

Network-centric Policy Design

By

Araz Taeihagh

Full reference:

Araz Taeihagh, (forthcoming). Network Centric Policy Design, *Policy Sciences Journal*, accepted. Doi: 10.1007/s11077-016-9270-0

Link to published article:

<http://link.springer.com/article/10.1007%2Fs11077-016-9270-0>

<http://doi.org/10.1007/s11077-016-9270-0>

Network-centric Policy Design

Araz Taeihagh

School of Social Sciences, Singapore Management University, 90 Stamford Road,
Singapore 178903, Phone: +65 6828 0627, Email: araz.taeihagh@new.oxon.org

Abstract – Two important challenges in policy design are better understanding of the design space, and consideration of the temporal factors. Moreover, in recent years it has been demonstrated that understanding the complex interactions of policy measures can play an important role in policy design and analysis. In this paper the advances made in conceptualisation and application of networks to policy design in the past decade are highlighted. Specifically, the use of a network-centric policy design approach in better understanding the design space and temporal consequences of design choices are presented. Network-centric policy design approach has been used in classification, visualisation and analysis of the relations among policy measures as well as ranking of policy measures using their internal properties and interactions, and conducting sensitivity analysis using Monte Carlo simulations. Furthermore, through use of a decision support system, network-centric approach facilitates ranking, visualisation and selection of policies using different sets of criteria, and exploring the potential for compromise in policy formulation. The advantage of the network-centric approach is providing the ability to go beyond visualizations and analysis of policies and piecemeal use of network concepts as a tool for different policy design tasks to moving to a more integrated bottom-up approach to design. Furthermore, the computational advantages of the network-centric policy design in considering temporal factors such as policy sequencing and addressing issues such as layering, drift, policy failure and delay are presented. Finally, some of the current challenges of network-centric design are discussed and some potential avenues of exploration in policy design through use of computational methodologies, as well as possible integration with approaches from other disciplines are highlighted.

Keywords: policy design, networks, policy patching, policy packaging, policy mixes, visualization, virtual environment, decision support system, computer-aided design.

1-Introduction

While policy design is essential and is increasingly understood as a critical factor in policy success or failure, it is surprisingly little studied (Marsh and McConnell 2010; Bobrow 2006; Howlett 2010). Howlett (2014) argues that from the mid-1990s, political science and public administration scholars have shifted their focus away from policy design as a research topic to the study of institutional forms and alternative governance arrangements. Fortunately, in the last decade there has been a resurgence in calls to develop approaches that allow a deeper understanding of policy design, and special attention has been focused on policy measures and their configurations in the formulation of policies (Majone 2006; Taeihagh et al. 2009a; Howlett and Lejano 2013). The understanding of what makes good policy design has shifted from a “one goal – one instrument” approach, to addressing more complex policies and use of tools in the new “multiple goals – multiple instruments” paradigm that often aims at addressing multiple goals through use of a variety of policy instruments (Howlett and del Rio 2015; Taeihagh et al. 2013, Givoni 2014).

It is now well understood that in policy design generic solutions should be avoided and there is a need to consider a range of context-specific feasible options (May 1981). In this context, two particular challenges in policy design are: gaining a better understanding of the design space (better exploration of the combination and interaction of various design alternatives), and temporal factors (e.g. sequencing of policy measures, analysis of the dynamics of policy implementation and their potential for failure). Howlett (2010) argues that establishing the nature of the design space is crucial and he draws attention to the

need for a full consideration of both substantive and procedural measures in design¹. Taeihagh et al. (2009a) draw attention to the size of the design space and the fact that often decisions about what to include in policies are made manually, highlighting that as a consequence a large portion of the design space is left unexplored. They advocate the development of systematic approaches and tools for the exploration of design spaces and the generation of policy alternatives, as well as consideration of the diversity of preferences of different stakeholders using computational methodologies, with the aim of accelerating policy-making, and improving policy effectiveness and acceptability. Furthermore, with the recent developments in crowdsourcing, it might be possible to address some of the challenges involved in acquiring data and judgments, and the uncertainties surrounding this process which is an important development for policy design and analysis. Use of crowdsourcing also has the added benefit of increasing citizen engagement in policy-making. Such engagement has traditionally been limited in the policy formulation phase (Prpic et al. 2014a, 2015; Aitamurto 2012).

In this paper the advances made in conceptualisation and application of networks to policy design in the past decade are highlighted through development of a network-centric policy design approach. The remainder of the paper is structured as follows. In Section 2 background information on the challenges due to complex interaction of policy measures in policy design studies is provided. The latest advancements in network-centric policy design are presented in Section 3 and Section 4 outlines how network-centric design can help in addressing temporal factors in policy design. Section 5 highlights some of the

¹ Substantive policy measures directly affect the production, consumption, and distribution of goods and services while procedural policy measures modify or alter the nature of policy processes used in the implementation (Howlett 2010).

challenges network-centric policy design presents, and it also indicates future avenues for research into network-centric policy design. This is followed by some concluding remarks in Section 6.

2- Policy Measure Interactions and Policy Mixes in Policy Design

Gunningham et al. (1998) highlight the importance of utilizing the full range of policy measures and avoiding unnecessary duplications and conflicts in policy design research. This issue is becoming increasingly important as experts have access in the design space to increasing numbers of policy measures, which can have multiple types of interactions (Taeihagh et al. 2009b), and even larger numbers of possible combinations of them. This problem is further exacerbated by time and resources constraints, which result in inertia and a tendency to explore only a limited number of alternatives (Kelly et al. 2008, Jones et al. 2009). As such, Givoni et al. (2013) stress that a deep understanding of the interrelationships between policy measures is as important in policy formulation as a thorough knowledge of the policy measures themselves.

Howlett et al. (2014) point out that over time, and since the 1950s, researchers have articulated a series of principles to help promote better and more effective policy designs. Undertaking a consideration of combinations of policy measures, instead of implementation of individual policy measures, is increasingly recognized as helping to achieve complementarity among policy measures and to avoid redundancy and contradictions (May and Roberts 1995, Grabosky, 1995, Feitelson 2003, Howlett et al. 2006, Taeihagh et al. 2009a, Hou and Brewer, 2010). In case of existing policies in place increasing efficiency and effectiveness in policy mixes can be achieved through patching and restructuring of the existing policy elements or through packaging in case of

developing new alternatives (Howlett and Rayner 2014). Givoni et al. (2010, page 4) defines a policy package as “a combination of individual policy measures, aimed at addressing one or more policy goals; a package is created in order to improve the impacts of the individual policy measures, minimize possible negative side-effects, and/or facilitate the interventions’ implementation and acceptability”. Justen et al. (2014) point out that although policy packages cannot solely be created based on formal procedures, it is widely acknowledged that to formulate consistent and implementable policy packages reference to some form of strategic process is needed.

In this new “multiple goals – multiple instruments” paradigm, with the increased understanding of the complexity of policy problems, there are rarely shortages in possible options to consider. Rather, the opposite problem of having too many avenues and options to explore is prevalent. However, there is a disconnect between this new understanding and access to adequate tools and techniques to facilitate the development of alternative policies with varying costs, risk and complexity, and better understanding of the trade-offs between them. Taeihagh et al. (2009b, 2013) introduced the possibility of a broad use of network concepts in policy design to facilitate addressing some of these shortcomings. In the next section the use of networks in policy design is discussed².

² Unlike in policy design, networks have been used extensively in policy studies for the examination of policy actors and communities (e.g. Rhodes and March 1992, Hermans and Cunningham 2013). These forms of network analysis (Freeman et al. 1991, Wasserman and Faust 1995) are an important tool for the systematic description and analysis of relational dimensions in politics and society (Schneider 2005). Moreover, with recent advancements in network science (Newman et al. 2006, Milo et al. 2002, Boccaletti et al. 2006) and with the innovative applications of networks in assessing issues such as policy capacity (Craft et al. 2013, Middlemist et al. 2013) the use of networks analysis is becoming even more popular. It must be pointed out that the use of a policy networks approach has not been free from critique. These critiques range from criticizing the policy networks approach for not paying attention to factors that motivate policy actors, to the charge that they are descriptive rather than explanatory, and metaphorical rather than theoretical (John 1998, McPherson and Raab 1988, Dowding 1995, Jenkins-Smith and Sabatier 1999, Peters, 1998).

3- Network-centric policy design

Howlett (2010) provides a summary of the work of policy design pioneers in the 1980s and 1990s. These pioneers argued that policy design, like other kinds of design, such as manufacturing and construction, involves three fundamental aspects: gaining knowledge of the basic building blocks (policy measures), in order to construct policies; using a set of principles to combine the building blocks, in order to create structures (policies); and understanding how these policies can be turned into realities. Taeihagh et al. 2009 (a,b) demonstrated in detail the parallels between process design and policy design, and discussed how some of the advancements in design thinking, such as extended use of conceptual design and computer-aided design principles in process design, can be adopted and/or adapted to policy design.

Moreover, it has been made clear that any design activity, regardless of the quality of its implementation, can be done well or poorly depending on the capabilities of the designer, the available time and the available access to appropriate information and resources (Howlett 2010). In the design process it is important to use visualizations and to record the decision rationale. In the policy domain, approaches based on issue-based information systems (IBIS) (Rittel and Webber, 1973) have been demonstrated to provide such capabilities (e.g. Shum et al. 2006). Moreover, certain problem-structuring methods (Mingers and Rosenhead 2004), such as the combined use of conceptual mapping and system diagrams for complex problem-structuring in policy analysis, as used by Van der Lei et al. (2011), incorporate visualization and implicitly record some aspects of the design rationale by highlighting how the policy instruments are perceived to affect

subsystems and achieve outcomes, while taking into account interactions and externalities.

