Chapter 10
Limits to Systems Engineering

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Abstract In this chapter I will analyze the concept of boundary and the rationale behind considering elements part of a system in three key systems engineering texts. Using examples of electric power systems in Europe being sociotechnical systems, I will argue three points. (1) First, I will argue that the systems engineering approach excludes certain elements from its conceptual representation of systems that are essential for the functioning of sociotechnical systems. (2) Secondly I will argue that the rationale behind this exclusion is based on an understanding of the behavior of its elements and their relations that leaves no space for the 'missing' elements. Therefore simply adding the elements is not an option. (3) And thirdly I will argue that because those left-out elements have a vital impact on (the functioning of) the system, a systems engineering methodology that does not and cannot take this vital impact into account is not fit for the practice of designing and managing even just the technical part of sociotechnical systems.

In the night of September 23, 2003, around 3 AM, a power line collapsed on the Swiss-Italian border. Just over half an hour later over 50 million people in the whole of Italy were left without electricity. On November 4, 2006, around 10 PM on a Saturday evening, a planned action to switch off a line was followed by a cascade of tripping lines and blackouts throughout Europe, even affecting countries in North-Africa. In both cases the problems happened at times of a relatively low use of electricity. The subsequent reports traced the train of technical events leading up to and following the initial incidents meticulously. Besides analyzing the technical aspects, both reports also point to a change in use of the network, a change that contributed to high loads on power lines during off-peak hours, a change in use following a change in governance of the electric power system in Europe.

The European electric power system is an example of a so-called sociotechnical system. In these systems technical and non-technical elements are strongly

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interconnected and are both essential for the systems to function the way they do. They are hybrid systems, containing elements of a different nature. With a rapid development of technology in the last century, both in scale and complexity, the interdependence of technical and non-technical elements (e.g. humans, legislation) has increased. In the above examples changes in legislation concerning the governance of electric power systems affected the physical flow of electricity. Such sociotechnical systems bring new challenges to the field of engineering. These challenges are addressed in a discipline of engineering specifically focusing on systems: the systems engineering discipline. However, despite the claim made in key systems engineering texts that systems engineering is applicable to large, complex systems (and to human and social systems) (INCOSE 2004, p. 14), and that the approach is adequate for any man-made system (ISO 2002, p. 1), I will argue that the current conceptual framework used in systems engineering is not fit for the practice of designing and managing sociotechnical systems such as the current electric power system in Europe.[1]

I will focus in particular on the rationale for considering specific elements part of the system by analyzing the use of the concept of *boundary* in three key systems engineering texts: two systems engineering standards by "the world's largest developer and publisher of International Standards", the ISO[2] and by "the world's leading professional association for the advancement of technology" the IEEE,[3] and a systems engineering handbook by INCOSE,[4] "the world's authoritative systems engineering professional society."[5]

Throughout this analysis I will refer to examples of electric power systems in Europe. I focus on electric power systems for two reasons. (1) First because these systems are paramount examples of engineering ingenuity. Unlike many other sociotechnical systems like, for example, transportation systems and communication systems, the existence of electric power systems does not predate the discipline of engineering. Engineers have been deeply involved in the development of these systems from the start. The fast growth of these systems and their increased reliability points to a successful engineering effort. (2) The second reason to focus on electric power systems is because in Europe (and in North America) these systems faced a major shift in mode of governance in the last decades. This shift in governance affected the physical flow of electricity through the network, raising questions to the status of policy and legislation in a practice of modeling, designing and managing such systems. This shift emphasizes the sociotechnical character of these systems.

By focusing on the concept of boundary, and the rationales behind the decision to take certain aspects into account and not others, I will argue three points.

[1] Similar remarks can be made about electric power systems elsewhere, but I will focus on the European system.

[2] International Organization for Standardization (ISO 2002).

[3] IEEE (2005).

[4] International Council on Systems Engineering (INCOSE 2004).

[5] The three quotes come from the respective websites of the organizations: www.iso.org, www.ieee.org and www.incose.org (Accessed March 27, 2008).

