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Development of a novel framework for the design of transport policies to achieve environmental targets

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Abstract - The formulation of policies requires the selection and configuration of effective and acceptable courses of action to reach explicit goals. A one-size-fits-all policy is unlikely to achieve the desired goals; as a result, the identification of a suite of alternative policies, together with clear indications of their trade-offs, is crucial to accommodate the diversity of stakeholders’ preferences. At present, the formulation of transport policies is done manually; this fact, together with the size of the space of possible policies, results in a large part of that space being left unexplored. A six-step framework to explore the space of alternative transport policies in order to achieve environmental targets is proposed. The process starts with a user-defined set of specific policy measures, using them as building blocks in the generation of alternative policy packages, clusters and future images according to the user’s preferences and goals.

The analysis framework is based on the visioning and backcasting approach used in the VIBAT report (Banister & Hickman, 2006a). The framework is being implemented as a prototype decision support system around a case study: the formulation and analysis of policies required to achieve CO$_2$ emission targets for the transport sector in the UK. Important insights on how to develop the framework have also been elicited from engineering design. The goal is to accelerate the task of policy-making and improve the effectiveness of the resulting policies.

The proposed method and computer implementation is fundamentally different from the tools commonly used in the transport sector and is intended to assist (not replace) transport policy makers, and complement (not substitute nor compete with) existing mathematical modelling tools. This research constitutes the first step towards the development of a general family of computer-based systems that support the design of policies to achieve environmental targets – not only for transport, but also for other sectors such as energy and water.

Keywords: Decision support systems, Process design, Policy design, Transportation, Emission reduction, Conceptual design.

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1. Introduction

There is a consensus in the scientific community recognizing the effect of man-made emissions on climate and acknowledging the importance and urgency of tackling the climate change issue to avoid its catastrophic consequences. A delay in addressing the issue will result in costlier solutions that might not be as effective or even too late/ineffective. In 2007 the IPCC third working group published an assessment report on climate change mitigation (IPCC, 2007); however, an understanding of how to develop effective, acceptable and detailed policies has yet to be attained, as recent high-profile cases show, e.g. the failure of the first phase EU Emission Trading Scheme to cut emissions. Addressing such a complex problem requires the formulation of integrated policies that are coordinated and reciprocally reinforcing.

Targets on anthropogenic greenhouse gases emissions are being set by national and international bodies to stabilise their atmospheric concentrations. The United Kingdom published the Climate Change Bill in March 2007 (DEFRA, 2007; DEFRA, 2008), introducing a long-term and binding target of a 60% reduction in the UK’s carbon emissions by the year 2050 in comparison to their levels in 1990. There is a wide debate on the level at which these targets should be set, but once values are agreed, there are a number of possible alternative strategies (policies) to achieve them.

The precise nature and scope of policies designed to achieve environmental targets are necessarily geographically and culturally dependent given the variability of resources, of access to technology and of political constraints at different locations and times. For this reason, a one-for-all and static policy is unlikely to achieve the desired targets. On the contrary, the need for bespoke policies that are able to accommodate periodic revisions is now widely recognized. Even for a fixed time and place, the identification of a suite of alternative policies (rather than a single “optimal” one), together with clear indications of their trade-offs, is crucial to accommodate the diversity of the stakeholders’ preferences.

The introduction of a systematic approach for exploring alternative policies using a computational methodology will accelerate and improve the process of policy-making. Based on the visioning and backcasting approach (Banister & Hickman, 2006a) a new framework for policy formulation is being developed and implemented as a prototype decision support system around a case study: the formulation and analysis of the policies required to achieve CO₂ emission targets for the transport sector in the UK. The goal is to accelerate the task of policy-making and improve the effectiveness of the policies. The transport sector has been chosen for the case study because it is the second largest growing source of greenhouse emissions (IPCC, 2007).
The background to policy design and the backcasting methodology are discussed in Sections 2 and 3 respectively. Section 4 describes the proposed framework for policy formulation and justifies the development of the resulting decision support system. Details of the decision support system (DSS) are provided in Section 5. The results achieved in the development of the system are presented in Section 6 followed by a discussion of its limitations and proposed future work in Section 7. The conclusions for the work are presented in Section 8.

