Increasing Systems-Safety by Meliorating Policy-Processes under Conditions of Ambiguity

Analyzing Interdisciplinary Ascendancies of the German Traffic System by Using Cybernetic Hazard Analyzing Methodologies

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ABSTRACT

This paper shows the results of incorporating the MSP (multiple streams perspective) into the cybernetic-based hazard analyzing methodology STAMP (systems-theoretic accident modeling and process) to improve the development-process of policies within socio-technical systems. Understanding policy processes is seen as crucial in improving safety-compliance of policies and thus increase system's safety. MSP illustrates several obstructions to safety-compliant policy making e.g. due to unclear preferences, time restrictions or manipulation. In contrast the application of cybernetic-based analyzing methodologies shows significant improvement in increasing systems' safety, because it generates a deeper understanding of hidden processes and feedback-loops within socio-technical systems. STAMP models control structures of systems' resources, showing the cascaded relationships between interdisciplinary control components, e.g. market actors and policy entrepreneurs. This paper initially focuses on the description of socio-technical systems, MSP and STAMP. Afterwards it focalizes the analogy between MSP and STAMP and subsequently generates a hybrid methodology incorporating MSP into the system's control structure modeled by STAMP. Furthermore the explanatory power of STAMP-MSP is exemplified by analyzing the German traffic system.

Keywords: STAMP, Policy Process, Hazard Analysis, Multiple Streams Perspective, Control Structures, Ambiguity

1. CHALLENGES OF COMPLEX SYSTEMS FOR POLICIES AND SAFETY

Policy within a socio-technical system is seen as a key to sustain system's safety and to control social components within safety-relevant constraints [1]. Recent research has shown that the application of system dynamic models improves the policy process and the intended impact. Some decades ago the adaptation of cybernetics to political science led to partial models of the policy process like "Information Flow in Foreign Policy Decisions " by Karl W. Deutsch which where renowned at due time [2]. Nevertheless political systems and policy processes have diversified and became more complex and those models do not seem to be state of the art anymore. Modern systems have similarly evolved from formerly simple mechanic systems to complex systems with a vast number of components, like hard-, and software, personnel, equipment, environment, functions, procedures, and policies [3,4]. Generally safety can be defined as the absence of undesired events [5], which means it is measurable by its complement, the accident [6].In contrast to this trend the so-called classic hazard analyzing methodologies have not been developed adequately to fulfill the exigencies of complex systems, especially the influence of policies. Methodologies like FMEA (failure mode and effect analysis) or FTA (fault tree analysis) are still based on the assumption that accidents result from chains of events leading to an undesired event, thence all events must be predictable. Breaking these chains consequently will hinder the accident to happen. The primary problem lies in the fact that complex systems cannot be understood thoroughly and that breaking event-chains is not sufficient in order to prevent accidents. [4]

There is a range of developments which abet the systems' complexity and strengthen the need for renewed policies and thus analyzing methodologies. Minding the fast pace of technological change while the range of a product's functions is increasing [7] the period of a product's life-cycle is decreasing [8]. Using software within systems generates new kinds of hazards, which do not stem from mechanical dysfunctions. Nowadays an incremental amount of information is necessary to control a social-technical system. [9] “The operation of some systems is so complex that it defies the understanding of all but a few experts, and sometimes even they have incomplete information about its potential behavior.“ [10] Consequently the less is known about accidents, the more often personnel are accused as the initiators of accidents. [5] Usually human behavior only is reported, if it generates an undesired event. Often humans need to intervene in a system’s operative process if an accident is already inevitable [4]. Ergo tolerance for simplified accident decreases and understanding of an accident must be based on the analysis of the system’s design and not on human failure [11]. Furthermore public opinion tends to force the policy giving institutions to take more responsibility in achieving safety and increase the control of human behavior to more safety compliance, because “[…] safety exists within a complex environment involving interactions between people, equipment, policies and operating conditions.” [1] “Effectively preventing accidents in complex systems requires using accident models that include that social system as well as the technology.” [11] Therefore analyzing safety requires an approach which is capable of identifying the meshed interactions between social and technical controllers. Every social-technical system is influenced by society, psychology, economy and politics. Following the ascendancies on shaping human behavior will be regarded more intensely [12].

