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A Case Study in the Application of Design Structure Matrix for Improvement of Policy Formulation in Complex Industrial Wastewater Treatment

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Abstract: Designing effective and acceptable policy is a non-trivial task for decision makers and stakeholders. Especially, policy formulation related to environmental management is still a serious challenge. It requires development of new tools to support better understanding of the complexities involved in addressing problems and finding the best solutions. We believe that using a systematic approach to design public policies helps to model the structure of complex policies, which can drive the whole system structure of organization management towards sustainability. A case study in policy formulation and analysis related to a large industrial wastewater treatment plant in Brazil is presented. The results obtained from the morphological analysis are used in the formulation of policy alternatives through the application of design structure matrix. The results have the potential to further promote the use of modeling tools in the formulation of policies for improvement of policy performance and effectiveness for different areas.

Keywords: policy design, public formulation, design structure matrix, complex systems, sustainability

1 Introduction

The increased complexity of our socio-technical systems confronts us with increasingly difficult policy design problems that are not easily solved (Flüeler, 2006). In modern organizations and enterprises, people must work together and face the need to solve problems and upgrade environmental public policy design (Steward, 2003; Birkland, 2005). These types of problems are rather complex, involving a large amount of tasks and multidisciplinary fields (Eppinger and Browning, 2012), e.g. engineering, architecture, planning and operation management, with internal communications and numerous possible measures (Steward, 2015). One of the major challenges in organizational problem complexes is considered to be sustainable policy design and upgrading policy measures, (Birkland, 2005) which includes for example knowledge designers, planners and policy makers who work with complex tasks (Browning, 2001). It requires development of new tools and modeling to support better understanding of the complexities involved in addressing problems and to find the best solution. Modeling has always been an essential part of organizational design as well as information systems development. Models enable decision makers to filter out the complexity of the real world, so that efforts can be directed towards the analysis of the most important parts of the system. Moreover, in recent years there has been a growing interest in designing environmental public policy, which demonstrates a framework for linking policy design with sustainable development within an organization. This motivates this study to develop a systematic approach that helps to improve the entire system structure of a complex organization.

Within the specific context of this study, the problem is to propose and establish a systematic approach enabling the formulation, design and improvement of wastewater treatment (WWT) public policies for modern enterprises. As both complex systems and environmental policy problems are emerging research areas, still a need exists for research on development of a new integrative approach for designing sustainable environmental public policies for modern enterprises.

The design and development of complex engineering processes, methods and tools requires the expertise of many participants from different backgrounds, leading to the efforts and cooperation of the complex relationship between people and tasks (Yassine, 2004). We believe that by introducing a systematic approach for exploring, designing and improving the alternative policies using a computational methodology that integrates diverse modeling techniques such as: morphological analysis (MA), design structure matrix (DSM), network analysis (NA) and business process modeling and notation (BPMN), we can: (1) Better understand the problem structuring and decomposing into sub problems, (2) Improve analysis and optimization of the process of environmental policy formulation, (3) Decrease the required time for problem analysis.

A case study devoted to policy formulation and analysis related to a large industrial wastewater treatment plant (WWTP) in Brazil is presented. The case study considers the design, procurement, construction and operation of an industrial WWTP. The approach is based on the previously proposed integrative modeling methods, in a way that the integrated approach supports complex problem solving of public policies in WWTP (Buzuku at al., 2015). The research is focused in the application on industrial WWT systems as they are classified as complex systems (Buzuku at al., 2015). An analysis of policy measures for development of policies is carried out based on their internal connection and interconnections as well as their relations/interactions with other policy measures. The optimal combination of policy measures derived from MA is fed into DSM that formulates policy alternatives (clusters) for analyzing the process flow of the dependencies/variables. Thus, a set of policy measures, or cluster, is modeled in BPMN to formalize the description of the integration processes (still under development). The final decision on which policy to implement will remain a crucial task for the decision makers and analysts. From an implementation point of view, the decision makers will decide whether if they may include additional policies or remove some of the recommended ones. We expect the results will further promote the use of modeling methods for policy formulation in different sectors (energy, environment, healthcare, food, water, etc.) that can be systematically employed for decision support systems (DSS). This facilitates modeling procedures in problem solving of complex systems such as those found in environmental policy management.

The document is organized as follows: The background information on policy design is briefly discussed in Section 2. Methodology is explained in section 3. In Section 4 we introduce the proposed approach. The results achieved in the development of the system with an illustrative example are described in Section 5 followed by the conclusions and future work in Section 6.