In network-centric policy design focus is shifted away from the traditional use of network analysis in examining a network of actors and the interactions between them (as examined in detail by Burt (1980) and van Waarden (1992)), towards the policy measures considered for addressing policy problems (Taeihagh et al. 2009b, 2013). In Taeihagh et al. (2013), which discusses network-centric policy design, networks were used in: (a) the definition and classification of the relations between policy measures; (b) the visualization and analysis of the networks of relations between policy measures (with policy measures as building blocks (nodes) of the networks); and (c) the ranking and assessment of policy measures using a network-centric multiple-criteria decision analysis (MCDA)³ approach. More recently, other applications of networks in policy design have been demonstrated, through their use in the formulation, selection, and visualization of policy packages in decision support systems. Here networks have been used both for the visualization of policy measure relations and policy packages, and for exploring the potential for compromise through negotiation in the selection of policy packages (Taeihagh et al. 2014, Taeihagh and Bañares-Alcántara 2014). These approaches are briefly highlighted in Sections 3.1-3.4 as part of a network-centric policy design.

³ Multi-criteria Decision Analysis is a method used for comparing different alternatives using different criteria to help the decision maker towards a judicious choice through application of a set of techniques and procedures for structuring the decision-making process (Roy 1996).

3.1 Definition and classification of policy measure relations

Taeihagh et al. (2009b) identified five types of mutually exclusive relations among policy measures: precondition, facilitation, synergy, potential contradiction and contradiction (Table 1 provides a definition of each relation type). The five types of policy measure interaction defined were deemed to be sufficient to capture the relations between policy measures. However, it is possible to consider additional types of interactions and take into account the strength of interactions if the experts choose to define them⁴. In subsequent use of the policy measure relations types that were defined, experts have used various combinations of these relation types, given the context and their preferences.⁵

Table 1: Description of policy measure relation types

Relation Type	Description
Precondition (P)	Defined as a relation that is strictly required for the successful implementation of another policy measure. For instance, if policy measure B is a precondition to policy measure A, the successful implementation of policy measure A can only be achieved if policy measure B is successfully implemented beforehand. The precondition relation is a direct relation.
Facilitation (F)	In a case where a policy measure ‘will work better’ if the outcome of another policy measure has been achieved, the relation is considered as a facilitation relation. For instance, policy measure B facilitates policy measure A when policy measure A works better after policy measure B has been implemented; however, policy measure A could still be implemented independently of policy measure B. The relation is also directed.
Synergy (S)	A special case of facilitation relation in which the ‘will work better’ relation is bidirectional (undirected relation). It can be argued that such a relation can be treated as a two-way facilitation; however, we believe that treating this relation as a separate type is advantageous, as it suggests a higher effectiveness of both of the policy measures having the synergetic relation vis-à-vis the overall policy.
Potential Contradiction (PC)	A potential contradiction exists between policy measures if the policy measures produce conflicting outcomes or incentives with respect to the policy target under certain circumstances, hence the contradiction is ‘potential’. This relation is undirected.
Contradiction (C)	In contrast to the conditional nature of potential contradiction, the contradiction relation is defined when there are ‘strictly’ conflicting outcomes of incentives between policy measures. Similar to the potential contradiction relation, this relation is undirected.

Source (Taeihagh et al. 2013)

⁴ The term expert in this paper refers to policy-makers, domain specialists, or analysts.

⁵ Givoni et. al. (2010) and OPTIC (2010) used two types of relations preconditions, and synergies/facilitations (as an interchangeable single type); Givoni et al. (2013) and Justen (2014) used three policy measures types of precondition, synergy/facilitation (interchangeable), contradiction/potential contradiction (interchangeable); Matt et al. (2013) used precondition, synergy, facilitation and potential contradiction; and Taeihagh et al. 2014 (a,b) and Champalle et al. (2015) have used five types of policy measure relations defined so as to capture the interactions between policy measures in different capacities such as building frameworks and methodologies, or for analyses or visualizations.

The classification of the relations among pairs of policy measures is carried out by the experts involved and stored in an adjacency matrix. This adjacency matrix is multi-relational, and is capable of storing the different types of relations among policy measures as they are mutually exclusive. To store the relations among n policy measures and form a network, an n by n adjacency matrix is created, in which each element represents a relation between the corresponding row and column nodes. An edge, which can be directed or undirected, exists between two nodes a and b if element (a,b) of the matrix is equal to 1 (an element being 0 indicates there is no edge between a and b if element (a,b)).

Theoretically it is possible to have a more nuanced definition of the relations among policy measures and to better capture real-life interactions among them by assigning weights to the edges in the network and define the strength of the relations. It might be possible to justify certain interactions among policy measures, particularly when those measures have a technological or economical nature (more likely to be quantifiable). However, justification of the relations among measures in their entirety (the whole network structure) and the extent to which a relationship can be quantified, e.g. the degree to which facilitation can increase effectiveness, is questionable. Nevertheless, if models exist or are developed that can provide these estimates, or if the experts involved are confident in their assessment of the effects of policy measures on each other (for instance, when only a handful of measures are being considered and modeled in detail), such information should be considered (Taeihagh et al. 2014).

The task of classifying the policy measure relations can be carried out individually or in a group setting. However, since complex relations often exist between the policy

measures, and it can be difficult at times to clearly distinguish the relation type, using a collective decision-making procedure will be beneficial as it can increase the robustness of the analysis.

The classification method requires the analysis of only two measures at a time, independent from the rest of the policy measures in the inventory, thus simplifying the task for the analyst. An iterative approach, whereby at least one iteration is performed for the identification of each type of relation by each member and then shared in group setting, is important for correct identification of policy measure relations. Group members can exchange their views on policy measure relations and can better identify inconsistencies and errors and make more informed decisions in regards to the relations. Furthermore, evidence shows that if more information is explored by group members, better information exchange can take place (Larson et al. 1994; Wittenbaum 2000). This is in line with the concept of collective learning as through this process analysts are better able to understand policy measure relations and to develop a collective understanding of the options analyzed (Camagni 1995). Furthermore, it is known that splitting the decision-making into two components – information search, followed by integration and decision-making – helps ensure that more relevant information is shared and used in the group decision (Brodbeck et al. 2002).⁶

⁶ It is important to point out that the group decision-making literature mainly focuses on how alternatives are selected, rather than on how groups learn about and examine relationships between different alternatives. The method proposed requires discussion among group members. A method such as Delphi can be used to decide the relations among particular measures or to examine key properties for policy measures. However, discussion which seeks to understand and analyze the policy measure relations is important. Given the number of policy measures considered in relation to modern policy problems and the tendency to reach quick agreement on known solutions it might be useful to use support systems in order to manage the information. Using a facilitator might also be helpful. We believe studies examining various approaches, such as the ones highlighted for expert group decision-making in the classification of policy measures, need to be carried out in the future, in collaboration with psychologists.

3.2 Policy measure analysis and visualization

Based on the policy measures defined and classified in Section 3.1 it is possible to visualize policy measures (nodes) and policy measure interactions (edges), and to form policy measure networks. Aside from the main aim of analyzing the policy measure networks, visualizations of policy measure relations serve as an additional means of checking the integrity and validity of the defined policy measure relations. The multiplex⁷ network of policy measure interactions formed in the previous step provides an overall view of network interactions and can be decomposed into individual networks that only entail a single type of relation (through decomposition of the multi-relational adjacency matrix).

After classification of the pair-wise relations among policy measures and formation of the policy measure networks it becomes possible to examine the interactions of policy measures as a whole. For instance, the most central policy measures in the precondition network, which have a considerable effect on other policy measures, can be identified.⁸ The approach helps in identifying and visually presenting the policy measures that act as enablers for many other nodes (i.e. they make their implementation possible, if they are implemented beforehand) and for the most demanding nodes (i.e. those that require implementation of other policy measures beforehand for their successful implementation). In addition, when examining facilitation or synergy networks for addition to the policy mix, policy measures that may have limited effect and that are

⁷ Multiplex networks are sets of nodes that link to other nodes with more than one type of relation (Wasserman and Faust, 1995).

⁸ The centrality of a node is a measure of its importance or influence in a network (Freeman 1979).

disjointed from other potential synergistic policy measures can be identified and dropped from consideration (Matt et al. 2013).

3.3 Policy measure ranking methodology

Hollingshead (1996) demonstrated that groups instructed to rank order the alternatives, compared to groups instructed to directly choose the best alternative, were more likely to consider all of the alternatives and their trade-offs, to exchange information about unpopular alternatives, and to make the best decision. Furthermore, given the limited availability of time and resources it is difficult to consider all possible policy measures when building new policy packages. Therefore, similar to choosing appropriate initial conditions when solving complex mathematical equations, it is important to choose appropriate policy measures in order to start formulating policies.