Social learning postulates that individuals adopt habits of other role models. These habits may be contrary to policies but legitimated by others. Thus policies almost never get full compliance and the system drifts into an unsafe state [13]. Dulac also anticipates that social systems continuously shift into an unsafe state, because in some way unsafe states are higher rewarded to the social controllers than safe states [5]. This effect is supported by psychological ascendancies on humans within socio-technical systems. Walter [14] introduces a model, which is based on the Law of Effects by Thorndike [15] that can be used for describing the link between stimulus and response of humans. The model separates humans’ behavior into the state of rule-compliant and rule-non-compliant behavior. The non-compliant behavior is kept until it results in a negative response. If a stimulus results in a negative response humans switch back to the safety-compliant behavior [14]. Knowledge of this stimulus-response link is crucial because it forces politics to take this into account while creating safety-increasing policies. Furthermore it strengthens the need for combining interdisciplinary research approaches in order to create a better knowledge about systems and thus develop adequate policies.

In policy-processes numerous concepts and theories exist to explain the process and results of the policy process. These theories deliver conflicting perspectives though. The political sphere is a crucial variable for system-safety since its decisions affect the whole safety environment. In accordance [12] the cybernetic model describes the interaction between the political system and its environment mainly with the simple but established triad of input, throughput and output [12, 16, 17]. On the input side demand and support are generated and progress through the political sphere to meet certain ‘checkpoints’ “ occupied by gatekeepers” [17] who have a major influence on the systems agenda, thus its decisions or policies [16]. The underlying logic of this textbook perspective is the policy cycle that focuses separately on each stage. Input, throughput and output occur at an univocal moment in time involving specific actors and institutions [17].
MSP in contrast presumes that the policy process consists of changing constellations of different actors at different moments in time [18]. This assumption draws upon the “garbage can model of organizational choice”, which was introduced by Cohen, March and Olsen (1972) [19, 20]. Cohen, March and Olsen define choice in organizations as a garbage can into which an alternating set of actors discards solutions and problems [18]. Kingdon applies this concept to the policy process and presumes that those constellations emerge under conditions of ambiguity and with the possibility of political manipulation [20, 21]. MSP thereby assumes that the policy processes is shaped by "fluid participation, problematic preferences, and unclear technology" as Robinson and Eller (2010) underline by citing Kingdon´s key indicators for ambiguous policy processes [22]. The MSP model of the policy process consists of three rather independent streams which are coupled by a policy entrepreneur during open windows of opportunity [23]. The distribution of all necessary information for policy makers is hampered by systemic conditions which refer to a notion of a very broad spectrum of motifs, ideas, beliefs and other patterns of thinking that could be connected to the same phenomena [24]. Neither the epistemic and ontological foundation nor the perception of phenomena as problems or solutions is definite [20, 25].This affects the whole policy process. Problems and solutions are not determined and policy outcomes are utterly variable. Thence the conversion of different opportunities into decisions within a political system is not predictable [20, 26].
Against the background of the increasing challenges within complex socio-technical systems and the conflicting theories of policy-processes, the following chapter will present interdisciplinary perspectives on systems and thus generate a hybrid methodology for gaining a deeper understanding of policy-processes using cybernetics.

2. POLICY PROCESSES UNDER AMBIGUITY: THE MULTIPLE STREAMS PERSPECTIVE

The political system is capable of affecting system´s safety especially through legislation. It sets framework conditions for engineering, education, enforcement, and the economy. The assumption of ambiguity affects the model of the policy process as rationality cannot be improved by more information and policy choice is hardly predictable.

Zahariadis [20] names three assumptions of the MSP. Firstly the difference between serial and parallel attention, respectively processing: serial attention applies to individuals e.g. policy makers who are only able to regard one issue at a time due to the limits of human cognition and other constraints. Political systems in contrast have the possibility of parallel processing.. Secondly time restrictions are an important aspect: issues are non-permanent phenomena. They only remain salient for a certain time until another competing issue raises on the policy agenda. The third assumption focuses on the independence of the streams: The streams within a policy subsystem not only generate different contents but usually do so without considering each other. For example policy “solutions” might be produced even before an issue floats on top of the problem stream.

The implications for the policy process that result from these assumptions are quite unique. First of all it is necessary to consider which should be the level of analysis: Should this be the individual with serial attention and processing or the subsystem with parallel attention and processing. Increasing system’s safety by providing all necessary information might especially be hampered when decisions are made at an individual scale. Secondly policy makers’ shortness of time limits their rationality and problem orientation [26]. Furthermore data validity might not have an impact on policy output if data and policy makers meet at the wrong time. Thirdly to improve system’s safety one needs a deep understanding of how the streams of the policy process are structured.