2. Background to policy design

2.1. Policy and policy process

A policy is a principle or guideline for action in a specific everyday-world context (Pohl, 2008). Figure 1 shows a model of the policy process and sets in context the Policy Design step, a step whereby the components of a policy are selected and the overall policy formulated.

![Figure 1. A model of the policy process](image)

The development of a successful policy is a manual, labour-intensive task involving many types of objectives and criteria for success. Policies may be related to technological, economic, political and social aspects. Some technological and economic factors can be modelled mathematically, resulting in complex simulation/prediction models such as those using MARKAL (Seebregts et al., 2001). Mathematical models provide valuable insights, but are only part of the required inputs to a general policy-making process because, after all, decisions about desirable futures, and the policies to attain them, are essentially a question of social values and political choice (Robinson et al., 2006). Furthermore, it is acknowledged that different stakeholders (the public, government, industrial, NGO, and research sectors) attach different preferences to alternative solutions because of their diverse objectives and values (Stirling, 2003).

2.2. Simulation and evaluation of policies in the transport sector

The focus within the transport domain has been on the development of mathematical models and tools for assessment of large-scale infrastructure projects and analysis of transport policies. Monetary-based techniques (e.g. Cost-Benefit Analysis (CBA)) and Multi-Criteria Analysis techniques
(especially Multi-Criteria Decision Analysis techniques (MCDA) such as the Analytical Hierarchical Process (AHP (Saaty, 1990)) and the Simple Multi-Attribute Rating Technique (SMART (Edwards, 1977))) form the basis of the models and tools. Often, risk analysis techniques and probabilistic models (e.g. Monte Carlo Simulation (MCS)) are used to further refine and fine-tune the models. The majority of the DSS used in the transport sector use combinations of the above-mentioned techniques and focus on the evaluation and optimization of different alternatives. There are:

- Generic systems, such as HUGIN EXPERT (which utilizes Bayesian Networks and Influence Diagrams) (Madsen et al., 2003), Expert Choice (utilizes AHP), and Criterion DecisionPlus (CDP) (which uses AHP and SMART),
- Purpose built systems for the transport domain, such as an infrastructure investment prioritizing tool (Tsamboulas & Mikroudis, 2006), CLG-DSS (Salling et al., 2007), CBA-DK (Salling & Leleur, 2006), COSIMA-DSS (Salling et al., 2005), SMILE (Tavasszy et al., 1998), and the multi-criteria evaluation of transport options method (Sayers et al., 2003), and,
- Geographical Information Systems (GIS) (Arampatzis et al., 2004; Symeonidis et al., 2004).

2.3. Problems of policy formulation

Both in the case of policy design in general and in the transport sector specifically, the decisions on what to include in the policies (their synthesis) is done manually. This fact, together with the size of the space of possible policies, results in a large portion of the design space left unexplored. New options are made available due to a variety of reasons such as the introduction of new technologies, the rapid advancement of current technologies and an increased level of complexity in the socio-economical systems. The latter being a consequence of issues such as globalization and increases in the power of multinational corporations, demand for energy, and environmental constrains (both intentional, e.g. health and safety standards, and unintentional, e.g. global warming).

A systematic approach to explore the space of alternative policies using a computational methodology will accelerate the task of policy-making and improve policy effectiveness. Furthermore, accommodating the diversity of preferences from different types of stakeholders would improve policy acceptability (trust and credibility).

2.4. Process design and policy design

Important insights into a policy design methodology can be elicited from engineering design. The design of physical artefacts and industrial processes requires bringing together many different kinds of knowledge and techniques in order to meet a set of defined technical objectives. This paper argues
that engineering design methodologies offer a productive framework and a suite of practical tools for supporting policy design. Similarly to the transport domain (see Section 2.2), there are powerful simulators used for chemical process design (Finlayson, 2006), such as ASPEN Plus (Aspen Plus, 2008), HYSYS (HYSYS, 2008), PRO/II (PRO/II, 2008). However, in contrast to the transport sector, process engineers have developed a set of tried-and-tested synthesis methods which help in the selection of the items of equipment and how they are to be interconnected in a flowsheet structure (Westerberg, 2004).