Assessing policy measures for the formulation of policy packages can be done using a variety of frameworks and methodologies (May and Roberts 1995, Banister et al., 2000; Feitelson, 2003; OECD 2007, Taeihagh et al., 2009a; Givoni et al., 2013, Taeihagh et al. 2013). The proposed network-centric approach discussed in this paper – and various interpretations and/or applications of it as part of new decision-making frameworks (OPTIC 2010, Givoni et al. 2013, Matt et al. 2013, Justen et al. 2014, Champalle et al. 2015) – are unique in their explicit consideration of policy measure interactions as part of the decision-making procedure.

A network-centric multiple-criteria decision analysis (NMCD) (Taeihagh et al. 2013) ranking approach aids in systematically considering and ranking a large number of policy

measures, and examining their trade-offs. The results of this analysis can assist in determining which policy measure or set of measures to implement first. The proposed network-centric policy measure ranking and analysis methodology consists of the following stages: composition of the inventory of policy measures of various types (regulatory, technological, economical, exhortation, etc.); definition of the criteria for analysis (qualitative or quantitative, given the context); definition and classification of the policy measure interactions; visualization and analysis of policy measure networks; and ranking of the policy measures to select policies for implementation. The ranking is based on the policy measures' internal properties and their interactions.⁹ Policy measures might be assessed across a single (precondition) network or across multiple networks (taking into account preconditions, synergy and facilitation networks and the negative consequences of potential contradictions and contradictions among measures) and using a single or multiple context-specific criteria set(s) (e.g. effectiveness and efficiency of policy measures). The differentiating factor of this approach, which sets it apart from traditional MCDA approaches, is consideration of the policy measure network information in the assessment of policy measures. For instance, when considering the precondition network as part of NMCDA, when considering the cost of a policy measure, the total cost equals the sum of the cost of the policy measure and its preconditions (since a policy measure will only work if its preconditions have been implemented), or when considering various timescales of implementation, the total time required for implementation is the sum of the implementation time of a policy measure and those of

⁹ Givoni (2014) points out that, unlike in network theory and network analysis, when ranking the individual policy measures the interest in policy formulation is in the policy measures themselves and not the network. Therefore, using various indices commonly used in network analysis is not as valuable for the ranking of policy measures. The information provided from a network analysis of policy measures can be better used in order to understand the interactions and to design policy packages.

its preconditions (assuming sequential implementation of preconditions, as a general assumption that all of the preconditions can be implemented in parallel cannot be prescribed).

The ranking score of a policy measure in a set is calculated using Eq.1 (a measure with a higher score in a criterion set is the top-ranked policy measure vis-à-vis the criteria). The first term on the right side is the score of the measure vis-à-vis the desirable criteria (for a desirable criterion, a higher value is preferred, e.g. higher effectiveness), and the second term calculates the score for the undesirable criteria (for an undesirable criterion, a lower value is preferred, e.g. lower cost). The final ranking score of a policy measure in a policy measure network is the weighted summation of the different criterion sets considered. It is possible to further aggregate the results from the ranking of measures in different networks if the experts deem this to be defensible and logical.

$$\text{Score of policy measure } k \text{ in a set: } S(k) = \sum_{j=1}^d \left(\frac{c_{k,j}}{\sum_{i=1}^p c_{i,j}} \times w_j \right) + \sum_{j=1}^u \left(\frac{\frac{1}{c_{k,j}}}{\sum_{i=1}^p \frac{1}{c_{i,j}}} \times w_j \right) \quad \text{Eq.1}$$

where:

d : Number of desirable criteria

p : Number of policy measures

$c_{i,j}$: Score of the policy measure i with respect to criterion j

w_j : Weight assigned to criterion j

u : Number of undesirable criteria

This approach was later extended for comparison of alternative policy packages using performance and complexity criteria sets in Taeiagh et al. (2014) and can be applied for policy patching for visualization, ranking and analysis. It can also later be used in virtual

environments if the network of policy measures in place, along with potential measures that are being considered for patching, are all mapped and analyzed using the methodology described earlier.

3.4 Virtual environments for policy design

One of the main challenges of policy packaging is the assessment and evaluation of large amounts of information. Capturing and processing this information is difficult (McKee 2003). In many modern policy studies the initial list of policy measures (the inventory) reaches over 100 policy measures, and these policy measures have complex interactions with each other and with policy goals, as described earlier. This issue, combined with the fact that policies are often designed manually without any systematic use of decision aid tools, makes the task of policy design more difficult. Furthermore, it is also known that the “bigger” the problem (in terms of spatial scale, number of policy objectives, etc.), the greater the likelihood that policy packaging will be beneficial (Givoni 2014).

Taeihagh et al. (2014) and Taeihagh and Bañares-Alcántara (2014) highlight advancements in the development of a virtual environment for the exploration and analysis of different configurations of policy measures using a network-centric approach to examine a range of plausible alternatives. The virtual environment uses the internal properties of the measures, policy measure networks, user interactions and user preferences, and integrates various methodologies, such as conceptual design, MCDA, and network analysis with agent-based modeling to build policy packages and to test the effects of changes and uncertainties when formulating policies.

By using virtual environments in policy formulation it becomes possible to better understand the complex interactions of policy measures, to analyze a larger number of alternatives at a greater depth, and thus to explore a larger portion of the design space (Taeihagh et al. 2014). Furthermore, it is possible to scale up and further explore alternatives in the design space in parallel, at no cost to the user. The system makes it easier to obtain access to information about individual policy measures and their interactions in different policy measure networks, and allows real-time assessment of alternatives, which makes it possible to provide feedback to policy-makers on the effects of their decisions (changes to the configuration of policy measures in the formulation of policy packages). This, ultimately, can assist in the process of formulating more effective policies with synergistic and reinforcing attributes, whilst also avoiding internal contradictions.

Furthermore, in the virtual environment networks are used for visualization of policy packages, representation of their structure and characteristics (e.g. through different user-defined criteria sets, such as performance and complexity criteria), and the policy measures they contain, through two-mode networks.^{10,11} At each stage, when designing policy packages and with every change in the configuration of packages, the performance of the different policy packages is re-evaluated and compared, and updated, through various graphical representations (networks, charts, time-series). This information is

¹⁰ In two-mode networks two sets of node types (in this case, policy measures and policy packages) constitute the nodes of the network and a relation type (edge) that connects the two types of nodes. In Taeihagh et al. (2014) the two-mode network demonstrates the policy measures selected by each policy package. Furthermore, the characteristics of policy packages based on the number of policy measures they connect to (policy measures they have selected) can be illustrated by adjusting the size of this node type (e.g. if total cost is being represented the size of the package node will be bigger if it costs more).

¹¹ Provision of access to information during discussions (rather than relying on memory) has been demonstrated to be beneficial in decision-making (Sawyer 1997, Sheffey et al. 1989).

presented to the user to inform the decision-making process and to help them to understand and compare the consequences of their decision regarding policy packages.

3.5 Integration of various components

Figure 1 depicts the integrated use of the approaches highlighted in Sections 3.1-3.4 as part of the network-centric policy design approach.

The initial phase of the network-centric policy design is composition of the library of policy measures and the definition of the criteria for differentiating among the policy measures and the characterisation of the policy measures and the definition and classification of the relations between policy measures. Following the creation of policy measure network, it is possible to use this information to visualization and analyse the interactions of policy measures and assess the performance of the policy measures using the user defined criteria through NMCD. This information can then be used in a decision support system to facilitate visualisation, analysis, ranking of alternative for policy packaging (as well as policy patching in case existing policies as well as new potential instruments under consideration are mapped and analysed). Moreover, the decision support system can facilitate conducting sensitivity analysis, examining the potential for compromise, and providing real-time feedback to user during the design process.

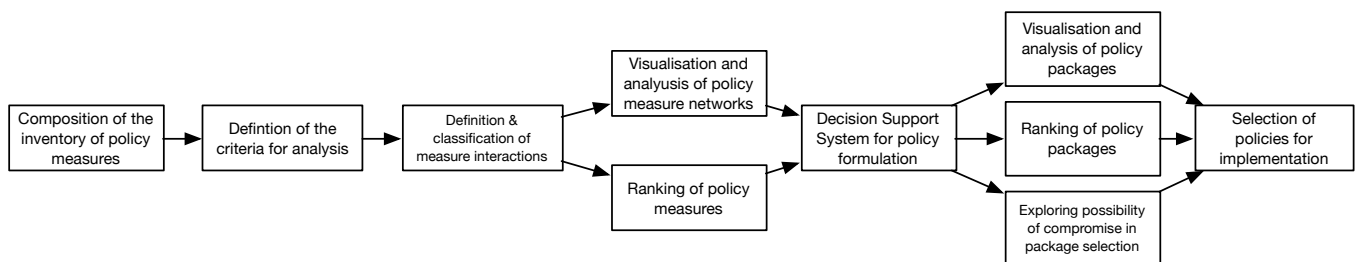


Figure 1: Network-centric policy design, its components and stages

Figure 2 is an alternative view that shows how using networks as a core concept in this network-centric methodology makes subsequent layers of analysis possible, and it demonstrates how a sequential combination of these design stages can be helpful when carrying out the next stages of the analysis. The nodes (policy measures) are first identified and characterised and then their relations are examined to form the edges. This results in creation of networks of policy measures. These networks can then be visualized, analysed and used for ranking of policy measures and the outcomes from these analyses are taken as input for the virtual environment for exploring alternative configurations of policies. Ultimately through these conscious and systematic analyses the author argues the likelihood of reaching a more integrated, consistent and synergistic overall design increases.