2 Background on Policy Design

Firstly, it is useful to define the terms policy formulation, policy design and policy tools. A policy is a principle or guideline for action in a specific context (Pohl, 2008), and policy design is the task in which the components of a policy are selected and the overall policy is formulated. The term policy formulation is the development of effective and acceptable courses of action to address items on the policy agenda (Birkland, T., 2005). Within environmental management studies, environmental policies have traditionally been defined as policies, which support the successful introduction of sustainability. Several authors have discussed system engineering approaches and tools connected to policy design and proposed them to solve environmental problems in the early stage of conceptual design. Many of traditional approaches such as Cost-benefit analysis (CBA) techniques and Multi-criteria decision analysis (MCDA) techniques are commonly used in the policy domain (Taeihagh et al., 2014). For example, some aspects of a policy are modeled mathematically. However, decisions about the desirable future also involve social values and political influence (Robinson et al., 2006). We believe that traditional approaches to policy-making is not well suited for solving the 21st century's complex problems. Therefore, further research and development is required. A methodology that supports the identification, design, modeling and evaluation of public policies to tackle complex problems is still missing. This is because existing methodologies and frameworks are not fully developed to deal with the complexity of policy formulation in organizations. A review of existing traditional methodologies shows drawbacks when applied for public policy design of sustainable development in organizations. Therefore, different approaches and tools will have to be used in order to take into account these differences and limitations while introducing avenues for their integration based on the concept of designing public policies (see Buzuku et al., 2015 for further motivations). This paper proposes to systematically apply and combine MA, DSM and BPMN to better facilitate modeling processes in problem solving of complex systems and DSS.

3 Methodology

The methodology consists of proposing an integrative framework for designing a public policy that helps to improve the policy effectiveness, as well as the whole system structure for sustainable management in organizations. The method is based on the organization of policy design in engineering companies exploring and observing legal, technical, financial, social and environmental dimensions from a life cycle perspective.

In this paper a new methodology is proposed by incorporating two or more existing modeling methods in order to encompass all properties and impacts of complex systems. This combines analytical models (i.e. MA, DSM and BPMN) to understand how complex systems operate, model a complex system, how well systems meet overall goals and objectives and how they can be improved (William & Nicoleta, 2014) in order to find the best solution. Therefore, the adapted methodology is depicted in Figure 1, which consists of: Step 1. Policy formulation, Step 2. Design modeling methods and tools, and Step 3. Process of evaluation and validation. This systematic approach enables modeling complex systems that involve a large number of stakeholders and many possible measures connected by multiple domains. Using advanced computer techniques, it is possible to solve very complex computational problems in a large-scale hierarchical model for DSS.

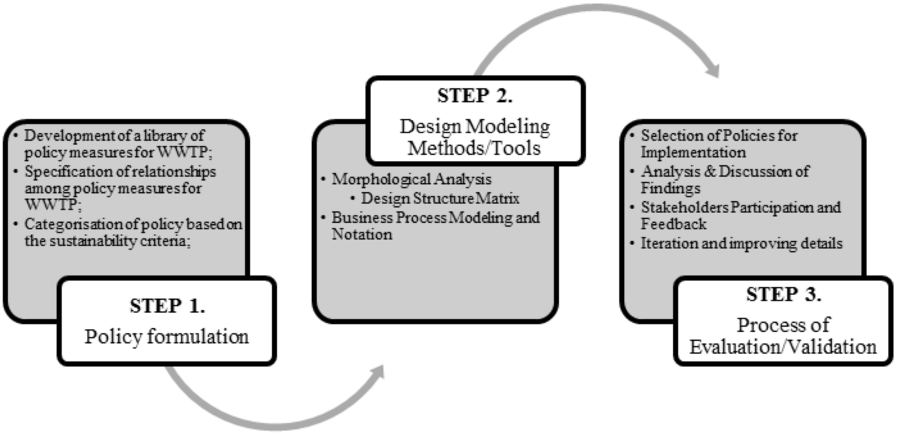

Figure 1. Steps for development a systematic approach for design and improvement of public policy

STEP 1: Many policy measures have been developed to address the multiple environmental externalities of WWT management. The first step of the methodology is to define the scope of the project. The development of policy measures is created in several steps and it is based on sustainability criteria. These steps are: (1) Development of a library of policy measures for WWTP; (2) Definition and specification of relationships among policy measures for WWTP; and (3) Categorization and analysis of the policy-measures based on the sustainability criteria.