In process design synthesis and simulation steps are applied in tandem and iteratively: a synthesis step generates alternative designs and the output from a simulation step is used to compare those alternatives and inform the application of the next synthesis step (see Figure 2(a)). The introduction of the aforementioned techniques changed the way in which chemical processes were designed. The plan is to adapt/adopt existing process synthesis and design methods to the design of policies, i.e. to provide practical frameworks and tools for better policy design and support decision-making regarding which measures to use and how to combine them to achieve the targets (the set of tasks included inside the dashed box in Figure 2(b)).

(a) Process design

(b) Policy design

Figure 2. Analogy between (a) process design and (b) policy design

Two conceptual frameworks are especially important:

- The exploration-based model of design (Smithers & Troxell, 1990), which understands design as an ill-structured problem where the design goals and the designed artefact evolve in a single front because a complete specification of the design objectives is not available at the outset of the design process.
- The use of a hierarchical organization, which makes the analysis, understanding, description, and development of systems easier than for non-hierarchical structures due to their decomposability (Simon, 1996).
Both of these ideas are reflected in the widely accepted Hierarchical Design Method (Douglas, 1988) and its variations, and have been embodied in design support systems such as n-Dim (Westerberg et al., 1993), KBDS (Banares-Alcantara & Lababidi, 1995), and Improve (Marquardt & Nagl, 2004).

Our hypothesis is that the process by which the collection of operators is synthesized is similar. However, process and policy design are not identical and, as a result, different approaches will have to be used to take into account their differences, in particular, the pervasiveness of non-quantifiable factors in policy-making.

3. Background on backcasting and the VIBAT Project

The proposed framework and the decision support system make use of the normative scenario analysis known as the Visioning and Backcasting Approach (Banister & Hickman, 2006a). Section 3.1 provides a brief description of the backcasting approach and Section 3.2 introduces the specific terminology that is used throughout the rest of the paper.

3.1. Backcasting

Backcasting was first proposed in (Robinson, 1990) and has become a well-established methodology. It involves the development of normative scenarios aimed at achieving desired end-points, i.e. working backwards from a desirable state to determine what policies would be required to reach it. Unlike forecasting, it is intended to suggest the implications of different futures, not based on their likelihood but based on criteria associated with values and norms such as social and environmental desirability (Robinson, 2003). Given the limitations of current models and the uncertainty in data, forecasting is better suited to address short-term solutions (the traditional trend in the transport sector), but problems such as climate change mitigation and adaptation require long-term planning. Backcasting is useful for addressing highly complex and long-term problems as it has the potential to identify unresolved subproblems and bottlenecks that are critical in the solution of the overall problem, thus guiding policy makers where action is required and helping them in creating solutions that are creative and radically different from the status quo.

3.2. Visioning and Backcasting for UK Transport Policy (VIBAT)

The VIBAT project studied the potential for 60% reduction of emissions due to transport by the year 2030 through the use of scenario-building and backcasting approach (Banister & Hickman, 2006a). The study examined an array of policy measures and considered whether they could be effectively
combined in order to reach the target. The goal was to establish whether reaching the target is feasible, identify the difficulties, and the key decisions that need to be taken.