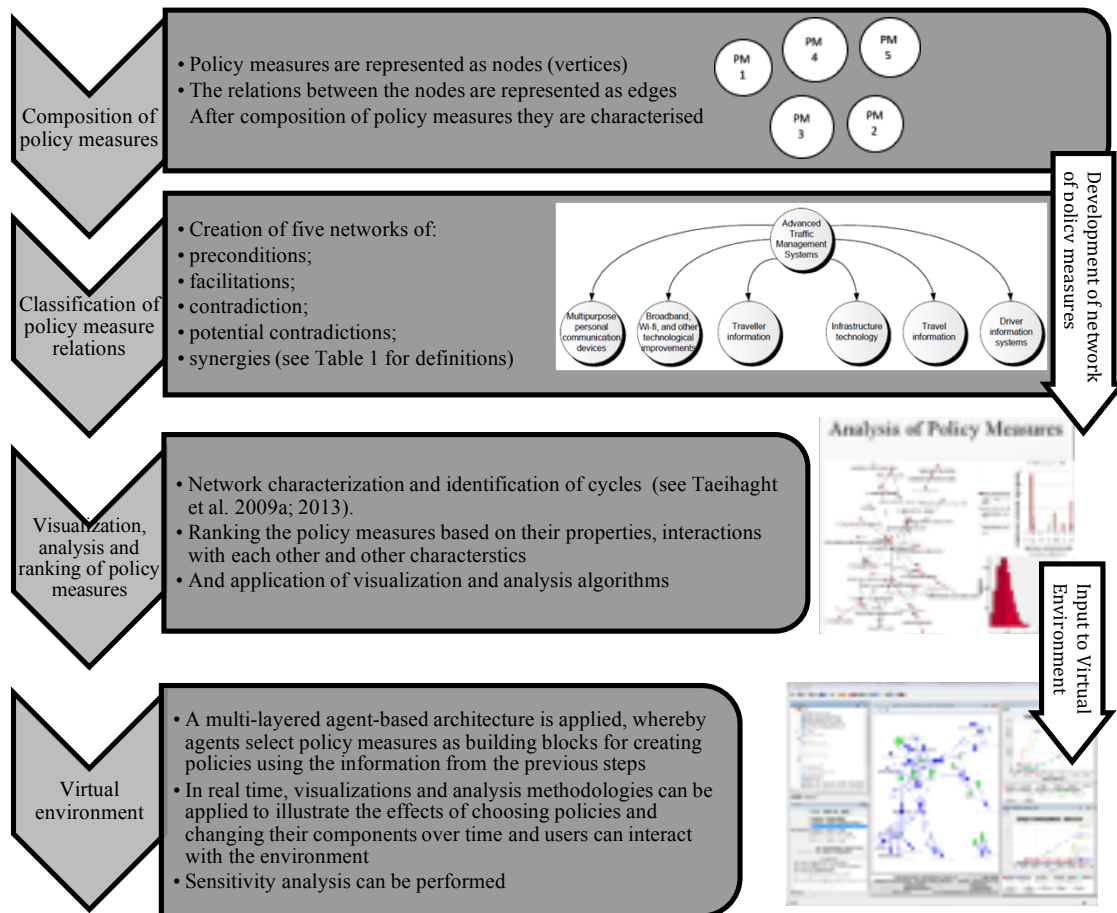


Figure 2 Integration of network concepts in policy design

4- Addressing temporality through network-centric policy design

In the previous section various uses of networks in policy measure ranking, packaging and virtual environments were briefly highlighted. Whether one is dealing with existing policies or developing new designs, a network-centric approach can be used to address temporal factors in analysis, visualization, ranking and simulation of the policies under study.

Except as regards the case of new designs in new policy areas, Howlett et al. (2015) highlight the rich literature in policy design that demonstrates that it is very common for

policy measures and goals to be added to existing policies in place without abandoning the previous ones (layering) or changing policy goals while policy measures remain unchanged (drift). Phenomena such as layering and drift often develop over a long period of time and result in incoherence amongst the policy goals and/or inconsistency with respect to policy measures in the case of layering, and inconsistency with respect to changed goals and ineffectiveness of policy measures in achieving them in the case of policy drift (Orren and Skowronek 1998; Rayner et al, 2001; Thelen, 2004; Hacker 2005; van der Heijden, 2011; Carter 2012). As such, designers resort to packaging or patching to address these shortcomings, depending on the possibilities available for new designs or restructuring (Gunningham and Sinclair 1999; Howlett et al. 2015). Network-centric design can be useful in both patching or packaging. In the case of patching the first step is to map the current policy measures and goals in place and to examine them for layering and drift. Then it can be decided whether patching is possible or packaging is needed in order to improve their consistency, coherence and congruence (Howlett and Rayner 2007; Kern and Howlett 2009).

Carrying out a sophisticated examination of temporal factors in modern policies is challenging (Howlett and Goetz 2014) because of the complexity and wickedness of those policies and due to the challenges present in the examination of alternatives and validation of the outcomes, as well as the lack of stopping rules (Rittel and Webber, 1973). Nevertheless, given the non-linear and often complex interactions of policy measures and policy goals, along with interactions with actors, subsystems, and externalities, the use of causal maps, system diagrams and networks are beneficial as they can facilitate the elaboration and recording of the rationale for design choices, and the communication of

non-linearities, and they can increase transparency and address the complexities involved (Conklin 2005; Taeihagh et al. 2009a; Hermans 2011, Van der Lei et al. 2011, Aldea et al 2012, Taeihagh et al. 2013 and Hunt et al 2013). To demonstrate this point a simple two-mode network depicting the interactions of policy measures and policy goals is presented to demonstrate the benefits of visualizations in identifying and illustrating potential inconsistencies. Figure 3 depicts an example of a conceptual network of policy goals and policy measures in a precondition network, depicting temporal relations among policy measures. Figure 3-a depicts an intended policy that over time, due to the effect of layering (Figure 3-b shows the contradiction between the policy goal and policy measures, Figure 3-c shows the contradictions between the old goal and the new goal) and drift (Figure 3-d shows a number of policy measure being orphaned as goal 2 is no longer a part of the policy and instead goal 4 has been introduced, with a new set of policy measures¹²), needs to be patched (Figure 3-e) or packaged (Figure 3-f), in order to address the inconsistencies.

¹² Orphaned policy measures might even contradict the new goal and policy measures.

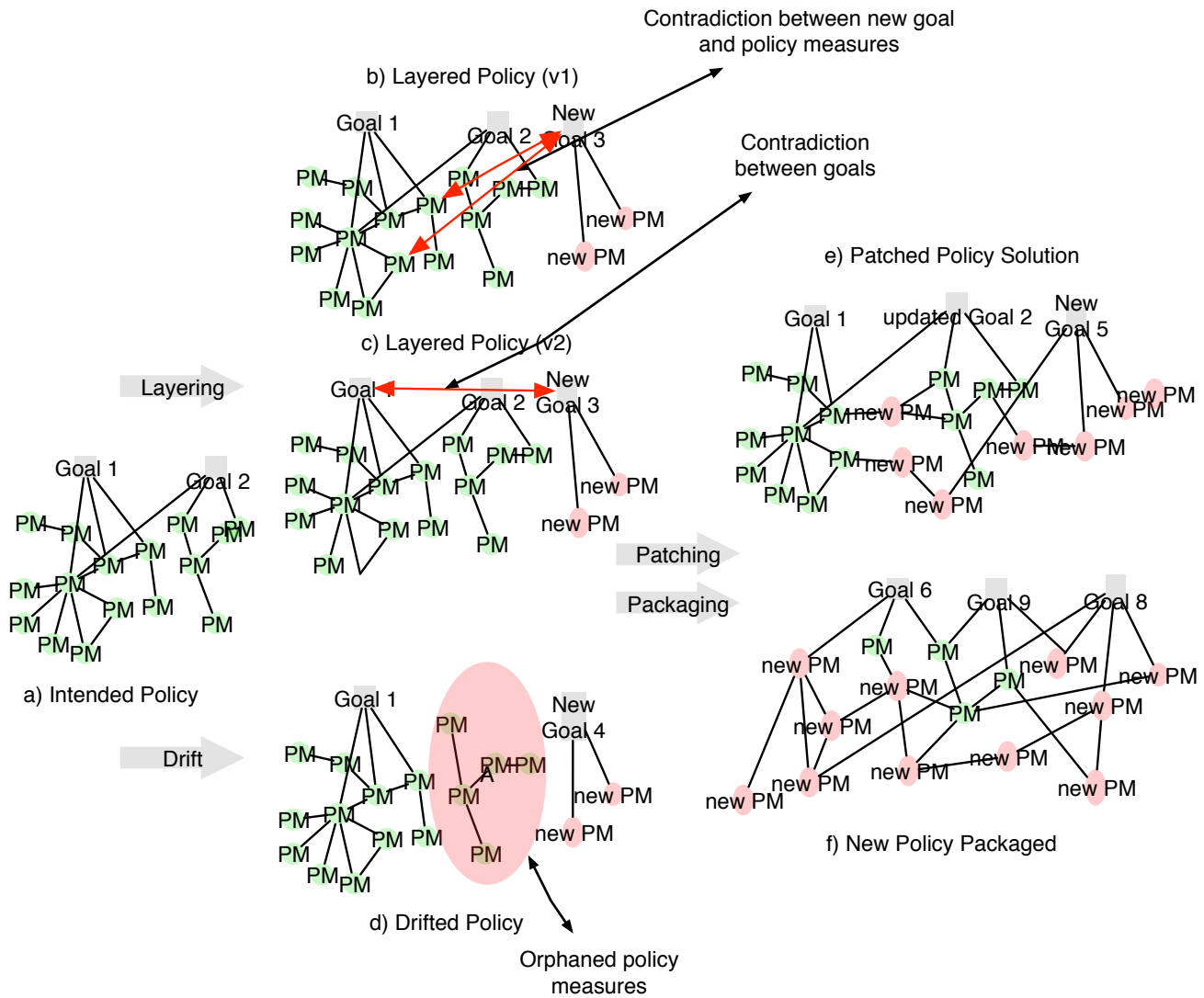


Figure 3 – Conceptual example of a two-mode network of policy measures and goals illustrating shift from intended policy (a) due to policy layering (b and c) or drift (d), and patching (e) and packaging (f) to address them.