STEP 2: A framework to facilitate the policy formulation leading to the effective achievement of its objectives has been proposed and a software system is being implemented using this framework with the purpose of usability for different policy design areas.

1. Morphological Analysis – has been widely used as a general method for formulating, structuring and studying complex problems (Zwicky, 1969). The MA technique is a decomposition method that breaks down a system into subsystems with several attributes and selects the most valuable alternative (Yoon and Park, 2007). MA has been used in many fields: jet and rocket propulsion systems (Zwicky, 1969), computer-aided design modeling (Belaziz et al., 2000), language modeling (Huckvale and Fang, 2002), mathematical modeling (Arciszewski, 1987), technology forecasting (Wills, 1971) and policy formulation (Buzuku and Kraslawski, 2015). In all these domains MA has been a powerful tool for linking and evaluating possible combinations of the variables in the given problem and for establishing an internal structure, based on iterative cycles of analysis and synthesis in a systematic manner.

2. Design Structure Matrix – DSM has been widely used in several contexts, especially in product/project decomposition, and it is considered a consolidated approach to

manage complexity (Browning, 2001). The DSM representation was originally developed by Steward (1981a, 1981b) for the analysis of parametric description of designs (Ulrich and Eppinger, 1995). According to Eppinger and Browning (2012) the diagonal cells represent system elements and off-diagonal cells are used to record relationships among them. The basic procedure of system design using the DSM approach was developed by Eppinger and Browning (2012). Moreover, DSM has been a powerful tool that aids business analysis through visualizing, analyzing, innovating and improving systems including product architectures, organizational structures and process flow (Eppinger and Browning, 2012).

STEP 3: Process of Evaluation and Validation. Selection of policies for implementation, analysis and discussion of findings, stakeholder participation, feedback, iteration and improving details.

4 Proposed approach

This section examines the overall process, giving a brief explanation of each stage at the same time. The proposed approach for managing complexity of environmental policy formulation for industrial wastewater management is shown in Figure 2. It consists of three stages: (i) Policy measure derivation with MA, and (ii) Reorganizing and improving the policy measures in DSM and (iii) application of UML language of policy implementation process.

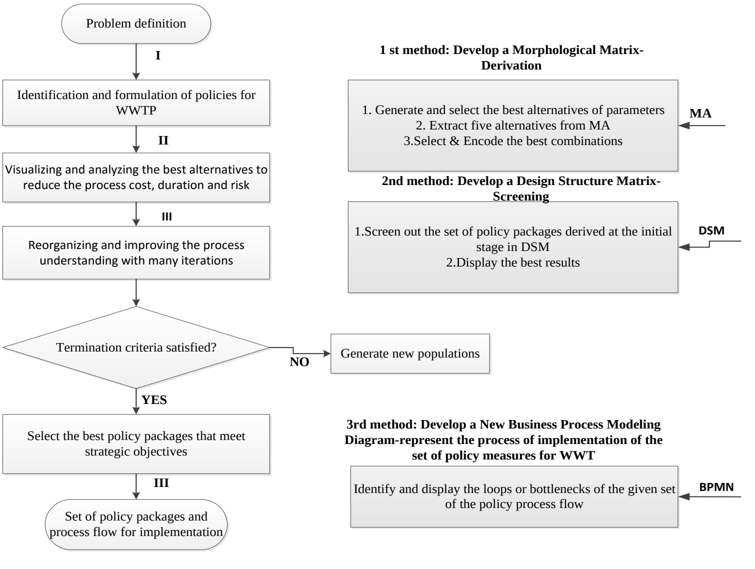

Figure 2. Overall process of using design modeling methods for policy formulation

5 An illustrative example

This section shows the effectiveness of our proposed approach by an illustrative example. Here, a case study related of a large industrial pulp and paper mill for building, construction and operation of a WWTP is presented to show the proposed approach.

