problems is to place a driver in the truck doing nothing, but with the ability to overrule the system if anything goes wrong. However if the trucks drive at one meter distance, the driver will never have enough time to actually overrule the system if anything goes wrong. Another interesting issue that comes forward when this system is considered is an economic one. Systems like this cost money. When half the transport sector buys this system the other half will profit as well: since roads will be more efficiently used and therefore less crowded, travel time will decrease overall. So not only accountability needs to be dealt with, but also these economic issues are important to make the system function.

3.2 ITS for public transport

For public transport two systems are currently operative or under development in the Netherlands: the Parkshuttle in Capelle aan de IJssel and the Phileas system in Eindhoven. These systems have their own driving lanes, but the lanes cross public roads. Both systems are pilot projects. The Parkshuttle uses a small amount of unmanned small vehicles, available on demand. It replaced a regular bus connection between a metro station and a business park. For this project a special bridge and special lanes were constructed. The Phileas system uses a special lane as well. It has a small amount of manned (but not conducted) larger vehicles. Advantages are supposed to be the smaller size of the lanes as compared to normal roads and in the case of the ParkShuttle, the on-demand availability (Graaff, van de, 2000). Unlike the OLS, no agreements with potential users are possible about a guaranteed amount of transport. But like the OLS the initial investments are considerable compared to classic means of transport, due to the construction of the special lanes. This causes an uncertainty regarding the benefits that will result from the project. Therefore the system is designed to become available for mass-use and to appear as attractive as possible.

The Parkshuttle en Phileas systems are both public transport systems. Since unmanned vehicles are not allowed to drive on public roads, according to Dutch law, this could pose a problem regarding public transport. The Parkshuttle therefore drives on private roads. In the Phileas system this problem is tackled by introducing a non-driving driver in the system. By introducing this driver they also tackle the problem that unmanned vehicles only are allowed to drive at a certain (low) speed when they are in the same area as humans or when they are transporting humans. This solution makes the system more expensive, however, since you need both advanced technology and a driver.

When dealing with passenger transport through areas populated with pedestrians and other road users, not only the technical elements need to be taken into account but also actors outside the vehicles and their intentions. In the case of the ParkShuttle, for example, cyclists tended to use the bridge made for the shuttle, and school kids deliberately forced the vehicles to make emergency stops. One report concluded (Krämer, 2001): "Merely scheduling vehicles on designated tracks is insufficient; an automatic road transportation system must also consider non-cooperative road users.". A technical solution to these social problems is to fence off the complete system. A social solution would be to forbid people explicitly to enter the lanes and see to the enforcement of this. Apparently, the correct technical functioning of the vehicles is not enough for the system as a whole to function adequately.

3.3 ITS as socio-technical systems and the IEEE standard

The ITS examples show the intertwined character of technical and social aspects in the systems. In both cases laws and regulations are not simply constraints for the design. They influence the functioning of the system to such a degree that sometimes it seems more appropriate to adjust the law than to adjust the technology. For example, if the OLS will be realized as a public infrastructure and if the road-traffic code applies, then either the technical system or the code needs to be adjusted. It seems not very useful to oblige the vehicles to carry headlights and rear lights and license plates when they only drive around unmanned in an area without human presence.

If one adopts the point of view, to which IEEE Std 1220-1998 confirms (p. 37: "6.1.6 Define system boundaries"), that everything not open to design must be relegated to the system's environment, then it becomes questionable whether laws and regulations must be conceived as belonging to the environment and must accordingly be treated as external constraints. Regulations and standards often co-evolve during the development of an engineering system and change or are changed as the system's functionalities are modified or become modified. Such rule-like elements are the product of intentional action and can therefore be said to be 'designed', not unlike a technical product, often during a process of 'interaction' with the designing of the hardware elements. Ignoring this would certainly be a very unsatisfactory approach if the government is directly involved in the design and/or the management of a technological system.

The discussed ITS, however, also have to take non-cooperative humans into account. They have their own particular intentions with respect to the vehicles. The non-cooperative users ascribe a function to the vehicle just as the cooperative users do, albeit a different function: they use the vehicle as a toy, so to speak. Since this does not contribute to the function intended by the designers of the system, it should probably be considered dysfunctional behaviour. IEEE Std 1220-1998 does not leave space in the design for intentions of users toward the designed product or system that do not derive from the system's intended function. Human actors figure only for the purpose of understanding the human/system integration issues and ensuring that the system products are producible, maintainable, and usable, ... (pp. 3-4). They associate humans to products and processes in the system; they are considered elements but not building blocks, like processes and products.