(1) First, I will argue that the systems engineering approach excludes certain elements from its conceptual representation of systems that are essential for the functioning of sociotechnical systems. (2) Secondly I will argue that the rationale behind this exclusion is based on an understanding of the behavior of its elements and their relations that leaves no space for the "missing" elements. Therefore simply adding the elements is not an option. (3) And thirdly I will argue that because those left-out elements have a vital impact on (the functioning of) the system, a systems engineering methodology that does not and cannot take this vital impact into account is not fit for the practice of designing and managing even just the technical part of sociotechnical systems.

I will start outlining some physical, technical, historical and organizational characteristics of electric power systems in Europe, to provide a background for my analysis.

10.1 Electricity and Electric Power Systems

The convenience that comes with electricity, our daily use, is perhaps most apparent when it fails. In the European electric power system failures leading to outages are rare. Nevertheless outages do happen and provide challenges to an engineering practice concerned with improving electricity supply. With the changes of governance of the electric power systems over the last decades came a change in the physical flow of electricity on the network, playing a role in recent outages of the network. To understand this role I will highlight a few characteristics of electricity and give a short history of the development of electric power systems in Europe.

10.1.1 Physical and Technical Characteristics

(1) Electricity flows at near light-speed velocities. (2) It follows the path of least resistance.[6] And (3) electricity is hard to store. In order to keep the output at the outlet within the small range of voltage and frequency that our electric appliances need to operate, and given above three characteristics, a continuous and near-perfect balance of supply and demand of electricity needs to be maintained. Managing the balance is only possible because the flow of electricity is highly predictable. It will *always* follow the path of least resistance and because we can make a fair estimate of this path given our knowledge of the physical characteristics of the grid, we do have functioning electric power systems of the current scale.

Unfortunately there are some complicating factors in transporting electricity that add to the volatility of the system. (1) The nowadays continent-wide system in Europe has hundreds of millions of individual users switching their appliances on and off following their own intentions. While the general patterns of electricity use are predictable, the precise demand is unknown. (2) Electricity needs a conductor

[6] Technically speaking this should be called impedance, but I will use the term resistance instead for the purpose of clarity.

to flow. In most electric power systems networks of power lines (e.g. metal cables) are used as conductors. These cables have a limited capacity for electricity transport and their resistance will vary with the load on the cable. In order to transport electricity and overcome the resistance, so-called *reactive power*[7] is needed, with can be generated alongside the so-called real power that we pay for. Power lines both produce and consume reactive power while transporting real power, depending on the technical characteristics of the lines and the size of the load. Because of this both the relative and absolute locations of generation and consumption of electricity need to be taken into account when balancing the network. With a change in governance, location became a more important factor.

10.1.2 History and Governance

In less than a century electric power systems developed from local small-scale systems to city-scale and from interconnected cities to nationwide, international and even intercontinental systems (Schot et al. 2003; Liscouski et al. 2004). The initial isolated systems had a relatively simple balance to maintain in terms of the amount of suppliers and clients. Over time engineers built more reliable power plants for generation, more reliable networks and on the demand side a wide variety of artifacts using electricity. They developed tight control mechanisms to govern the balance of the system. Since the task of maintaining the balance is very much contingent on the state of the technology used, these technological advances made it possible to scale up the networks, while simultaneously improving the balance.

The systems were initially governed by vertically integrated utility companies, who generated electricity, distributed it using the network, and sold it to the clients. The electric power systems were controlled from supply to demand by one authority.[8] The utility governed networks were interconnected to be able to draw upon generation capacity from other utility companies in case of local failures. Following an increase in interconnections between networks and between countries, a call for a free market for electricity grew and translated to electricity policy in large parts of Europe and North America. The vertically integrated utility companies were

[7] "Elements of AC systems supply (or produce) and consume (or absorb or lose) two kinds of power: real power and reactive" (O'Neill et al. 2005, p. 17). Already terminology wise this is puzzling, since reactive power is not less real than "real power". I will not explain the difference between this real and reactive power here (you can read (O'Neill et al. 2005) or search the internet for a good explanation). For my analysis it is only important to understand that both these kinds of power are needed to keep electricity power systems up and running, but that we (as consumers) only get billed for the use of real power. Reactive power is needed, for example, to transmit high amounts of real power over long distances. It can be generated, just as real power can be generated, and it can be provided or absorbed locally by respectively capacitors and inductors. Generation, however, is the main source of reactive power.