The terms policy measure, policy package, policy cluster, future image and policy pathway used in this paper are adopted from VIBAT project. Below, a definition of each term is given and Figure 3 illustrates their relation:

- **Policy measure.** A policy measure is the building block used for the creation of policy packages, clusters and, ultimately, the future images to reach the target. A total of 122 policy measures were identified, based on the research done in (Banister et al., 2000; Marshall & Banister, 2000; VTPI, 2007). They have been categorized as technological, regulatory, economical and social.
- **Policy package.** Policy packages help in structuring the policy measures by grouping those that are similar, work together, and/or have a synergistic effect. In VIBAT, eleven policy packages were proposed covering all transportation modes relating to spatial and land use. Similar to policy measures, policy packages have themes: some are technological, and others rely on regulatory, economic or behavioural change.
- **Policy cluster.** Clusters are formed based on core packages to which other supporting packages are added. Their purpose is to reach the emission reduction target levels for each image (scenario) of the future. There is no claim on the clusters being comprehensive.
- **Future image.** Each future image is a result of the implementation of one or several policy clusters to reach the emissions reduction target.
- **Policy pathway.** The policy pathways indicate the temporal ordering in which certain decisions need to be made. They are useful since, for example, long lead times are required for implementing groundbreaking policies, e.g. introducing legislation, providing incentives for the industries to move towards the target, and changing public attitude and individual behaviour.
4. Development of the design support system

4.1. Objectives of the proposed decision support system

The research objective is to develop a working prototype of a decision support system (DSS) to facilitate and speed up the design of transport policies in order to achieve environmental targets. The proposed techniques should be applicable to different targets (e.g. CO$_2$, CH$_4$, NO$_x$ emissions); in different sectors (e.g. industry, transport, energy generation); with different geographical scope (e.g. local, national, regional and international); and with integrated strategies (e.g. one that ensures that transport policy meets future mobility needs and emission targets while avoiding inconsistency with other important government strategies such as energy security and the curbing of global poverty, as envisaged in (UOXPanel, 2007)). Furthermore, the system architecture should be able to support policy development approaches other than Visioning and Backcasting, such as Forecasting.
The proposed DSS is developed around a case study: the formulation and analysis of policies required to achieve CO₂ emission targets for the transport sector in the UK. The backcasting approach for policy development (presented in Section 3) currently relies on the manual elaboration of policies, which can explore a handful of alternatives at most. The only similar policy formulation support tool is GB-QUEST (Carmichael et al., 2004), which provides a relatively small and fixed catalogue of policy measures and a set of predetermined combinations. The proposed DSS allows the user to define new policy measures and to edit them interactively. This added flexibility increases the need for computer support. To put the problem in perspective, more than 120 policy measures were identified in (Banister & Hickman, 2006b); finding interesting combinations of these and new user-proposed measures is a daunting task if approached manually.

4.2. Proposed framework for policy formulation

The proposed policy formulation framework is broken down into six steps (see Figure 4).

1. Identification of the relevant concepts, such as targets and goals.

This study a target has a numerical value relating to a performance metric that is to be attained by a given date, e.g. 60% CO₂ emissions reduction by the year 2030. The terms goal and objective are used interchangeably, and are the desired results of a strategy. A goal has a more qualitative nature although associating numerical values is also possible. Achieving a number of goals will facilitate achieving the ultimate desired outcome defined as the target, for instance, the goal can be to avoid or mitigate climate change. A subgoal is an intermediate goal that facilitates achieving a higher order goal.
2. Development of a library of policy measures.

The creation of a repository of available measures requires the participation of experts in the field and different stakeholders using available scientific data and reverse engineered knowledge from existing transport policies. New measures may be created at any point in time.

Policy measures have very different nature and characteristics. They may be of an economic (e.g. taxation on emissions), regulatory (e.g. introduction of emission limits), technological (e.g. substitution of fleet with hybrid technology vehicles) or social (e.g. increase of social awareness) type. Some of the measures are expressed quantitatively, but many have a qualitative nature. Measures can be characterised in terms of their priority, degree of effectiveness in achieving the target, time-scale necessary for implementation, current best practice, side-effects, affected stakeholders, trends with other variables, preconditions required for implementation, targeted objective(s), level of uncertainty, level of risk, associated cost(s), etc. A simplified example of the “hybrid technology vehicles” measure is shown in Figure 5.