4 The conceptualization of socio-technical systems

The previously introduced examples show several problems of a non-technical nature intertwined with technical issues. We argued that a conceptualization different from the one used in the IEEE standard is needed to overcome these problems. In this section we will introduce a preliminary version of such a conceptualization.

System theories usually take technical elements (like hard- and software) and actors (fulfilling a role as subfunction in the system) into consideration. To conceptualize socio-technical systems we introduce a third kind of element and take a closer look at the possible relations between all these elements. This third type of element is a 'social element'. The distinction between technical and social elements in large technological systems is not a new one. Hughes (1987) and Nelson and Sampat (2001) distinguish elements of a non-technical nature in systems. Hughes mentions organizations and legislative artefacts and Nelson and Sampat consider social technologies next to physical technologies. A reason for making this distinction in elements is the difference in laws these elements are subject to and the difference in nature of these elements. Both actors (as physical bodies) and (physical) technical elements are subject to the laws of nature, but social elements and the behaviour of actors additionally refer to individual intentions and to more complex guiding principles like social rules.

From a systems-engineering perspective (aimed at modelling the system) the introduction of social elements apart from actors and physical hardware seems to be an promising one. In large technological systems the inclusion of this element reflects the need for the (re)design not only of the technical side of the system but also of the social side. The design of social elements, however, lies largely beyond the scope of current engineering practice. While systems engineering is already multidisciplinary among the engineering disciplines, the proposed inclusion of a social element needs an approach where also non-technical disciplines have to be involved.

If the system is conceptualized using these social elements next to technical elements and actors a simple picture of the system can be drawn with the different elements and their relations (Figure 2).

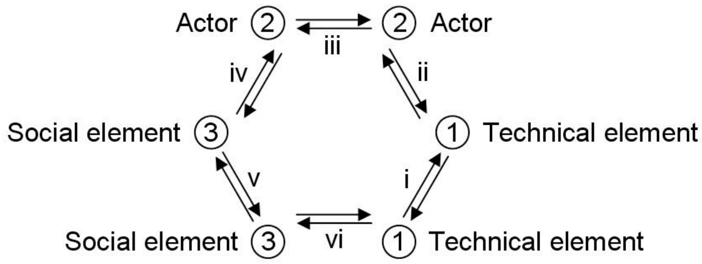

Figure 2 *Elements (1-3) and relations (i-vi) in a socio-technical system*

A closer look at the elements and relations, using the examples of ITS, will clarify what this conceptualization adds to the model of a system as used in the IEEE standard.

4.1 Elements

Technical elements (1) To point out the technical elements in ITS is a fairly straightforward matter. The vehicles, the infrastructure, the command computers, the 'bus' stops or transhipment terminals are all physical elements in the system. Next to that the software that controls the vehicles and determines how and where they go can be considered technical elements as well.

Actors (2) Individual human beings are the primary actors. Next to that organizations might be considered actors as well. According to (Dutch) law organizations as legal bodies can be considered as actors. Like humans they can act in a legal sense. One of the uncertainties in the OLS project is for example the future of the actors Schiphol and NS Cargo and possible changes in their behaviour when they would be privatized.

Social elements (3) A lot of non-technical elements influence decisions concerning the design of the physical structure of the OLS. For example, the diameter of the tubes and the map of the structure depend on financial (how is the project financed, who is paying for what part) and organizational structures (how is the project organization set up, is it a public or private project). Other elements are the policy of governmental organizations regarding how to deal with laws and regulations in relation to e.g. underground building, and how to deal with laws regarding for example speed of unmanned vehicles. These social elements are not so easy to comprehend. The vehicle can be pointed at, while a social 'element' like financial structure is intangible and difficult to model, and unavailable for testing purposes. Nevertheless this kind of element is to some extent 'designed' and has a considerable influence on the functioning of the system as a whole.

4.2 Relations

By setting up a model with three kinds of elements, where all elements can be related, six relations can be distinguished. In a first exploration we take a closer look at these relations to see whether we can come up with a classification of these relations. Relations between different elements can be of the same kind, and between any two elements different kinds of relations are possible. In performing this exploration we will use the examples previously introduced.

Technical-technical (i) The various technical elements in ITS can be physically connected to each other: the vehicles are driving on roads, they can bump into each other or be connected through radio signals. Technical elements can be functionally related as well, like in the case of the Chauffeur 2 system where the first truck is guiding the other trucks, or when magnets in the road function as a guidance system for the Phileas bus. We call a relation between two elements *functional* if one elements fulfils a function within or for the other element.