[8] "For almost a century, electricity policy and practice were geared to the vertically integrated utility. Tradeoffs between generation and transmission investments were largely internal company decisions and, for the most part, out of the public view" (O'Neill et al. 2005, p. 21).

broken up in separate companies for generation, transmission and resale. Subsequently generation and resale did no longer necessarily happen in the same geographically region. This change in governance adds a complicating factor to maintaining the balance.

I argued before that an electric power system needs a near-perfect balance of supply and demand and that demand is unpredictable. When governed by the utility companies both the network and the supply were controlled by one organization, which also signed the contracts with the clients. The companies were in control of the flow of electricity in their local region. Interregional connections functioned as "a backbone for the security of supply" (UCTE Investigation Committee 2004, p. 3). Under new governance, generation, transportation and re-sale became separated entities and trade is internationalized. With this so-called unbundling of the electric power systems, keeping the balance became, virtually overnight, more complicated. Apart from an unknown demand, the unbundling can theoretically lead to an unknown supply as well,[9] because the manager in charge of keeping the balance, i.e. the network manager, is no longer in charge of the power generation. Furthermore, international trade increased long-distance electricity transport, with its earlier mentioned complications concerning real and reactive power. The very cross-border power lines that were built to improve stability functioning as a back-up system were used to first argue for and then practice international trade of electricity.

10.2 The Concept of Boundary in Systems Engineering

The problems that occurred in the European electric power system are not unique to Europe. In the same year when the blackout hit Italy, a similar power outage happened in North America.[10] A couple of years prior to these events, a series of rolling blackouts hit California, just after a change in governance to a deregulated market (Roe et al. 2002). Reports were written analyzing the cascade of technical failures in the different incidents. Next to providing a meticulously mapped out sequence of events, the reports emphasized the role of non-technical aspects in the failures. In the California case, management decisions to withhold generation capacity from the market, seriously and negatively affected the stability of the grid. Following the two incidents in Europe mentioned in the introduction, the respective reports emphasized the importance of the governance of the system for the overall functioning of the system, while simultaneously drawing boundaries around engineering practice: "Although it is not strictly an UCTE[11] competence, clearly, market rules

[9] I say "theoretically" here, but during the California energy crisis in 2000, suppliers intentionally turned of power plants in order to drive up electricity prices, indeed creating an "unknown" on the supply side.

[10] "On August 14, 2003, large portions of the Midwest and Northeast United States and Ontario, Canada, experienced an electric power blackout. The outage affected an area with an estimated 50 million people and 61,800 megawatts (MW) of electric load" (Liscouski et al. 2004, p. 1).

[11] Union for the Co-ordination of Transmission of Electricity.

and incentives tending towards better adequacy are essential" (UCTE Investigation Committee 2004, p. 100). This demarcation of the engineering job, focusing on the technical aspects only, is reflected in the conceptual representation of systems in systems engineering. To understand the rationale for taking certain aspects into account in the systems engineering approach and not others, I will turn to (the use of) the concept of boundary in systems engineering literature. I will use my analysis of the concept of boundary to show the limits of systems engineering with regard to modeling, designing, managing and/or implementing sociotechnical systems like electric power systems.

10.2.1 Boundary in Systems Engineering Literature; Three Distinctions

Sociotechnical systems, I argued, consist of technical and non-technical elements. Most technical elements are composed of matter; they are concrete.[12] Following an argument made by Bunge (1979) that every concrete system is a subsystem of a greater system, with the exception of the universe as a whole, sociotechnical systems are open systems (Bertalanffy 1968). They are in interaction with an environment. An important question raised in systems engineering literature is the question how to demarcate the system from this environment, or where to draw or find its boundary.[13]

While the concept of boundary and the question where to find or draw it are considered important, the systems engineering texts are rather vague in their characterization of the concept of boundary. Following my analysis of the texts I came up with three distinctions with regard to the characterization of boundary in systems engineering: (1) a distinction between physical and metaphorical boundaries, (2) a distinction between demarcating the actual systems from their environment and demarcating possible solutions from impossible "solutions" (the design space), and (3) a distinction between system models and implemented systems.