<table>
<thead>
<tr>
<th>Policy Measure Name: Hybrid Technology Vehicle</th>
<th>Policy Measure Id: 122</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy Measure Type: Technological &amp; Economical</td>
<td>Preconditions: None</td>
</tr>
<tr>
<td>Related to Goal: P1 (Reduce total vehicle fleet emission and use hybrids)</td>
<td>Effectiveness: High</td>
</tr>
<tr>
<td>Uncertainty: Low</td>
<td>Timescale of Implementation: Long</td>
</tr>
<tr>
<td>Cost: Medium</td>
<td>Risk Level: Low</td>
</tr>
</tbody>
</table>


The relations among policy measures are currently categorized as precondition, contradiction and synergy. Furthermore, the strength of the relation can be described using qualitative labels, e.g. low, medium or high.


In this step synthesis and configuration techniques are applied to generate alternative combinations of measures into compatible policy packages, as it is widely accepted that policies combining diverse and reinforcing measures are required.
For example, a simplified policy package could consist of a combination of the three measures: “consumer tax incentives”, “higher fuel taxes” and “ban non-hybrid vehicles from ‘green’ areas”, all of which reinforce a consumer preference for “hybrid technology vehicles” (see lower mid branch in Figure 6). The nodes labelled as “MIX” in the figure represent an operator that takes one or more measures and combines them in some proportion to be determined later in the formulation process.

Powerful concepts and techniques such as abstraction/refinement hierarchies and generic methods such as Generate&Test are utilized for the generation of policy packages (see (Westerberg, 2004) for details on these and other methods used during chemical process synthesis). In addition to the aforementioned techniques, graph theory and network analysis techniques are used for exploring the relations among different policy measures to better understand the overall effect of the implementation of policy measures on the system and on each other. In particular, the network is analyzed for cycles in order to acquire additional information to assist policy evaluation.

The tree in Figure 6 represents several alternative policies. It is constructed incrementally using the measures in the library as building blocks, with the node properties constraining the valid links in the tree. However, the tree will be editable by the user at any point in time. Furthermore, using the properties of the nodes, the contents of the tree are assessed with respect to the goals and criteria.
declared by the user. This results in the elimination of some of the possibilities and produces a list of alternative policies in order of desirability.

5. Application of planning techniques in the scheduling of policy packages resulting in alternative policy clusters.

Going back to the example in Figure 6, some “manufacturing infrastructure” to produce hybrid vehicles needs to be in place before “hybrid technologies vehicles” take a significant share of the fleet; “incentives to manufacturers” should precede “consumer tax incentives”, and both types of incentives may be decreased gradually as production and consumption increases (not shown in the figure). The application of policies is time dependent due to the lead times required by some of the policy measures, the desirability of a phased introduction of some others, and the time delays associated with the observation of their effects. It is important to avoid making early decisions that would preclude the application of other desirable policy measures in the future, and to make sure that precondition measures are scheduled at an appropriate time. All of these issues are considered in the generation of a partially ordered schedule of policy packages.


This step involves evaluation of the alternatives generated and recommendation of the most suitable ones by aiding the user in their comparison. Furthermore, sensitivity analysis will be employed in order to observe the effects of perturbations on the overall system.

5. Development of the decision support system

5.1. Software architecture and implementation details

Figure 7 illustrates the software architecture of the decision support system. The Java programming language (Java, 2008) has been chosen for the development because of its characteristics of platform independence, automatic memory management and access to an extensive library of freely available code and software. The program utilizes MySQL (MySQL, 2008), which is the most widely used open source relational database management system. The connection between the database and the core of the system is achieved through the Java Database Connectivity Application Programming Interface (JDBC, 2008). In order to help the Java code interact with the database and allow object/relational mapping, the Java Persistence API is utilized (JPA, 2007). The Java code currently uses Mathematica’s kernel as its main computational and visualization engine (Mathematica, 2008). In addition, Mathematica is used for data manipulation, in particular for accessing the discrete
mathematics package Combinatorica (Pemmaraju & Skiena, 2003; Pemmaraju & Skiena, 2004). The integration between Java and Mathematica is established using J/Link (J/Link, 2008).

