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By

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Abstract. The increased complexity in our socio-economical systems requires the development of new tools to support a better understanding of the intricacies involved in addressing problems associated with such systems. We believe that by introducing a systematic approach for exploring alternative policies we can improve the decomposition of these problems, decrease the required time for analysis and formulate more effective polices. A case in policy formulation and analysis in the transport sector for achieving CO_2 emission targets in the UK is presented; this solution is based on a previously proposed framework (Taeihagh et al., 2009a). The results obtained from the analysis of policy measures and their relations are used in the formulation of policy alternatives (packages and clusters) through the application of agent-based modelling. The results have the potential to further promote the use of computational approaches in the formulation of polices through the development of software systems that can support the design of policies for different sectors and geographical scopes.

Keywords: Policy design, policy formulation, agent-based modelling, decision support systems, planning, network analysis and transport emission reduction.

1 Introduction

The increased complexity in our socio-economical systems requires the development of new tools to support us in better understanding of the intricacies involved in addressing problems associated with such systems. We believe that by introducing a systematic approach for exploring alternative policies using a computational methodology that integrates diverse techniques such as backcasting, conceptual design, network analysis and agent-based modelling, we can (a) better decompose the problem into subproblems with more manageable size, (b) decrease the required time for analysis, and (c) formulate more detailed and effective polices (Taeihagh et. al. 2009b). A case in policy formulation and analysis in the transport sector for achieving CO2 emission targets in the UK is presented. The approach is based on a previously proposed six-step framework (Taeihagh et al., 2009a). We focus the application on the transport sector as it is the second largest growing source of greenhouse emissions (IPCC, 2007), contributing around 25% of CO_2 emissions and with no contribution to emission reduction (Hickman et al., 2010). An analysis of policy measures as instruments for development of policies is carried out based on their internal properties

and their relations/interactions with other policy measures. This information is fed to an agent-based system that formulates policy alternatives (packages and clusters). The final decision on which policy to implement will rest with the decision makers who may decide to include additional policy measures or remove some of the recommended ones. We envisage the results will further promote the use of computational approaches in the formulation of polices for different sectors (transport, energy, food, water, etc.) aiming to achieve environmental, security, health or safety targets for different geographical scopes (international, national, municipal, etc.).

The background information is briefly discussed in Section 2. Section 3 describes the architecture and implementation of the agent-based approach. The results achieved in the development of the system and the future work are described in Section 4 followed by the conclusions in Section 5.

2   Background on Policy Design and the Proposed Framework

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. Some aspects of a policy can be modelled mathematically, however, mathematical models are only part of the general policy-making process as decisions about desirable futures and the policies to attain them, are questions of social values and political choice (Robinson et al., 2006). Currently, decisions on what to include in policies (their *synthesis*) is done manually, and considering the size of the space of alternative policies, a large portion of the space is left unexplored.

We believe that such traditional approach to policy-making is not well suited for solving 21st century's complex problems (see Taeihagh et al., 2009a and 2009b for further motivations). The methodology for the development of alternatives can be greatly enhanced, and a systematic approach will accelerate the task of policy-making and improve policy effectiveness. We have previously motivated the use of engineering design principles along with complexity science to enhance the process of policy-making (Taeihagh et al., 2009b). Our hypothesis is that the process by which the operators are selected and organised in chemical process synthesis and policy design is similar (Taeihagh et al., 2009c). However, different approaches will have to be used to take into account their differences, in particular, the pervasiveness of non-quantifiable factors in policy-making.

A framework to facilitate the formulation to achieve user-defined goals and targets has been proposed and a software system is being implemented using this framework with consideration for reusability with different targets, sectors and geographical scopes (for more information see (Taeihagh et al., 2009a)).

3   Agent-Based Modelling (ABM) Approach

3.1   System Architecture and Implementation Environment

Figure 1 illustrates the software architecture of the decision support system (DSS) based on the framework. Mathematica is used for computation (Mathematica, 2008) and to access the discrete mathematics package Combinatorica (Pemmaraju & Skiena, 2003).