Technical-actor (ii) Actors (if physical themselves) and technical elements can be physically related as well, a passenger or driver can be seated inside a vehicle. They can also be functionally related, either in the usual way of a technical artefact fulfilling a function for a human actor or in the way of a human actor fulfilling a technical subfunction (as is the case for the driver of a car). Actors, however, can also have an intentional relation to a technical element, next to physical and functional relations. A relation between two elements is *intentional* if one element figures in an intentional state of the other element, which other element must therefore be an actor. The passenger in the Parkshuttle has the intention to use the Parkshuttle to travel, while a young rascal can intend to force the Parkshuttle to make an emergency stop just for fun.

Actor-actor (iii) Actors can (if they are physical themselves) be physically related to each other, simply by touching each other. You can also use someone to fulfil a function for you, for example to drive your car. This last relation has an intentional aspect as well: you want someone to drive your car for you, and the driver, one may presume, even when pressured into the job, chooses to do so. A relation between actors can be intentional without being functional or physical, for example when people are avoiding bumping into each other in crowded streets.

Actor-social (iv) Social elements seem to bring a new kind of relation into play, not found in the previous examples. A law can allow or forbid an actor to act in a certain way. It prescribes, for example, that a passenger must have a valid ticket when using public transport. We will call such relations normative. A relation between elements is *normative* if one element figures in a rule to which the other element must subscribe. Actors can however also have functional relations to a social system. They can carry out policies, enforce law, and inspect the tickets in public transport. Additionally actors can have an intentional relation to social elements; they can for example break the law and jump in front of the Parkshuttle or use it for their own individual purpose.

Social-social (v) Social elements can fulfil social subfunctions of other social elements, making them functionally related. Laws can help a policy to work, a contract or agreement between the government and a transport company can help the policy to stimulate new technologies like ITS. These contracts are normatively related to laws that forbid or allow certain types of agreements.

Technical-social (vi) Like actors, technical elements can be functionally related to social elements. You can use a machine to inspect tickets or a surveillance camera to help enforce the law. Social elements can also be normatively related to technical elements. For example, the law restricts the maximum speed of unmanned vehicles in populated areas and forbids them to drive unmanned on public roads.

Our first exploration of the relations in our preliminary model gives us four different kinds of relations. In Table 2 these different kinds of relations are gathered together. All these relations seem relevant for modelling socio-technical systems.

Table 2 *Kinds of relations*

		kinds of relations			
i	technical - technical	physical	functional		
ii	technical - actor	physical	functional	intentional	
iii	actor- actor	physical	functional	intentional	
iv	actor- social		functional	intentional	normative
v	social - social		functional		normative
vi	social - technical		functional		normative

5 Discussion

The proposed conceptualization of socio-technical systems is by no means unproblematic. The notion of a social element is far from clear. Laws, regulations, policies, economic and organizational structure might be conceptually too different to capture in a single notion of social element. Moreover, it seems that a social element can itself be analyzed, at least sometimes, as a relation between actors and/or physical elements and also as a relation between other social elements. It is therefore not obvious how organizations, for example, should be treated, either as social elements, institutionalized behaviour of a group of people with similar interests, or as actors, in conformity with the status of legal actor that formal organizations have.

It is also not clear whether the functional relations between actors and between technical elements are of a similar kind. When actors are involved, intentions come into play, possibly leading to dysfunctional relations, where the function is determined ad hoc by the actor and differs from the 'proper' function of the system. In further research we will address these issues.

It is one step to conceive a conceptual framework for socio-technical systems, but quite another step to implement this framework in a model for the designing of such systems. Designing the separate elements seems not impossible. Both technical and social elements are currently already subject of design, as is human behaviour, for example by training. Designing a system, however, is more then simply aggregating the elements. In her book *Foundations of Complex-System Theories*, Auyang (1998) points out several sources of complexity: the variety and intricacy of the constituents, the variety and strength of their mutual interactions and the number of constituents. The possible states of a system increase dramatically with the increase of variety in the elements and relations and the number of elements. With the inclusion of social elements, not only the variety and number of constituents (elements) of the system increases, but also the variety of relations between the elements.

When considering socio-technical systems as products of engineering design, the approach taken in the IEEE standard runs into problems. Two things seem to be the most problematic. First the standard does not leave space for intentional relations between users and the other elements. And second the standard relegates all social elements to the context. Because of the necessity of social elements for the functioning of the system and intentional behaviour of actors with regard to the system both these exclusions are problematic. In this respect the standard is clearly ill-fit to the development of socio-technical systems. But it might already run into problems with more simple systems where only actors and not also social institutions are involved (Table 1), because of possible unanticipated behaviour of actors, since the standard leaves no room for such a phenomenon.

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