4.1 The computational advantage of a network-centric approach in exploring temporality

This paper is not the first attempt to introduce computation in policy design thinking.

Scholars have previously focused on combining networks with multiple-criteria

decision-making using a variety of other approaches (Saaty 1996, Hanne, 2001, Fenton

and Neil, 2001; Watthayu and Peng, 2004, Montibeller et al., 2005, Aldea et al 2012, Hunt et al. 2013). The advantage of a network-centric approach to policy design as described in this paper is the ability to go beyond visualizations, representations and analysis (mostly in causal diagrams) of policy concepts and piecemeal use of networks as a tool for different policy design tasks, and to apply a more integrated bottom-up approach to design.

In network-centric thinking designers can take a more conscious approach, in which policy measures form the core of policies and have complex interactions with other policy measures and/or with goals, and actors in various network structures, which allows systematic use of computational methodologies. Furthermore, these computable network structures are expandable and extendable, and can benefit from methodological advancements in other disciplines (described in the next section). A network-centric approach facilitates more nuanced temporal analyses, which include:

- a) Sequencing – Precondition networks, which are temporal in nature, have been used to demonstrate the use of algorithms in exploring the sequencing of policy measures and the order of implementation in a manner that allows for a greater number of future options for policy measure selection and implementation (Taeihagh et al. 2009a, 2013) and that allows for more dynamic thinking, by taking into account the changes that might take place over time and considering possible avenues for more easily making future adjustments and tweaking policies. Aside from considering the preconditions required for successful implementation of policy measures that are relevant in sequencing and making

sure policies are successful, explicit consideration of synergistic and facilitations among policy measures (in policy packaging) and with instruments already in place (in policy patching) can help to increase the efficiency and/or effectiveness of policies and their success over time (e.g. by considering potential contradictions, institutional complexities and public unacceptability).

- b) Exploring policy failure and delay – A myriad of factors can lead to policy failure, such as inaction, policy myopia, delayed action or wrong action due to incomplete information and uncertainties about the future (Walker 2000, Nair and Howlett 2016). Although better collection of information and calculation of risks and uncertainties can be achieved through increased efforts in this regard, when dealing with policy design, unknown unknowns and black swans are always a possibility (Taleb 2007, Walker et al. 2013). Once a policy is patched or packaged, depending on the circumstance, using virtual environments, such as in Taeihagh et al. 2014, it is possible to explore the consequences of policy failures and delays in regard to the formulated policy, regardless of the cause. Such explorations can be useful in identifying the critical components of a policy and trying to change or reinforce them with ancillary measures to increase redundancy and resilience (Figure 4 illustrates a conceptual example), or choosing the better alternative when faced with multiple viable choices.

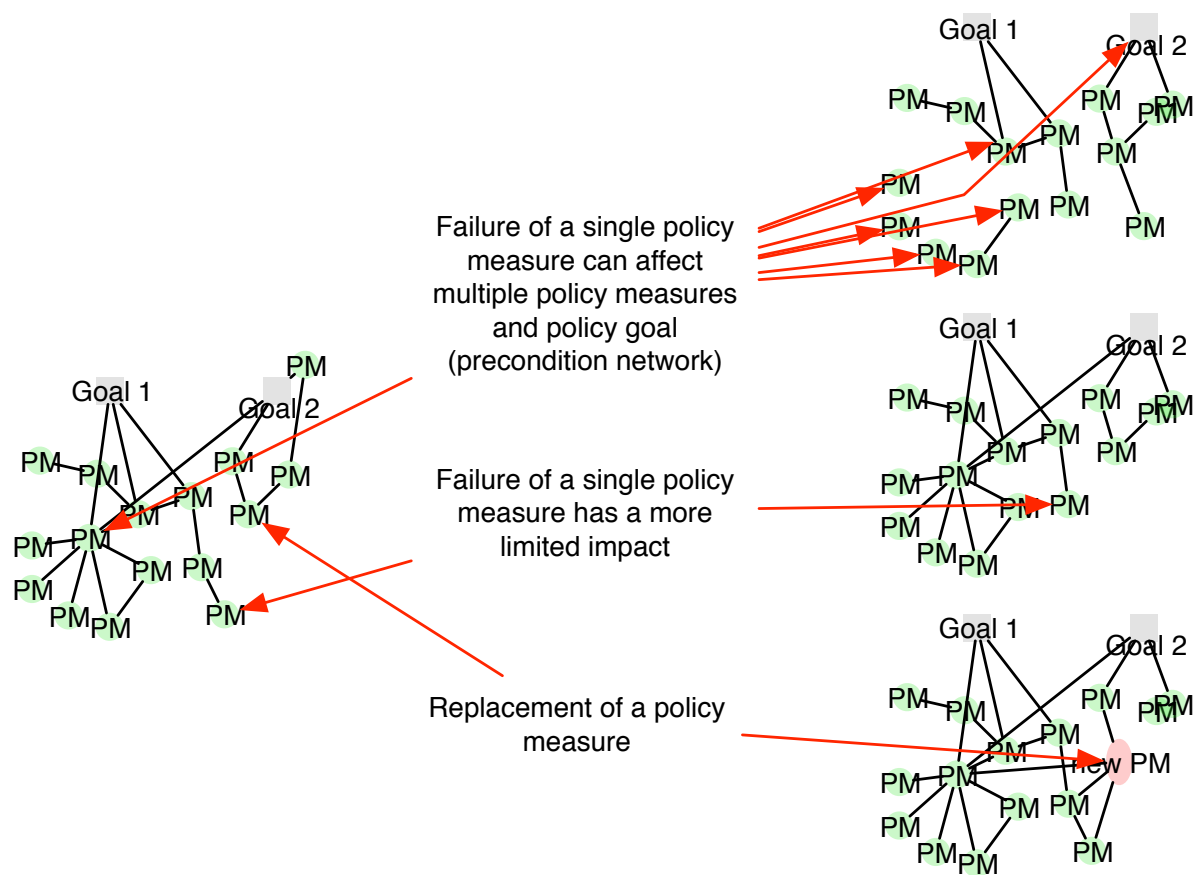


Figure 4 Exploring policy failure and delays in a policy

Furthermore, in complex multi-goal multi-actor settings by mapping actor networks and connecting them to policy measure networks through two-mode networks it is possible to explore the impacts of shifts of power, coalition building, conflicts etc. on the implementation success of policies over time. Previously this was done by considering criteria such as institutional complexity or public unacceptability, but through examination of these networks more directly it becomes possible to visualize and measure the strength of individual actors and their ties and centrality, and how the dynamics of these actor networks might affect the policies positively or negatively in a variety of scenarios. For instance, it is possible to improve the likelihood of policy success by implementing measures that are supported by a larger number of actors and

avoiding issues and measures that could result in conflict and contradictions in future scenarios in which a shift of power occurs.

- c) Monte Carlo simulation and sensitivity analysis – As discussed earlier, incomplete information, biases, errors in judgment and uncertainties can result in policy failure. This problem is more pronounced when there are competing goals and criteria, and large numbers of policy measures or scenarios under consideration. In network-centric policy design it is possible to use the computational advantage and test the effect of these issues on the policy outcomes in advance using sensitivity analysis and Monte Carlo simulation. The effects of errors in defining policy measure relations and the assigned weights for ranking criteria for policy measures have been explored (Taeihagh 2011). In this study, in order to understand the effect of such errors on the overall analysis, sensitivity analysis on the defined relations in the form of a Monte Carlo simulation with 10,000 iterations was performed. The error rate assumed was the upper-bound limit in defining the relations. Policy measure relations were manipulated randomly and the resulting outcomes from the rankings were compared with the original data. The results from the Monte Carlo simulation demonstrated the robustness of the ranking system.