I will use these three distinctions to point out the rationale behind the choices to consider certain elements (and relations) part of the system or certain solutions part of the design space for the system.

10.2.1.1 Two Kinds of Boundaries

(I) In our everyday life we frequently encounter *physical* boundaries. Usually they refer to things we set up ourselves, like fences, walls or even chalk lines, or they

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[12]Here I use an understanding of technical element that excludes rules on their own, like an algorithm used in software. In order to be a technical element, I argue, these algorithms need to be encoded in concrete, and they need to be executed. In this understanding procedures, prescribing human behavior, can only be considered technical if executed.

[13]". . . the challenge is to understand the boundary of the system, . . . and the relationships and interfaces between this system and other systems" (IEEE 2005).

can refer to natural obstacles, like rivers and mountains. These boundaries are for example used to spatially delineate areas. We can talk meaningful about what is on one side and what is on the other side of these boundaries. While objects can be on the boundary as well, even that is, although sometimes in dispute, fairly obvious.

(II) We also encounter *metaphorical* boundaries. An example is boundaries to what you deem socially acceptable. If someone "crosses the line" with regard to their behavior to you, they cross a metaphorical boundary. Talking in terms of locating this boundary is problematic, since "locating" refers to a spatial framing. Rather we talk about what we think is socially acceptable and what is not, about our understanding of different kinds of behavior.

When it comes to electric power systems we see both understandings of boundary surface. The European electric power system spans different spatially delineated jurisdictions. Within and between these areas we can find physical boundaries, like rivers, mountains and seas. With regard to the resale of electricity we set metaphorical boundaries for the amounts that can be sold between different places. Electricity, however, being physical, cannot be bound by metaphorical boundaries. While electricity became theoretically free to trade on an international level, it is impossible to earmark generated electricity to be delivered to specific clients following specific paths. In practice "[i]t is not unusual that in a highly meshed network, physical flows significantly differ from the exchange programs." (UCTE Investigation Committee 2007, p. 16). To be able to translate a governance based on "free" trade of electricity to a balanced network, the "metaphorical" contractual limits need to match the physical capacity of the network. The metaphorical and physical boundaries to electricity trade and transport are indirectly related.

The question of boundary in systems engineering, I will argue next, concerns primarily metaphorical boundaries, boundaries to what is (or can be) and what is not (or cannot be) part of the system under consideration. Certain elements and relations are explicitly or implicitly considered part of the system or not part of the system.

10.2.1.2 Two Uses of Boundary in Systems Engineering

Within the studied systems engineering texts, explicit references are made to the concept of boundary in two different uses, (I) as system boundaries and (II) as design constraints. This dual use of the term boundary relates to a dual understanding of systems engineering. As argued in (Ottens et al. 2005) systems engineering is understood both as "engineering of (complex) systems" and as a "systems approach to engineering". With this duality of the concept of systems engineering, a similar, and related, dual understanding of the term boundary surfaces in the systems engineering texts.

(I) In an understanding of "*the boundaries of the system*" (INCOSE 2004, p. 200) there is a "(complex) system" or "system under design" that is delineated from an environment by a boundary. Such boundaries manifest on two levels. First we need to address the question what *kinds* of elements can or should be taken as part of the system and which ones as part of the environment? In answering this question we draw metaphorical boundaries. We give a rationale for including or not including certain aspects. I will discuss this rationale in the last chapter, arguing that this rationale limits the kinds of systems that can be modeled and designed using systems engineering not including sociotechnical systems. Secondly we face the question what *particular* elements make up a system. In the case of sociotechnical systems, given their hybrid character, the boundaries of these systems cannot be solely physical. Whether we talk about the system as a conceptual representation or as the actual system it represents, in both cases we encounter metaphorical boundaries.

(II) The second use of boundary can be found in the concept of *design constraints*[14] (sometimes also called external constraints (IEEE 2005, p. 39)). These "boundaries" constrain a "design space". A design space contains solutions to a design problem. Not all solutions are feasible, or legal. Engineers look at what is technically feasible, given economical and knowledge constraints, and they look at what is legally possible, given legislative constraints.[15] The boundaries found here are boundaries to a set of solutions rather than a system. However, in limiting the solutions they can effectively constrain both what kinds of elements and what particular elements can be part of a system.