Analyses performed on the network of relations among policy measures are outputted to Excel files, which are, in turn, imported by the agent-based toolkit. The information acquired through user input and analysis in Mathematica is channelled towards Repast Simphony (Recursive Porous Agent Simulation Toolkit, North et al., 2005).
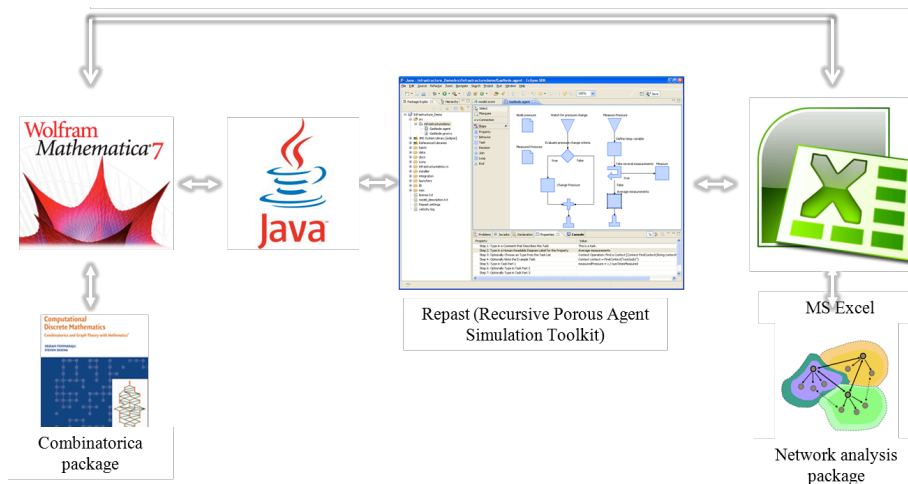

Figure 1 Software architecture of the DSS

3.2 Objectives of the Agent-Based Formulation System

The focus of the agent-based system is on steps 4 to 6 of the framework, i.e. generation of policy packages and their assessment. The reasons for adopting an agent-based approach are: (a) the possibility to combine top-down and bottom-up approaches; (b) the possibility to develop flexible systems that can handle incremental discovery, design and development (North & Macal, 2007); (c) the ability to decompose the overall problem, and through the use of a multi-layered approach, accommodate abstraction and the use of hierarchical structures (similar to the hierarchical design procedure (Douglas, 1988); and (d) their ability to deal with organisational relationships as found in complex systems (Jennings, 2000). The system has been designed to be open so that data can be added at any time and not be a limiting factor. This effectively allows the user to adopt the design approach (defended by strategic thinkers such as Ansoff (Ansoff, 1991)) or the organizational learning approach (advocated by Mintzberg for strategic thinking (Mintzberg, 1990)). It is worth emphasising that in this ABM system the authors are more interested in exploring and tackling the technical problems resulting from the complexity in policy formulation and to showcase the use of a computational framework rather than in exploring or simulating human behaviour in decision-making. Therefore, using agent architectures such as BDI (Bratman et al., 1988 and Rao & Georgeff, 1995) or PECS (Urban, 2000) is not the focus of this research, although they are relevant from a social science perspective.

3.3 Conceptual Model

In the ABM system, policy packer agents (animated agents) undertake the selection process among policy measures (inanimate agents) to create the policy packages. Similarly, policy clusterers use the results from the policy packer agents work to create the policy clusters. After the generation of the policy packages and clusters, a higher-level agent formulates the alternative policies and then connects them to the goals defined by the user. Definition of the goals and the acquisition of the user preferences take place in the first step of the framework, and the development of the library of policy measures and the specification of their interactions in steps two and three (Taeihagh et al., 2009a). The preferences acquired from the user are fed to the system as global parameters, and goals as inanimate agents.
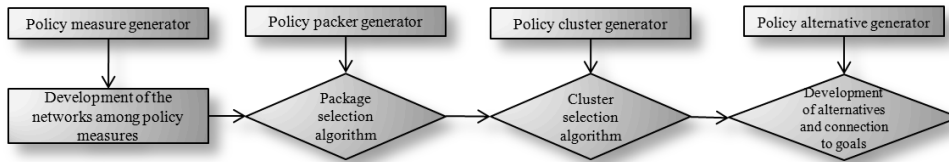