- The *problem stream* consists of conditions and information that under conditions of ambiguity are neither obvious problems nor have public attention [22, 27]. The mechanisms of attention drawing include indicators, feedback and focusing events. Indicators like the number of deaths on the road or people without health insurance are either periodically published or emerge in single studies. Feedback from former programs highlights best practices as well as failed policies. Focusing events are able to disrupt the dominant pattern of thinking about a problem and thus the erupting policy process. [20] For instance multiple vehicle collisions or other unpredictable fatal traffic accidents might shift the actors' perception and increase the contingency of the underlying policy system. The conversion of such conditions into problems is a genuine political process. Kingdon alleges that problems have a "perceptual, interpretive element" [27]. In addition specialized actors draw policy makers´ attention to a limited spectrum of problems [22].
- The *policy stream* represents a "soup of ideas that compete to win acceptance in policy networks" [20]. These ideas might be "solutions" to one or a set of problems [22] but without an obvious nexus between problem and solution since the streams are independent and problems have an interpretative element. Zahariadis identifies "technical feasibility " and "value acceptability" as "selection criteria" of the policy stream. The selection effects on ideas reach from no change at all to their total disappearance. [20] Robinson and Eller point out that policy selection in MSP is dominated by an elitist set of actors and public opinion is mainly disregarded [22].
- The *politics stream* includes three elements, namely the "national mood, pressure group campaigns, and administrative or legislative turnover" [20]. National mood and pressure group campaigns are important to policy makers since they have to identify which policies are zeitgeisty and will be supported by interest groups. Turnover in administration or legislation change the political conditions in the way that a different set of actors with different beliefs and values might change the value acceptability of some policies. [20]

Policy Windows or "windows of opportunity"[1] are points in time when "advocates of proposals [are able] to push their pet solutions, or to push attention to their special problems" [27]. Policy windows do only open when each of the independent streams functions complementarily. Firstly at certain moments in time a phenomenon must be defined as a problem. Secondly a technical feasible and value acceptable solution has to be at hand and thirdly restrictions within the politics stream must not be too intense. Policy windows are only of short duration independently on whether they have opened from the politics stream e.g. through changes of individual actors or by new problem definitions e.g. shaped by focusing events [27]. Policy windows might be predictable e.g. through elections but can also emerge out of the sudden e.g. epidemics, nuclear or natural disasters [28]. Although those more or less predictable events might provide the opportunity for decisions to be made, MSP assumes another venue for policy change which involves active coupling or joining of the three streams [20, 22, 27]. Individual or corporate actors who are trying to use these windows by coupling of the streams are labeled "policy entrepreneurs". In order enforce policy change policy entrepreneurs try to manipulate policy makers and develop a decision context within which the political framework, problem definition and their pet solution work complimentary [20,27]. Zahariadis 2007 identifies three factors that have an impact on coupling. Firstly access through value compatibility is helpful to convert an entrepreneur´s solution into actual policy. Policy entrepreneurs who have general access to policy makers due to similar values are more successful than others. Secondly the more resources they have to promote their solutions the more successful they tend to be in achieving their goals. Thirdly policy entrepreneurs who are skilled at using manipulating strategies, e.g. salami tactics, framing or affect priming have greater chances of success [20]. In summary policy entrepreneurs that couple streams and open policy windows can use everything that either improves the perceived feasibility of a solution that increases the normative acceptance of a policy and/or that lets a problem appear more urgent.

The multiple streams perspective helps analyzing policy processes on the qualitative level, but it lacks capabilities in quantifying policy processes. Thence the aim of this research is to combine the multiple streams perspective with cybernetics-based hazard analyzing methodology and thus quantify policy processes to certain amount.