5.1 Policy measures derivation with MA

The first stage of MA was conducted with the participation of a panel of domain experts in a two-day workshop that resulted in a policy measure reduction model, which allowed modelers to compare different policy options in terms of sustainability planning and implementation. Figure 3 shows the development of the morphological field with five parameters and their range of values. The problem field includes legal, financial, technical, social and environmental variables. Referring to the above classification, it follows that the morphological field potentially contains a total of 2250 (6x5x5x3x5) distinguishable configurations, which are designated by the matrices [P1V1…6; P2V1…5; P3V1…5; P4V1…3; and P5V1...6;], where all V(s) may be assumed as taking the specific values 1, 2, 3, 4, 5 and 6. In this case, there are clearly too many combinations to enable a reasonable choice. We select P1V1 as independent variable because it shows high potential priority for WWTP according environmental experts judgments. For instance, if P1V1 Environmental Law Conama 20 is selected as an independent variable marked with red, we gain the two sets of results marked in blue as are: P1V1 = P2V1, P3V1, P4V1, P5V1 and P1V1 = P2V1, P3V1, P4V1, P5V3, which is considered to be the best solution of policy measures to create a policy package.

Parameters / Values	P1 Implement Legislation	P2 Water/Effluent Quality	P3 Effluent treatment plant	P4 Capacity building	P5 Monitoring
V1	Conama 20 Requirements – Brazilian Environmental Law	Temperature = 40°C, Settleable solids = 1 ml/1 L	Cooling towers	Training for safety measures in the working place (for all)	River water (Authorities)
V2	EU- BAT Bref (2001)	COD = 8 – 23 kg/ADt, AOX< 0.25 kg/ADt	Oxygen delignification, ECF bleaching	Training for general environmental aspects (for workers at various departments)	Untreated effluent quality
V3	World Bank/IFC EHS Guidelines	Temperature increase no more than 3°C at mixing zone	Extended aeration	Training for operators of the Effluent treatment plant	Treated effluent quality
V4	Parana River Water Quality Requirements (Class II)	DO = 5 mg/l, minimum Turbidity 100 NTU, Maximum	Collecting, control, recycling used clean waters		Groundwater (especially in the surroundings of big tanks)
V5	Water footprint	Separation of uncontaminated and contaminated storm waters	Storage lagoons		Groundwater (especially in the surroundings of big tanks)
V6	Storm water control				Outlet of storm water lagoons

Figure 3. Development of the morphological field with five parameters and their ranges of values

5.2 Input Data

The 25 policy measures identified in the case study of the WWTP project are used to build the DSM matrix. Firstly, the policies are represented and mapped on a 25 x 25 square DSM model (Figure 4), where these policies are listed on the left side of the DSM. Secondly, input and information dependencies between each of the identified policy measures were defined. Three dependency levels between policy measures were identified: low, medium and high according to Yassine et al. (1999). Based on the policy measure dependencies, a DSM graph structure was build and analyzed. Next step, an analysis of the created DSM and optimization of the policy sequence through partitioning and tearing of dependencies within iteration blocks was performed. The screening mechanism was constructed and implemented using ProjectDSM v2.0 project planning software (www.projectdsm.com).

5.3 Analysis and visualization of the policy measures using DSM

Once the appropriate policy measures that comprise a project have been identified based on expert's interviews, they are listed in the DSM as row and column symmetrically. The policy measures relationships within DSM are identified by asking the appropriate group of experts and planners for input, information and dependencies between each of the identified policy measures. The results from the DSM are the formulated policy partitioning and tearing, which in turn are used for the future work on development of business process diagrams. The second stage consists on visualization and analysis of the best alternatives in order to estimate and reduce the process costs, duration time, risk (high, medium, low) and effort (days). The information on cost estimation analysis is still underway and the final results of this step cannot be published yet. Below, each block is visualized separately and independently from the others, which places the most connected elements in the matrix. Figure 4 visualizes the potential partitioning policy process in the matrix. It provides the graphic information on combinations of measures that should be avoided, or at least be considered carefully before implementation.