Alternative use of sensitivity analysis was later explored in policy package rankings using the virtual environment created and for exploring the potential for reaching a compromise in the selection of policy packages (Taeihagh et al. 2014; and Taeihagh and Bañares-Alcántara 2014).

d) Scale-up, real-time performance evaluations, and user interaction – Virtual environments make it possible to explore a larger number of alternative policies in the design space in parallel, at no extra cost and furthermore make it possible to focus on a single policy and to explore alternative configurations to gain real-time insights. This is especially useful considering the difficulties of judging the effects of changes in policies and the attributes of the policy measures when complex interactions exist. Furthermore, another benefit of using virtual environments given the limited time and resources available, complex interactions among policy measures and the vast amount of available (but not readily accessible) information is the ability to explore the consequences of changing decisions in real-time. This makes it possible to anticipate the effect of changing or enhancing policies over time by adding or removing policy measures and exploring whether the selected policy measures still perform well vis-à-vis the policy goals. It has been demonstrated this use of virtual environments for identifying and visualizing the “sweet-spots” for policy packages in terms of the size of policy measures to include and stopping rules, by examining the policy package performance and implementation complexity given the number of policy measures selected (Taeihagh et al. 2014).

Furthermore, when faced with existing policies, such as the ones shown in the conceptual example presented in Figure 3, use of the virtual environment can aid the users’ understanding of choices and developing user interactions can highlight policy layering or drift or warn of the consequence of certain actions that can lead to these phenomena when patching policies.

5 Challenges and future avenues for research

The advantage of network-centric policy design lies in its integrated bottom-up approach to design through the use of network concepts. However, using such an approach requires a high level of analytical policy capacity. Policy capacity is the ability to organize required resources to make intelligent decisions and to set strategic directions for the allocation of these resources to benefit the public (Painter and Pierre 2005). This analytical capacity, however, varies significantly in different countries, and across governance levels and sectors (Wu et al. 2015).

As such, the availability of policy capacity has a direct impact on the possibility of using more sophisticated approaches – approaches that can in turn affect the quality of policy outcomes as they improve the capability in regard to analyzing problems and recommending policy solutions. Policy designers need be able to use these new approaches, and have substantive knowledge of the specific policy domains and subsystems. However, the challenge of changing practice is substantial, as switching to more advanced approaches in policy design involves a high level of transaction costs as it often requires overcoming political and institutional barriers, and access to staff that are specialists in the use of sophisticated tools and techniques or the ability to access training to acquire these skills (Milgrom and Roberts, 1990).

Moreover, a network-centric approach is most useful in complex settings that can benefit from the use of computational and analysis capabilities. In such instances, as explained earlier, it will be beneficial to conduct rigorous psychological studies to identify how to

best collect expert judgments regarding a large number of policy measures, their interactions and characteristics, while avoiding groupthink (Janis 1982).

The work presented in this paper has set forward a number of original ideas in regard to the use of networks in policy design. The work can be enhanced and expanded in future by focusing on:

- Collective intelligence

The experience of developing a virtual environment and the use of artificial intelligence for policy design demonstrates the challenges of acquiring data for a large number of policy measures and the uncertainties surrounding their properties and interactions. The approach taken by Taeiagh et al. (2013) for coping with this challenge was to create an inventory of measures and to scale down the number of policy measures for full consideration through internal consultation and discussion within organizations. The use of artificial intelligence in concert with recently developed collective intelligence techniques might have the potential to address some of the data acquisition challenges. As with any new technology, initial expectations for collective intelligence approaches are high and already promises are being made about the potential efficacy of crowdsourcing in areas such as urban planning (Seltzer and Mahmoudi 2013) and transportation policy (Nash, 2009).

As the current use of crowdsourcing in policy design and analysis is extremely limited, Prpic et al. (2014a, 2015) have called for the exploration of the use of crowdsourcing and have suggested the development of novel frameworks and experiments for exploiting the

power of crowds in addressing policy issues (Prpic et al. 2014b,c). They suggest that future avenues for exploration should include examination of the potential new roles for expert and non-expert crowds in policy cycles and the integration of crowdsourcing with decision support systems. In network-centric policy design, crowdsourcing has the potential to be used in: (a) the identification and expansion of the inventory of policy measures; (b) the characterization of policy measures properties through information gathering; (c) the classification of policy measure interactions; and (d) the assessment and evaluation of formulated policies. One of the benefits of using crowdsourcing for these activities is the ability to increase the number of participants (expert or non-expert) and thus increase the speed of carrying out these activities relative to traditional approaches (such as organizing and conducting workshops or carrying out offline surveys¹³) as participation in, and the use of, crowdsourcing becomes more popular.¹⁴ In addition, as discussed earlier, another avenue for exploration is direct integration of the decision support system with crowdsourcing through Application Programming Interfaces (API) to facilitate data and judgment acquisition from expert and non-expert crowds through online platforms

- Automation

A complementary approach to the use of collective intelligence for addressing information gathering challenges is the use of text-mining. Text-mining is defined as the discovery and extraction of non-trivial and interesting knowledge from unstructured texts

¹³ Even in the case of online surveys the speed at which a worker can carry out a micro-task is much faster than an online survey (Taeihagh et al. 2014c).

¹⁴ Expert crowdsourcing mainly through competition-based platforms and non-expert crowdsourcing through the use of virtual labour markets. Open collaboration platforms provide access to both expert and non-expert crowds but require a more sustained effort in attracting and maintaining crowds.

(Kao and Poteet 2007). Bicquelet and Weale (2011) and Krishen et al. (2014) have demonstrated the potential and pitfalls of text-mining in the analysis of large-scale online consultations and consumer feedback in health and transportation policy, respectively. In network-centric design text-mining can be used for automated identification, characterization and classification of nodes (policy measures) and edges (policy measure relations) from text (academic papers, governmental reports, etc.). Furthermore, ontologies (Uschold and Gruninger 1996) can be used in the virtual environment as they provide formal, machine-readable and explicit representations of knowledge and they have the ability to represent concepts, their properties and relations, the use abstraction, and support reasoning and inference. This transition can be achieved by the development of ontologies for the specific domains under study (e.g. transport and environmental policy).

- Better coupling of instrument choices with context

Policy mixes must work in their respective contexts. This issue is currently implicitly considered when identifying, classifying, characterizing and ranking policy measures. However, it is possible to provide support through virtual environments in selecting a range of policy measures that are relevant in specific governance, sectoral, geographical and temporal contexts. For instance, at present the geographical boundary and the extent to which a policy measure is implemented while formulating policies is not accounted for explicitly. It is evident that the geographical boundaries within which a policy measure is implemented affects the complexity of the policy measure (e.g. how many jurisdictions are affected by it and what institutions need to collaborate?) along with its level of effectiveness (e.g. is the area in which a policy measure implemented sufficient to result in meaningful outcomes?).

6- Conclusion

This paper has emphasized the importance of providing new tools and techniques for dealing with complexity in policy design¹⁵. Going beyond the traditional use of networks in policy studies which is mainly focus on policy actors and communities, the benefits of a network-centric policy design approach were highlighted, demonstrating that network concepts can be used in a myriad of new and integrated ways (rather than the piecemeal use of tools) to facilitate the design and formulation of policies through a bottom-up approach that utilizes policy measures as the building blocks of policies. The use of network-centric policy design in the examination of relations among policy measures, the ranking of policy measures, decision support systems, and the visual representation of policy measure networks and policy packages were discussed. Focus was directed to the computational advantages of this approach in addressing temporal factors and the ability to integrate this approach with developments in other domains, such as crowdsourcing and automation.

Our interest in networks arose from the recognition that complex interactions exist among policy measures and the realization that capturing these interactions in conjunction with the internal properties of policy measures can be used to more effectively rank, visualize and assess policies. The importance of focusing on complex interactions of policy measures has caught the attention of scholars, as was highlighted in Section 3. Furthermore, the efficacy of network-centric policy design as the backbone of a decision support system (a first of its kind) that acts as a virtual environment for the formulation

¹⁵ This is while recognising that decisions and policies to attain desirable futures are essentially questions of social values and political choices and that different stakeholders given their diverse set of objectives and values have different preferences to alternative solutions (Robinson et al., 2006; Stirling 2003).

of policy packages was demonstrated. Given the complexities of modern policy problems the virtual environment facilitates the development and assessment of various configurations of policy measures in policy packages.

In Section 4 the benefits of a network-centric approach in explicitly addressing temporal factors in policy design were examined. For instance, networks can be used for exploring policy failures, delays, layering and drift in policy patching or packaging. Developing these systematic approaches makes it possible to conduct detailed analyses and to consider further alternatives, as well as to provide real-time assessment and feedback to experts, which will ultimately help them to formulate more effective policies. Subsequently, in Section 5, a number of areas for future enhancement and expansion were highlighted, focusing on the integration of network-centric design with recently developed collective intelligence and automation approaches that have the potential to address some of the current shortcomings in data collection and assessment, public engagement and access to expert judgments.

Innovative network-centric approaches, as highlighted in this paper, can assist policy-makers in understanding the complex interactions of policy measures and can facilitate the development of policies. The ideas explored in this paper have highlighted the steps taken towards the development of a network-centric approach to policy design that has the potential to address some of the current shortcomings in policy formulation by facilitating the visualization and analysis of policy measure relations and policy mixes, using decision support systems as virtual environments in the assessment of policy measures and policy mixes, and helping to explore temporal factors. Network-centric

policy design, especially when utilized through a decision support system, can act as a vehicle to facilitate different approaches in policy formulation, such as policy packaging or patching in a complex setting. The approach is generic in nature and applicable to diverse sectors, and geographical scopes.

Acknowledgment

I would like to acknowledge the helpful comments of the anonymous reviewers in improving the quality of this manuscript.