3. SYSTEMS-THEORETIC ACCIDENT MODEL AND PROCESS

An appropriate hazard analysis using cybernetics is represented by STAMP (systems-theoretic accident modeling and process), which has been introduced by Leveson. "[STAMP] is a new approach to hazard analysis that enables model-based simulation and analysis of risk throughout the system life cycle, including complex human decision-making, software errors, system accidents (versus component failure accidents), and organizational risk factors." [11] The primary aim of STAMP is to identify adequate safety constraints in systems, which are capable of sustaining safety and hinder accidents to happen. This can be achieved by analyzing all relevant control components, technical and social, within a system and ascertain their direct and indirect control loops. Within socio-technical systems most interactions between human and technical control components are cascaded control loops. The controlled process can be measured by sensors which deliver their information to the automated controller. The controlled process, also named operative process, transforms inputs into process outputs influenced by disturbances. The automated controller adhere a model of the process and a model of the interfaces. In order to conduct the adequate control actions, the automated controller controls the controlled process by the actuator. The human supervisor is located parallel to the automated controller. Thus the supervisor is able to influence the automated controller. The here presented control loop can be translated to the policy process by recoupling the human supervisor and automated controller by the actors of policy processes. In doing so, STAMP offers a further tool, which helps visualizing the relevant controllers. In our model the policy making process itself can be described as the controlled process, inputs from different streams are transformed into legislation. Policy makers function like automated controllers since focusing events or feedback as well as national mood meet their value based "sensors" and their decisions are comparable to the actuators. The policy entrepreneur's influence may lack of a predictable "if-then" function. Nevertheless their more or less successful attempts to frame information and manipulate have an influence on the policy maker´s sensors thus their decisions for instance. [4]

At the center of the STAMP analysis is the safety control structure. It represents all relevant control components involved in a

[1]Windows of opportunity and policy windows are often used interchangeably by MSP scholars like John W. Kingdon [19].

controlled process. The control structure models the in- and outputs of each control component and generates virtual container. These functional relationships of in- and outputs can be quantified by empiric data of the systems. By doing so, the static control structure can be translated into a dynamic system dynamics model which can be simulated. The basic structure of the system dynamics model is defined by the specific control structure. Thus STAMP is able to achieve the following main intentions to increase safety:

- Determining control limits for safe behavior
- Generating awareness of permissible behavior towards human and automated controllers
- Developing of strategies for coping with hazardous states
- Supporting of optimization and adaptation processes on contextual influences
- Admitting fault tolerances
- Ensuring visibility and reversibility of errors
- Liberating decision makers and system's operators of performance pressures [5]

Instead of seeing accidents traditionally as the result of event-chains, STAMP defines an accident as an inadequate implementation of safety constraints within the system's structure. The causal factors of accidents lie within the differing mental models about the system's structure and behavior of the system's controllers. The mental model of human beings can vary significantly to the models implemented within the automated controllers. The result of that are inadequate and conflicting controlling actions. STAMP is capable of analyzing technical and human errors within systems, but also the meshed control actions between humans, hardware, software, organizational factors, sociology, and management. [10]

4. CREATING A HYBRID METHODOLOGY USING STAMP AND MSP

In order to generate a hybrid model melding STAMP and MSP, one must get a basic understanding of how systems are designed and where the basic problems of operating process are located: Systems are generally designed by a system's designer with a certain mental model. Within this hybrid methodology the system's designer is the policy maker, e.g. the legislative authority. The designer develops the original design specifications of a socio-technical system, which is the basis for the manufacturers to translate the designer's mental model into an actual system. The mental model of the designer represents the ideality of a system. Controversy the actual system is implemented in the reality, which makes it a complex system so that a complete anticipation is impossible. Manufacturing and constructions variances generate discrepancies between the designer's mental model and the actual system. The policies are created on the designer's mental model, thus the developed policies do not fit the requirements of the actual systems, because they differ significantly from the mental model of the designer. Furthermore the operators create their own mental models of the system which is based firstly on the operating instructions (policies) and the experience with the actual system. The system's operators are according to MSP the policy entrepreneurs, which are trying to influence also the policy makers (designer) to achieve their own goals. The mental model of the operator is also differing from the designer's model and furthermore does not fit the requirement to understand the whole actual system but a few aspects in which the operator is involved. Thus the operator cannot foresee what consequences the individual control actions may generate at another place in the system. A single decision may be safety-compliant in one context of the system's operation. But at another context it may be hazardous (figure 1).

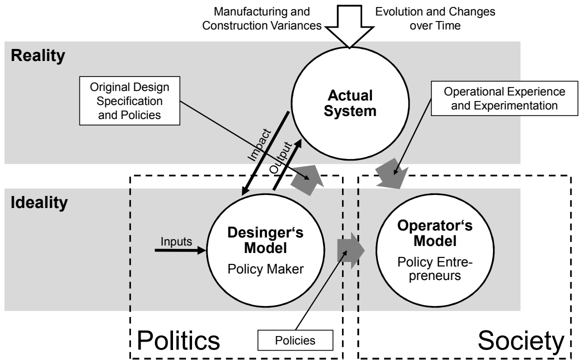

Figure 1: Principles of hybrid methodology, according to [4]