Figure 2 Overall conceptual model of the policy formulation ABM

3.4 Input Data

The 122 policy measures identified in the Visioning and Backcasting for UK Transport (VIBAT) project constitute the core of the library of policy measures used in the system. VIBAT studied the potential for 60% reduction of emissions due to transport by the year 2030 using a backcasting approach (Banister & Hickman, 2006). Five types of interactions between the policy measures were identified: Precondition, Facilitation, Synergy, Potential Contradiction and Contradiction. Based on the policy measures interactions, graph structures were built and analysed. Policy measures were then ranked using preference indices (PI) which allowed quantitative comparison (Taeihagh et al, 2009b). During the initialisation step, the aforementioned information was fed to the ABM system for the creation of policy hierarchies and the comparison of the alternatives.

4 Results and Future Work

4.1 Results and Discussion

The results from the ABM are the formulated policy packages, which in turn are used for the development of policy clusters and the overall policies. Figure 3 depicts a sample set of policy packages created by the policy packer agents. Each square contains a package in which the top measure is the first selected measure in that package (due to its high PI score) and a number of other policy measures that have been added to the top measure because of their positive interactions with it. As an example, "Improvement of public transport (bus, guided-bus, etc.)" has taken the top position in the package because of its PI score. In this case having an "Integrated planning" is essential for

success in the improvement of such services and providing "Public transport subsidy" in form of investment for public transport is vital for improvement of the service.

In general, the results from the system are promising and make logical sense. Use of the network of relations among policy measures greatly enhances the ability of the system to place measures/packages/clusters with positive relations alongside each other and to avoid contradictions; however, a number of limitations that need to be addressed have been identified. The input data from VIBAT has internal hierarchies, i.e. some of the policy measures are vague and have an overarching effect. This results in those measures being selected more often, which is not incorrect as they inherently require a number of preconditions and have a larger effect; however, in an ideal situation it would be preferable that all measures have the same level of granularity.

```
34, Decentralized
concentration and
polycentricity
84, Relocation of activities
77, Decentralization of
health and social services
78, Decentralization of
education facilities
40, Clustered and user/
location efficient
development
32, Regional development
policies, strategic planning
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```
8, Improvement of
public transport –
bus- guided bus and
LRT, etc.
31, Integrated
planning
10- Public
transport subsidy
(investment)
```

```
1-Standards for
emissions, noise and
safety
2-Fuel quality
standards
6-Vehicle test cycles
7-Enforcement and
monitoring
123-Causualty
reduction targets
(zero objective)
```

```
42, Pedestrianisation
82, Pedestrian and cycle friendly
development
112, Pedestrian priority and road
space
114, Direct routes for walking and
cycling and pt relative to car
18, Walking and cycling facilities
8, improvement of public transport
111, Road space relocation
37, public transport oriented
development
10, Public transport subsidy
101, Entry restrictions/access
control environmental
88, Car and cycle parking standards
for new developments
20, Cycle parking
```

```
81, Low emission zones
36, Zoning regulation
46, Car free planning
1-Standards for emissions, noise
and safety
2-Fuel quality standards
6-Vehichle test cycles
7-Enforcement and monitoring
123-Causualty reduction targets
(zero objective)
103, Road capacity restrain
89, Road pricing
84, Relocation of activities
32-Regional development policies,
strategic planning
31, Integrated planning
101, Entry restrictions/access
control environmental zones
```

Figure 3: A sample of policy packages created by the policy packer agents.

4.2 Future Work

We plan to enhance the generation and evaluation procedures and further improve the Preference Indices (used as input data to the ABM). As it is not possible to validate our results with real world experiments since this would require the implementation of the policies beforehand, we are in the process of comparing our results with those from the

VIBAT project and we are currently collaborating with transport policy experts in order to validate the results, carry out further enhancements, and explore other case studies.

5 Conclusions

We have explored the potential of applying an ABM system to formulate policies for emission reduction in the UK and have addressed some of the complexities involved. The purpose of the research is to facilitate the design of policies through knowledge transfer from engineering design and complexity science. This research constitutes the first step towards the development of a generic family of software systems to support policy design for different sectors. The results have the potential to accelerate and improve significantly the design of policies through use of a computational methodology and to improve their chance of success.

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