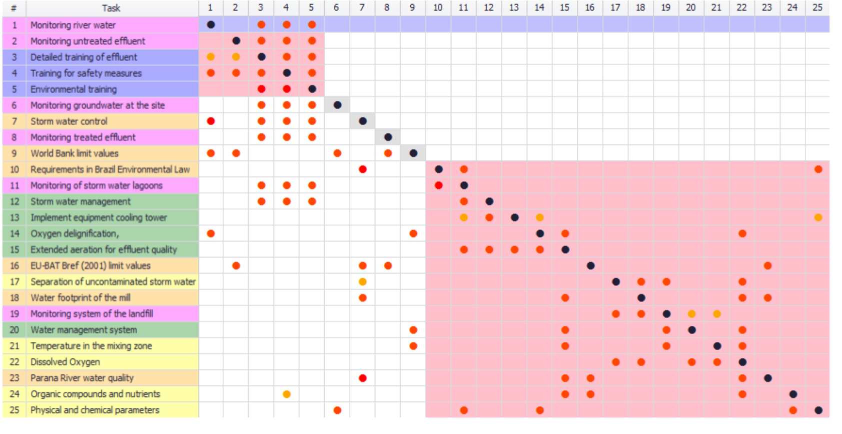

Figure 4. WWTP policy formulation process DSM after partitioning

5.4 Reorganizing, screening and improving of the policy measures in DSM

The last stage consists of the reorganizing, screening and improving of policy process understanding via diverse iterations. A two-day workshop is organized with the participation of panel experts of diverse background and specialization from the project to rate the sets of policy measures with respect to the screening and derive suggestions for improvements of the policy measures for environmental policy formulation. Although numerous criteria have been proposed to screen out or evaluate the policy measures and packages (Givoni, 2014; Taeihagh et al., 2014; Justen et al., 2014), details for a policy package have rarely been revealed with DSM. For this reason, the most critical factors to be considered were identified and analyzed for further improvements in the presence of domain specialists and expert managers involved in the project, who found the defining the process and its sequence of policy was valuable. Figure 5 visualizes the potential simplification of the largest coupled block into two smaller blocks achieved by tearing, which is much more complex. The results were validated in the presence of the panel of environmental experts, engineers and managers that were interviewed. As an example, the 'Requirements in Brazilian Environmental Law' row (10) in the first row of the biggest coupled block is in potential contradiction with four other policy measures in columns (20, 21 and 24, 25) in the inventory, taking the top position from both methods in MA as well as in DSM. This shows the highest priority among the other policies in MA and it is found to be unplanned iterations in the DSM model. In the discussion with experts and managers, the focus was directed to policy row (10) for reorganizing and improving the process flow of policies. However, this process highlighted some unexpected planned and unplanned iterations, and we embarked on addressing each of the unplanned iterations revealed in the DSM model.

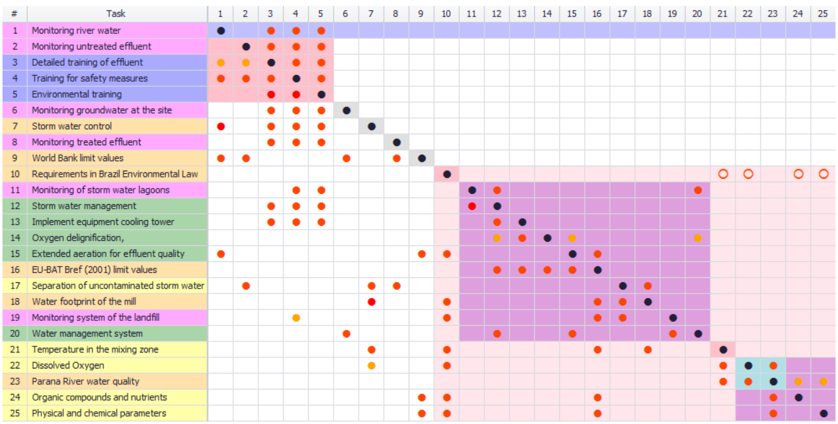

Figure 5. Simplification of the second largest coupled block was achieved by tearing two dependencies

6 Conclusions and Future Work

We proposed a new systematic approach for generation and improvement of policy formulation process in WWTP, which consisted of two stages: the possible combinations of policy measure derivation with MA and policy measure screening and improving in DSM. The MA has been used to structure and assess possible policy alternatives. Next, the obtained results have been applied in formulation of policy alternatives using DSM. The proposed approach can be effectively and efficiently used for managing complexity of environmental policy formulation for industrial WWT management. The results proved the usefulness of the approach in a real case study. A set of policy measures were derived at the first stage by exploring all possible combinations of the morphology matrix, and the second stage dealt with reorganizing, screening and improving the policy process understanding with many iterations. The effectiveness of this systematic approach was demonstrated by an illustrative example. The obtained results show the possibility of use of MA and DSM in formulation of policies applicable to management of complex systems. The result shows the potential of applying DSM to significantly improve the development of policy alternatives, accelerate the design of policies and improve the entire system's policy structure for sustainable management in organizations. As a future work we plan to enhance the generation and evaluation procedures and further improve the process implementation using BPM via BPMN (as well as input data to the MA and DSM).

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