In my analysis I am mainly interested in the boundaries to the conceptual representation of a system, and the rationale behind drawing these "metaphorical" boundaries. In part, however, the answer to this question is embedded in the understanding of design constraints. I will come back to this after I introduce a third distinction between two uses of the term system (as object of (re)design) in systems engineering, referring to (I) either an (idealized) system model or (II) an existing, already implemented, system.

10.2.1.3 Two Understandings of System in Systems Engineering

The third and last distinction is a distinction between systems that are not yet designed (system models) and already existing systems. This distinction is reflected in the characterization of boundaries in the systems engineering texts. There is a mention of *defining* boundaries (INCOSE 2004, p. 105), which is used next to (or instead of) *identifying* boundaries (INCOSE 2004, p. 200).

(I) The focus in systems engineering is on designing rather than redesigning. Given that systems engineering focuses on both the engineering of systems and on a systems approach to engineering, where in the latter understanding products are engineered, it is understandable that there is a strong focus on design. The question of boundaries in this focus is geared towards including that what we need

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[14] "*Design Constraints*. The boundary conditions within which the developer must remain while allocating performance requirements and/or synthesizing system elements" (INCOSE 2004, p. 278). "The project identifies and defines external constraints that impact design solutions" (IEEE 2005, p. 40).

[15] "These constraints constitute the sociopolitical climate under which commercial or industrial activities are regulated and include environmental protection regulations, safety regulations, technological constraints, and other regulations established by federal and local government agencies to protect the interests of consumers. Additionally, international, government, and industry standards and general specifications constrain enterprise and project activities and design options" (IEEE 2005, p. 69).

for the product to fulfill the function we have in mind for it, meanwhile protecting it from relations with an existing environment that we cannot control. These are the boundaries of a system model.

(II) However, the small products that systems engineering in this understanding caters for contrast with the large sociotechnical systems I introduced in this chapter. These systems have a long history, very specific local implementations, and strong mutual links with their environment. The question of boundary cannot be solely answered by focusing on the proposed, intended or designed function for the system. For one it is unclear what the function of a sociotechnical system is and secondly we cannot shield such a system from its environment. In part the existing implementation follows from decisions about boundaries taken before in designing the system model. But over time new aspects from "outside" the original design came to influence the functioning of the system. By merely resorting to *defining* system boundaries we can overlook influences that do not fit in the original system model.

This distinction and tension between the original system design and its latter use is recognized in the report that was made following the blackout in Italy:

> It must be emphasised that the original function of the interconnected systems is to form a backbone for the security of supply. To this aim the system has been developed in the past 50 years with a view to assure mutual assistance between national subsystems. This includes common use of reserve capacities and, to some extent, optimising the use of energy resources by allowing exchanges between these systems. Today's market development with its high level of cross-border exchanges was out of the scope of the original system design. (UCTE Investigation Committee 2004, p. 3)

The original focus on a robust system laid the groundwork for governance allowing international trade. A management approach sticking to an initial system model fails in the long term for sociotechnical systems. In dealing with sociotechnical systems, we need to understand what aspects play a role besides what, from an engineering perspective, we think should be system elements.

Like the first two distinctions, this distinction between these system models and implemented systems is not sharp. Not one product is designed in complete isolation from previous or other products that are already implemented in a society. However, even in that case the products are designed. When it comes to sociotechnical systems of the magnitude discussed, we do not, or hardly ever, design such systems in its entirety. The question that I will address here is whether a rationale for drawing boundaries "around" a 'system that is not yet designed' holds in the face of these changing sociotechnical systems, in specific whether it includes all elements essential for its functioning and if not whether it leaves room for such an inclusion.

10.3 Function, Control and Design, and the Limits of Systems Engineering

By focusing on the concept of boundary and the rationales behind the decision to take certain aspects into account and not others I will argue three points.