References

- Aitamurto, T. (2012). Crowdsourcing for Democracy: New Era in Policy-Making. Publications of the Committee for the Future, Parliament of Finland. 1/2012. Helsinki, Finland.
- Aldea, A., Bañares-Alcántara, R., and Skrzypczak, S. (2012). Managing Information to Support the Decision Making Process. *Journal of Information & Knowledge Management*, 11(03), 1250016.
- Banister, D., Stead, D., Steen, P., Åkerman, J., Dreborg, K., Nijkamp, P. And Schleicher-Tappeser, R. (2000). European Transport Policy and Sustainable Mobility, London: Spon Press.
- Bicquelet, A., and Weale, A. (2011). Coping with the Cornucopia: Can Text Mining Help Handle the Data Deluge in Public Policy Analysis? *Policy & Internet*, 3(4), 1-21.
- Bobrow, D. B. (2006). Policy Design: Ubiquitous, Necessary and Difficult. In B. Guy Peters and Jon Pierre (eds.), *Handbook of Public Policy*, London: Sage, 75-96.
- Boccaletti, S., Latora, V., Moreno, Y., Chavez, M., Hwang, D.U. (2006). Complex networks: Structure and dynamics. *Physics Reports* 424 (4-5), 175-308.
- Brodbeck FC, Kerschreiter R, Mojzisch A, Frey D, Schulz-Hardt S. (2002). The dissemination of critical, unshared information in decision making groups: The effects of prediscussion dissent. *Eur. J. Soc. Psychol.* 32:35–56.
- Burt, R.S. (1980). Models of network structure. *Ann. Rev. Social.*, Vol. 6, 79-141.
- Camagni, R. (1995). Global network and local milieu: Towards a theory of economic space. In S. Conti, E. Malecki, and P. Oinas (Eds.) *The Industrial Enterprise and its Environment: Spatial Perspectives*, Avebury, UK: Aldershot, 195-214.

- Carter P. (2012). Policy as palimpsest. *Policy & Politics* 40(3), 423-443.
- Champalle, C., Ford, J. D., and Sherman, M. (2015). Prioritizing Climate Change Adaptations in Canadian Arctic Communities. *Sustainability*, 7(7), 9268-9292.
- Conklin, J. (2005). *Dialogue Mapping: Building Shared Understanding of Wicked Problems*. John Wiley & Sons, Inc.
- Craft, J., Howlett, M., Crawford, M., and McNutt, K. (2013). Assessing policy capacity for climate change adaptation: Governance arrangements, resource deployments, and analytical skills in Canadian infrastructure policy making. *Review of Policy Research*, 30(1), 42-65.
- Dowding, K. (1995). Model or Metaphor? A Critical Review of the Policy Network Approach. *Political Studies*, Vol. 43 (1), 136-158. Edinburgh University Press.
- Feitelson, E. (2003) Packaging policies to address environmental concerns. In Hensher, D. A. and Button, K. J. (eds.) *Handbook of Transport and the Environment*, Amsterdam: Elsevier. 757-769.
- Fenton, N. and Neil, M. (2001). Making decisions: Using Bayesian nets and MCDA. *Knowledge-Based Systems*, Vol. 14(7), 307-325.
- Freeman, L., Borgatti, S., White, D. (1991). Centrality in valued graphs: A measure of betweenness based on network flow. *Social Networks* 13, 141–154.
- Freeman, L.C. (1979) Centrality in social networks. Conceptual clarification. *Social Networks*, 1, 215-239.
- Gunningham, N., Grabosky, P., and Sinclair, D. (1998). *Smart Regulation: Designing Environmental Policy*. Oxford: Clarendon Press.
- Gunningham N, Sinclair D. (1999). Regulatory Pluralism: Designing Policy Mixes for Environmental Protection. *Law and Policy*, 21(1):49-76.
- Givoni, M. (2014). Addressing transport policy challenges through policy-packaging. *Transportation Research Part A: Policy and Practice*, 60, 1-8.
- Givoni, M., Macmillen, J. and Banister, D. (2010). From individual policies to policy packaging. European Transport Conference (ETC), Scotland, UK, Oct. 2010.
- Givoni, M., Macmillen, J., Banister, D., and Feitelson, E. (2013). From policy measures to policy packages. *Transport Reviews*, 33(1), 1-20.
- Hacker, JS, 2005, Policy drift: The hidden politics of US welfare state retrenchment. In W Streek, K Thelen (eds.) *Beyond Continuity: Institutional Change in Advanced Political Economies*. Oxford: Oxford University Press. 40-82.

Hanne, T., (2001). *Intelligent Strategies for Meta Multiple. Criteria Decision Making*. Boston: Kluwer.

Hermans, L. M. (2011). An approach to support learning from international experience with water policy. *Water Resources Management*, 25(1), 373-393.

Hermans, L. M., and Cunningham, S. W. (2013). Actor models for policy analysis. In Thissen W. A. H. And Walker W. E. (eds.), *Public Policy Analysis*. Springer US. 185-213.

Hollingshead, A. B. (1996). The rank-order effect in group decision making. *Organizational Behavior and Human Decision Processes*, 68(3), 181-193.

Hou, Y., and Brewer, G. A. (2010). Substitution and Supplementation Between Co-Functional Policy Instruments: Evidence from State Budget Stabilization Practices. *Public Administration Review*, 70(6), 914-924.

Howlett, M. (2010). *Designing Public Policies: Principles and Instruments*. Taylor & Francis.

Howlett, M. (2014). From the “old” to the “new” policy design: Design thinking beyond markets and collaborative governance. *Policy Sciences*, 47(3), 187-207.
<http://doi.org/10.1007/s11077-014-9199-0>.

Howlett, M., Kim, J., and Weaver, P. (2006). Assessing Instrument Mixes through Program-and Agency-Level Data: Methodological Issues in Contemporary Implementation Research. *Review of Policy Research*, 23(1), 129-151.

Howlett, M., and del Rio, P. (2015). The parameters of policy portfolios: Verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environment and Planning C: Government and Policy*, 33(5), 1233-1245.

Howlett, M., and Goetz, K. H. (2014). Introduction: time, temporality and timescapes in administration and policy. *International Review of Administrative Sciences*, 80(3), 477-492.

Howlett, M., and Lejano, R. P. (2013). Tales from the crypt: The rise and fall (and rebirth?) of policy design. *Administration & Society*, 45(3), 357-381.

Howlett, M., and Rayner, J. (2007). Design principles for policy mixes: Cohesion and coherence in ‘new governance arrangements’. *Policy and Society*, 26(4), 1-18.

Howlett, M., Mukherjee, I., and Rayner, J. (2014). The Elements of Effective Program Design: A Two-Level Analysis. *Politics and Governance*, 2(2), 1-12. Doi:
<http://dx.doi.org/10.17645/pag.v2i2.23>.

- Howlett, M., Mukherjee, I., and Woo, J. J. (2015). From tools to toolkits in policy design studies: The new design orientation towards policy formulation research. *Policy & Politics*, 43(2), 291-311.
- Hunt, J. D., Bañares-Alcántara, R., and Hanbury, D. (2013). A new integrated tool for complex decision making: Application to the UK energy sector. *Decision Support Systems*, 54(3), 1427-1441.
- Janis, I. L. (1982). *Groupthink: Psychological Studies of Policy Decisions and Fiascos*. Boston: Houghton Mifflin.
- Jenkins-Smith, HC. and Sabatier, PA. (1999). The Advocacy Coalition Framework: An Assessment, In P. Sabatier (ed.), *Theories of The Policy Process*. 117-166, Boulder, CO: Westview Press.
- John, P. (1998). *Analysing Public Policy*. London: Pinter.
- Jones P., Kelly C., May A. and Cinderby S. (2009). Innovative Approaches to Option Generation. *European Journal of Transport and Infrastructure Research*, 9 (3): 237-258.
- Justen, A., Fearnley, N., Givoni, M., and Macmillen, J. (2014). A process for designing policy packaging: Ideals and realities. *Transportation Research Part A: Policy and Practice*, 60, 9-18.
- Kao A. and Poteet S.R. (2007). Overview. In: A. Kao and S.R. Poteet (eds.), *Natural Language Processing and Text Mining*. Springer, London. 1-7.
- Kelly C., May A. and Jopson A. (2008). The development of an option generation tool to identify potential transport policy packages. *Transport Policy* 15 (6), 361-371.
- Kern, F. and Howlett, M. (2009). Implementing Transition Management as Policy Reforms: A Case Study of the Dutch Energy Sector. *Policy Sciences* 42, no. 4: 391-408.
- Krishen, A. S., Raschke, R. L., Kachroo, P., Mejza, M., and Khan, A. (2014). Interpretation of public feedback to transportation policy: a qualitative perspective. *Transportation journal*, 53(1), 26-43.
- Larson JR Jr, Foster-Fishman PG, Keys CB. (1994). Discussion of shared and unshared information in decision-making groups. *J. Personal. Soc. Psychol.*, 67:446-61.
- Majone, G. (2006). Agenda setting. In Moran et al. (eds.), *The Oxford Handbook of Public Policy*. Oxford University Press. 228-250.
- Marsh D, McConnell A. (2010). Towards a framework for establishing policy success. *Public Administration*, 88(2), pp. 564-583.