MSP highlights the difficulties of policy making under conditions of ambiguity. In policy processes information is neither "value-neutral" nor an unused instrument for manipulation [20] One principle of STAMP is trying to make all relevant information to each control component accessible. Thus the individual mental models of the system can be updated continuously. Policy entrepreneurs are a crucial analytical figure within MSP and drivers for policy change. The combination of STAMP and MSP helps to understand policy maker's decision patterns and illuminate the consequences of policy processes for systems safety on the basis of a control structure representing all relevant policy makers (system designing control components) and entrepreneurs (system operating control components). In addition to the challenge of an anticipation of consequences of a policy due to complexity and differences between ideality and reality policy entrepreneurs might push a single pet policy which might actually obstruct system´s safety. This is also due to the inadequate mental models by the policy entrepreneurs.

After creating a control structure including all relevant policy makers and entrepreneurs the next step is to identify relevant variables which can be used to develop a system dynamics model of the political system. Making use of system dynamics in analyzing policy processes offers a significant improvement due to the following three aspects: Firstly, system dynamics is based on the feedback approach, modeling the effects of variables on themselves. Secondly, using control structures aggregates the relevant variables to a minimum and focuses on the main ascendancies. Thirdly, the research field of system dynamics provides umpteen simulation tools. By analyzing policy processes the formerly qualitative analysis can be upgraded to a quantitative analysis and hence become more profound.

5. PERCEPTIONS FOR POLICY PROCESSES ANALYZING THE GERMAN TRAFFIC SYSTEM

After describing the hybrid methodology, the next section will show selected results by applying STAMP and MSP on German Traffic Safety. The interdisciplinary ascendancies of the legislative authorities by the various players within the political system can be illustrated by the STAMP-MSP-analysis. The results of STAMP are based on expert interviews.

Analyzing the German traffic system one can identify 11 operative control components, e.g. the individual driver, and in sum 18 system designing control components including the legislative authorities. Within the analysis the legislative authority is represented by the German Politics and the European Union.

The legislative authority is located on the highest level within the policy giving institutions. Located directly under the legislative authority are the public institutions, like the BMVBS (Bundesministerium für Verkehr-, Bau- und Stadtentwicklung), KBA (Kraftfahrbundesamt) and the BAST (Bundesanstalt für Straßenwesen). The institutions take responsibilities for servicing the infrastructure, creating engineering standards, performing research for increasing traffic safety, prosecuting traffic offenders, etc. On the one hand the legislative authority supplies the public institutions with personnel and monetary resources. On the other hand the legislative authority receives information about the status within the traffic system by the public institutions. The basis of any policy is defined by the German Basic Law (Grundgesetz), which is located within the control component engineering standards. Any kind of traffic related policy must be created in accordance to the Basic Law. Minding the policy process under ambiguity, one can see within the control structure (see figure 2) that the processes are underlying lobbying influences. Also the insurance companies, private and professional, execute an influence on the legislative authority. These ascendancies may hinder the policy processes in their effectiveness. For instance the automobile industry does have an interest in bringing new innovations to the market, which may be hampered by regulatory hurdles.

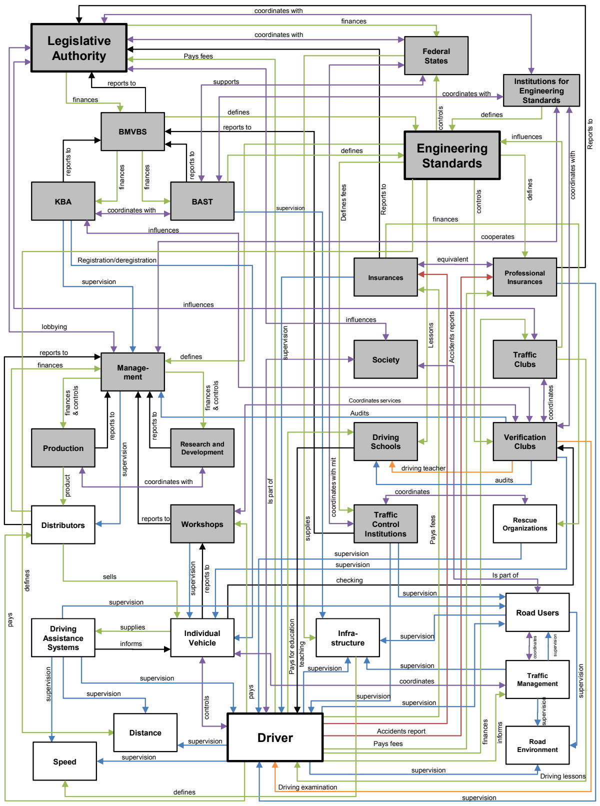

Figure 2: Control structure of the German traffic system, according to [29]