(1) First, I will argue that the systems engineering approach excludes certain elements from its conceptual representation of systems that are essential for the functioning of sociotechnical systems. (2) Secondly I will argue that the rationale behind this exclusion is based on an understanding of the behavior of its elements and their relations that leaves no space for the ‘missing’ elements. Therefore simply adding the elements is not an option. (3) And thirdly I will argue that because those left-out elements have a vital impact on (the functioning of) the system, a systems engineering methodology that does not and cannot take this vital impact into account is not fit for the practice of designing and managing sociotechnical systems or even just the technical part of such systems.

(1) Legislation, pictured as legislative design constraints, is seen as constraining the design space, limiting possible solutions. With this understanding of legislation it is excluded from being an element of the system under design. Nevertheless in the European electric power system changes in legislation pose a serious problem to the technical functioning of these systems. Given the scale and longevity of these systems an approach that merely understands legislation as external overlooks the mutual relation between legislation and technology. An approach to the design of systems with this conceptual understanding of legislation in mind cannot factor in the changes in legislation that might follow from technical implementations and will leave as the only option a redesign of the system after the fact, following suit. As is clear in the case of the electric power systems, this development worries the UCTE. In order to maintain a balance on the network, technical and non-technical elements need to be aligned. The changes in governance put stress on this balance.

In response to this problem (and to my argument) one may include those elements that mutually relate to the technical make-up of the system, elements that are currently not part of the possible system make-up. However, as I will argue next, the rationale behind this decision is based in an understanding of the behavior of its elements and their relations that leaves no space for the “missing” elements. Therefore simply adding these elements is not an option.

(2) To understand the rationale for delineating a system or system approach in systems engineering I turn to the understanding of three key concepts use when drawing boundaries: function,[16] control and design.[17]

10.3.1 Function

Function is a key concept in systems engineering literature. In the INCOSE handbook 42 pages are dedicated to functional analysis, which “establishes what the system must do” (INCOSE 2004, p. 5). In the IEEE standard functional analysis and functional verification make up two of the eight steps of the systems engineering

[16]“Define the functional boundary of the system” (ISO 2002, p. 27).

[17]Regarding a rationale for drawing boundaries the IEEE standard brings up the question: “Which system elements are under design control of the project and which fall outside their control” (IEEE 2005, p. 40).

process. And in the ISO standard the first two steps of the Requirements Analysis Process are “Define the functional boundary of the system” and “Define each function that the system is required to perform” (ISO 2002, p. 27). In the three texts the concept of function relates the different elements in the system. In a functional analysis, the overall system function is hierarchically split up in sub-functions. These sub-functions are in turn translated into specific solutions. The process of functional decomposition as systems engineering understands it hinges on the idea of function as a causal, predictable input-output relation, “expressed in quantitative terms” (ISO 2002, p. 26).

Such an understanding of function leaves little room for, for example, relations involving affection, expectations, reflection and intentionality, human characteristics that are not conceptualized in the systems engineering understanding of humans. Understanding such relations is essential for understanding the functioning of, for example, legislation.

10.3.2 Control

The conceptualization of function as a causal and predictable input-output relation testifies to the focus of the systems engineering approach on controlling the output of their designs. The conceptualization of function as an input-output relation works very well for the modeling and designing of purely technical artifacts where there is a relatively high level of predictability of output given a certain input. The pathways of mechanical devices, their reactions to actions follow laws of nature, and our approximations of these laws give credible predictions. The input-output model works, we can predict very complex technical situations given such models.

The sheer existence of electric power systems is only possible because of a high level of control of the processes involved in producing, transmitting and using electricity. The unknown factors in this process of control come from humans interacting with the system, humans that are “highly complex, with behaviour that is frequently difficult to predict” (ISO 2002, p. 53) and, as became apparent, from changing policies.

In the systems engineering literature it is recognized that humans can be “simultaneously or sequentially, a user and an element of a system” (ISO 2002, p. 52). Whereas in the vertically integrated electric power systems the only “unpredictable” humans were the end-users of the electricity, in the current unbundled system a new unknown factor to the stability of the network is introduced on the supply side. The operators of the power plants can theoretically withhold supply, and during the California energy crisis the operators involved actually did so. They are, however, unlike the users, seen as elements of the system that can be, at least partially, controlled through training and instructions. Instructions for their actions can be designed, like technical artifacts, using the same functional input-output models. The ISO standard correctly remarks that all humans, whether users or operators can be difficult to predict. The difference between humans in their roles of users and humans in their roles of operators is the means available for controlling their behavior.