- Matt, E., Givoni, M., and Epstein, B. (2013). A Procedure to Develop Synergetic Policy Packages and Assessing their Political Acceptability. Retrieved 14/01/2016, http://www.spreeproject.com/wp-content/uploads/2013/04/Deliverable-3.2-_website.pdf.
- May, P. J. (1981). Hints for crafting alternative policies. *Policy Analysis*, 227-244.
- May A.D. and Roberts M. (1995). The design of integrated transport strategies. *Transport Policy*, 2(2), 97-105.
- McKee, T.E. (2003). Rough sets bankruptcy prediction models versus auditor signalling rates. *Journal of Forecasting* 22, 569-586.
- McPherson, A.F. and Raab, C.D. (1988). *Governing Education: A Sociology of Policy Since 1945*. Edinburgh: Edinburgh University Press.
- Middlemist, G., Butz, E., Carter, D., and Leech, N. (2013). *Towards a Better Understanding of Organizational Policy Related Activity on the Internet*. Chicago.
- Milgrom, P. and Roberts, J. (1990). The economics of modern manufacturing: technology, strategy and organization. *American Economic Review* 80 (3), p.511-28.
- Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D. and Alon, U. (2002). Network motifs: Simple building blocks of complex networks. *Science* 298, 824.
- Mingers, J., and Rosenhead, J. (2004). Problem structuring methods in action. *European Journal of Operational Research*, 152(3), 530-554.
- Montibeller, G., Belton, V., Ackermann, F. and Ensslin, L. (2008). Reasoning maps for decision aid: An integrated approach for problem-structuring and multi-criteria evaluation. *Journal of the Operational Research Society*, Vol. 59(5), 575-589.
- Nair, S., and Howlett, M. P. (2016). Policy myopia as a source of policy failure: Adaptation and policy learning under deep uncertainty. *Policy & Politics*. Forthcoming.
- Newman, M.E.J., Barabasi, A.L., Watts, D.J. (2006). *The Structure and Dynamics of Networks*. Princeton University Press.
- Organisation for Economic Co-operation and Development (2007). Instrument mixes for environmental policy. Paris: Organisation for Economic Cooperation and Development.
- OPTIC (2010). Inventory of measures, typology of non-intentional effects and a framework for policy packaging, Optimal Policies for Transport in Combination, Seventh Framework Programme: Theme 7 Transport, Retrieved 14/01/2016, <http://optic.toi.no/getfile.php/Optic/Bilder%20og%20dokumenter%20internett/OPTIC%20D1%20-%20FINAL%20AND%20APPROVED.pdf>.

- Orren, K, Skowronek, S. (1998). Regimes and regime building in American government: A review of literature on the 1940s. *Political Science Quarterly* 113, 4, 689-702.
- Painter, M. and Pierre, J. (2005). Unpacking policy capacity: issues and themes. In M. Painter and J. Pierre (eds.), *Challenges to State Policy Capacity*. Basingstoke: Palgrave. 1-18.
- Peters, G. (1998). *Policy Networks: Myth, Metaphor and Reality, Comparing Policy Networks*. Open University Press
- Prpić, J., Taeihagh, A., and Melton, J. (2014a). Crowdsourcing the Policy Cycle, *Collective Intelligence 2014*, Massachusetts Institute of Technology, June 10-12, 2014 <http://ssrn.com/abstract=2398191>.
- Prpić, J., Taeihagh, A., and Melton, J. (2014b). A Framework for Policy Crowdsourcing, Oxford Internet Policy and Politics Conference (IPP 2014), University of Oxford, 26–28 September 2014. http://ipp.oii.ox.ac.uk/sites/ipp/files/documents/IPP2014_Taeihagh%20%282%29.pdf.
- Prpić, J., Taeihagh, A., and Melton, J. (2014c). Experiments on Crowdsourcing Policy Assessment, Oxford Internet Policy and Politics Conference (IPP 2014), University of Oxford, 26–28 September 2014. http://ipp.oii.ox.ac.uk/sites/ipp/files/documents/IPP2014_Taeihagh.pdf.
- Prpić, J., Taeihagh, A., and Melton, J. (2015). The fundamentals of policy crowdsourcing. *Policy & Internet*, 7(3), 340-361. <http://dx.doi.org/10.1002/poi3.102>.
- Rayner, J, Howlett, M, Wilson, J, Cashore, B, Hoberg, G. (2001). Privileging the subsector: Critical sub-sectors and sectoral relationships in forest policy-making. *Forest Policy and Economics* 2, 3, 319-32.
- Rhodes, R., Marsh, D. (1992). *Policy Networks in British Politics*. Oxford: Clarendon Press. 1-26.
- Rittel, H. W., and Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4(2), 155-169.
- Robinson, J., Bradley, M., Busby, P., Connor, D., Murray, A., Sampson, B., et al. (2006). Climate change and sustainable development: Realizing the opportunity. *Ambio*, 35(1), 2–8.
- Roy, B. (1996). *Multicriteria Methodology for Decision Aiding*, Kluwer Academic Publishers, Dordrecht, Netherlands.
- Saaty T. L. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process*. RWS Publications, Pittsburgh, Pa.

Sawyer JE. (1997). Information sharing and integration in multifunctional decision-making groups. Presented at Annu. Meet. Soc. Judgm. Decis. Making, Philadelphia, PA.

Schneider. V. (2005). Policy-networks in a complex systems perspective. a new look on an old data set, University of Constance, Baden-Wurttemberg, Germany. Retrieved 15/12/2015, <http://www.unikonstanz.de/FuF/Verwiss/Schneider/ePapers/ChemicalSys5Dez.pdf>.

Sheffey S, Tindale RS, Scott LA. (1989). Information sharing and group decision-making. Presented at Midwest. Psychol. Assoc., Chicago, IL.

Shum, S. J. B., Selvin, A. M., Sierhuis, M., Conklin, J., Haley, C. B., and Nuseibeh, B. (2006). Hypermedia support for argumentation-based rationale: 15 years on from gIBIS and QOC. In: Dutoit, A.; McCall, R.; Mistrik, I. and Paech, B. eds., *Rationale Management in Software Engineering*. Berlin Heidelberg: Springer. 111-132.

Stirling, A. (2003). Renewables, sustainability and precaution: Beyond environmental cost-benefit and risk analysis. *Issues in Environmental Science and Technology*, 19, 113–134.

Taeihagh A., Bañares-Alcántara R. and Givoni M. (2014). A virtual environment for formulation of policy packages. *Transportation Research Part A*, Volume 60, February 2014. 53-68. <http://dx.doi.org/10.1016/j.tra.2013.10.017>.

Taeihagh A., Bañares-Alcántara R. (2014). Towards proactive and flexible agent-based generation of policy packages for active transportation, 47th International Conference on System Sciences (HICSS 47), 4–9 January 2014. <http://dx.doi.org/10.1109/HICSS.2014.118>.

Taeihagh A., Givoni M. and Bañares-Alcántara R. (2013). Which policy first? A network-centric approach for the analysis and ranking of policy measures. *Environment and Planning B: Planning and Design* 40(4) 595-616. <http://dx.doi.org/10.1068/b38058>.

Taeihagh, A., Bañares-Alcántara, R. and Millican, C. (2009a). Development of a novel framework for the design of transport policies to achieve environmental targets. *Computers and Chemical Engineering*, doi:10.1016/j.compchemeng.2009.01.010.

Taeihagh, A., Wang Z. and Bañares-Alcántara, R. (2009b). Why conceptual design matters in policy formulation: A case for an integrated use of complexity science and engineering design, European Conference on Complex Systems (ECCS2009), UK, September 2009.

Taeihagh, A. (2011). A novel approach for the development of policies for socio-technical systems. DPhil. University of Oxford.

- Taleb, N. N. (2007). Black swans and the domains of statistics. *The American Statistician*, 61(3), 198-200.
- Thelen, Kathleen (2004). *How Institutions Evolve: The Political Economy of Skills in Germany, Britain, the United States And Japan*. Cambridge: Cambridge University Press.
- Van der Heijden, J. (2011). Institutional layering: A review of the use of the concept. *Politics* 31, 1, 9-18.
- Van der Lei, T. E., Enserink, B., Thissen, W. A., and Bekebrede, G. (2011). How to use a systems diagram to analyse and structure complex problems for policy issue papers. *Journal of the Operational Research Society*, 62(7), 1391-1402.
- van Waarden, F. (1992). Dimensions and types of policy networks. *European Journal of Political Research*, Vol. 21 (1-2), p. 29-52.
- Walker, W. E. (2000). Uncertainty: The challenge for policy analysis in the 21st century. Rand Corp Santa Monica CA.
- Walker, W. E., Lempert, R. J., & Kwakkel, J. H. (2013). Deep uncertainty. In *Encyclopedia of operations research and management science*, Springer US, 395-402.
- Wasserman, S. and Faust, K. (1994). *Social Network Analysis: Methods and Applications*. Cambridge University Press, Cambridge.
- Watthayu, W. and Peng, Y. (2004). A Bayesian network-based framework for multi-criteria decision making, Proceedings of the 17th International Conference on Multiple Criteria Decision Analysis.
- Wittenbaum GM. (2000). The bias toward discussing shared information: Why are high status group members immune? *Commun. Res.* 27(3):379-401.
- Wu, X., Ramesh, M., and Howlett, M. (2015). Policy capacity: A conceptual framework for understanding policy competences and capabilities. *Policy and Society*, 34(3), 165-171.