Also the legislative authorities are shaped by society. Minding the multiple streams perspective, different influences do shape the focus of politics to certain areas of interest. This is hard to model due to the numerous aspects having an impact on the attention of politics. Furthermore in Germany, the different federal states do have different policies defining the rules of traffic. Therefore the local influences do also shape policies and have an influence on the policy-processes. One more important aspect about the underlying control structure of the German traffic system is that the legislative authorities receive mostly their monetary resources by taxes which come from the people. But also the citizens do elect the politicians; hence they have an impact on the people defining the policy system.

A crucial part during the hazard analysis by STAMP is identifying missing safety constraints within the control structure. Focusing on the political aspects of the German traffic system one can see that it is mandatory to adapt the policies by the EU. Herein lays a hazard, because the policies of the EU may have a negative impact within the traffic system due to local and/or cultural aspects. Other aspects like the driver education are also hazardous. For instance it is possible to keep the driver license for decades but without any driving experience. There are only mandatory educational provisions at the beginning of a driver participating to the traffic, but no ongoing tests assuring the driver's capabilities.

Another aspect analyzing the control structure is that according to the number of control-relations within the system's structure, the legislative authority is inferior to automobile managements. Even though the legislative authority is strongly connected to other control components within the traffic system, it has just 11 relations to other components. But automobile managements have 13 relations within the traffic system, which are enabling them to perform more control actions influencing traffic safety (see figure 3).

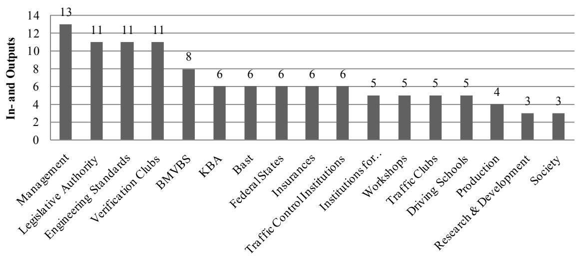

Figure 3: In- and outputs of system designing control components, according to [29]

The inferiority of the legislative authorities exemplifies that politics is hampered performing the optimal policies within the traffic system. But it shows also how interconnected the control loops are affecting safety and policy-processes within socio-technical systems. Furthermore the multiple streams can be visualized by analyzing the meshed relations of the different control components.

6. CONCLUSION

Very little research has been performed in order to analyze and improve policy processes by cybernetics, especially by theory [30]. Based on the MSP the policy process is described as ambiguous and often irrational phenomenon. This paper identifies two main aspects of the MSP that are crucial for a combination of this model of the policy process and cybernetics: the policy entrepreneur (system's operators) and the policy maker (system's designers) that by analogy can be modeled as components in a STAMP control loop structure. Furthermore the findings of this paper have shown that the incorporation of MSP into STAMP produces an enhanced analytical tool for the development of policies within socio-technical systems. We find strong support for our hypothesis that policy is a key variable for system´s safety.. STAMP-MSP illustrates that system designers' and operators' mental models of the system diverge from ideality thus creating a deterioration of system´s safety.

The results on implementing STAMP and MSP on the German traffic system show a strong dependency of policies by the automobile industry. One rationale for this phenomenon within the MSP is the successful use of resources by the automobile industry, which are influencing the policy process. Furthermore the distribution of all necessary information for policy makers is hampered due to a broad spectrum of different motifs, ideas, beliefs and other patterns of thinking. Thence the conversion of opportunities into policies is not determined and influenced by policy entrepreneurs. Modeling and simulating a system by STAMP and MSP can help constraining these effects and therefore increase the logical reasoning of policy processes. The results are based on semi-quantitative analysis (literature research, expert interviews) and must be fully quantified in order to verify the findings. The hybridization between STAMP and MSP shows significant improvement in the understanding of policy processes, especially applying cybernetics to policy-processes. Illustrating the policy process within control structures used by STAMP can help to identify all relevant actors and entrepreneurs engaged in the processes. This hybrid approach based on STAMP and MSP can be used for improving policies within the legislature, management and engineering standards and help increase compliance to safety-critical systems. Illustrating which information must be used for developing adequate policies helps to understand how a system is controlled by its system's resources.

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