This relates directly to the second “unknown” factor in the electric power systems, the changing policies and legislation. An understanding of control based on a law-like predictability fails for predicting the “outcome” of policies. Neither can the policies and legislation be controlled in this matter, nor can their effect on human behavior be modeled in such an understanding.

This understanding of control and function forms the rationale for exclusion of users and legislation from the “system under design”.

10.3.3 Design

Given that functional analysis in above understanding of function is central to the systems engineering design approach, it becomes clear that whether something is considered designable, is limited to whether it can be controlled. The emphasis in the systems engineering texts is on design of technology. However, if design is understood broader as “do or plan (something) with a specific purpose or intention in mind”,[18] legislation can be designed as well.[19] While it maybe a different kind of design, it does involve intentional creation. Following the UCTE’s concern about the engineering tasks, we cannot argue that we should do something that we cannot do. However, this does not mean that we can ignore it.

The understanding of the behavior of system elements following predictable input-output patterns, related through output to input based in a strict understanding of function and aiming to control all elements in the system leaves no room for adding elements that cannot be controlled in such a rigid manner. Elements whose function cannot be mapped in input–output relations that fit into technical functional decompositions. Such elements, in the light of this rationale, cannot be designed. A systems engineering approach using this rationale for drawing its system boundaries cannot include the “missing” elements.

(3) Given that in the current conceptual representation of systems in systems engineering the relation between the “missing” elements *is not* (my first argument) and *cannot* (my second argument) be taken into account, I will now argue that the use of the systems engineering approach is inadequate for the modeling, design and management of even only the “technical part” of the system.

Going back to the example, clearly the developments in the electric power system in Europe were not foreseen when the first cross-border connections were made. The influence, however, of this decision to improve the technical stability of the system by growing the network on the new policies are unmistakable. In a system as complex as the European electric power system, an approach focusing on designing

[18] An Oxford English Dictionary definition.

[19] In “A Functional Legal Design for Reliable Electricity Supply” Knops argues for an inclusion of legislation in the design of electric power systems. Legislation, as Knops (2007) argues is both designed and fulfills a function. However, to be able to argue this he stretches the understanding of these concepts beyond the understanding used in systems engineering.

only the technical elements is no guarantee for even just an adequate technical functioning of the system if potential vital impacts of non-technical elements cannot be taken into account.

While the aspects that are beyond their expertise are not completely ignored in the systems engineering conceptual representation of systems, they are relegated to the environment, the representation lacks an adequate understanding of the characteristics of these elements. And with that lack of understanding of the characteristics comes a lack of understanding of the possible relations between the excluded aspects and the elements that are part of the system. Even if the elements themselves are not considered part of the system, their impact on the system needs to be taken into account if that impact affects the technical functioning of the system, which it does in above examples of electric power systems. In the current conceptual representation this "taking into account" can only happen after the facts, following changes in the environment, not including them. This representation focuses on system models rather than existing systems with boundaries to those system based on a rationale of including the known and controllable.

Given the scale and longevity of sociotechnical systems and their hybrid character the current systems engineering approach as laid out in the central texts from the IEEE, ISO and INCOSE organizations is not adequate for the modeling, design and management of sociotechnical systems like the discussed electric power systems, despite their claims to be adequate. Furthermore the perceived limits to the engineers job in the practice of maintaining the electric power system in Europe indicates that despite a difference between engineering theory and practice[20] the limit to the conceptual representation of systems in systems engineering is, at least in this instance, limiting practice as well.

In more comprehensive continuing research I analyze different sociotechnical systems and give a more detailed analysis of systems engineering methodology, extending my argument beyond the case of electric power systems and the concept of boundary.

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[20]Engineering theory is prescriptive, it will give guidelines for the behavior of engineers, analyzing, modeling, designing and managing systems. Engineering practice deals with real-life problems, concrete situations that might or might not fit the conceptual representation at the basis of the prescriptive guidelines. Engineers can and do deviate from theory, taking approaches different from what the theory prescribes.

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