5.2. Specification of targets, goals and preferences

Accounting for the changes of perspective and priorities over time is a major concern addressed by the system. Such changes occur as a result of emergence of new and presumably more accurate and reliable data, better understanding of the climate change issue, and increased knowledge about the relation between the transport sector emissions and the overall level of emissions. The user goals are explicitly requested through the Goals tab in the GUI at runtime and can be adjusted at any given time, see Figure 8.

The Goals tab has three sections:

1. Specification of the CO₂ reduction targets.

The user must initially indicate the target year for emission reduction ranging from years 2010 to 2050. The target level of CO₂ emissions is set with respect to the baseline year and total emissions level set in the Baseline Data tab. The default value for the CO₂ reduction target is set to 60 percent of the baseline level.
2. Selection of policy types and levels of priority.

The majority of policy measures used in the software are based on the VIBAT project. Policy measures are categorized as technological, regulatory, economic and social. A policy measure may have multiple categories assigned to it.

In this section of the tab the user has the possibility to select any or all of the four policy types to be used and can set their priority. Prioritization enhances the ability to use the right types of policy measure to reach the set target based on the preferences of the user. Priorities can have values ranging from 0 to 100 which are interpreted, in turn, as not using the policy type at all to giving the policy type full priority.

One of the mechanisms that can drastically affect the way in which the emission reduction target can be met is the consideration of emissions trading as an acceptable measure. There is currently a debate on whether emissions trading can truly be considered an emission reduction measure. However, for completeness, the ability to consider it alongside carbon rationing is provided through the specification of the estimated amount in which such mechanisms reduce the total emission level.

3. Selection criteria.

Policy measures can be compared in terms of their: (a) timescale of implementation, (b) risk level, (c) cost, (d) whether they focus on adaptation or abatement, and (e) whether they provide incentives to shift towards the policy or penalize in case of non-compliance.

Policy measures can be short, medium or long-term and can have risk levels and cost that can be low, medium or high. By selecting any or all of the mentioned characteristics, the user can adjust the scope of the policy measure pool available to the software for analysis. One of the issues regarding policy design for emission reduction is the strategic decision of whether to focus on abatement or adaptation. The user also has the ability to apply the carrot-and-stick approach and give preference either to “carrot” regulatory policy measures such as incentives and promotions, or to “stick” regulatory policy measures, such as taxation and banning. Finally, limits for the size of packages and clusters need to be specified by providing the minimum and maximum number of acceptable policy measures.

The rationale behind providing an interactive Goals specification tab is to empower the user to take full control of the design of the policies and avoid misunderstandings resulting from lack of communication.
5.3. Development of the library of policies

As described earlier, the 122 policy measures from the VIBAT project constitute the core of the library. Properties such as the policy type, effectiveness and timeframe of implementation were populated using explicit and implicit information provided in the Stage 3 report of VIBAT (Banister & Hickman, 2006b), but their values are editable by the user. The use of the SQL server can allow multiple users accessing the system. The current prototype does not allow for such functionality but this feature is under consideration for future development.

An interface with the ability to create, read, update, delete (CRUD) and visualize measures was also developed. The Swing Application Framework was used for the development of the Graphical User Interface (GUI) (Muller, 2008). Additionally, JPA and Beans Binding (Man, 2008) were utilized for object/relational mapping and synchronization of the properties.
5.4. Development of a library of relations among individual policy measures

Currently, focus has been placed on the identification and processing of preconditions among different policy measures. A precondition of a policy measure is defined as another measure that is required by, or facilitates, the performance of the original measure and therefore should ideally be implemented earlier. It is evident that the preconditions that are essential for the success of a policy measure are different from the ones that only facilitate it. This situation can be represented by either defining different types of relation for these two precondition types or by assigning a measure of importance to the relation.

A precondition relation is directional. Each policy measure is depicted as a node and its preconditions as its links. Preconditions were defined for all policy measures when applicable; as an example, Figure 9 illustrates the preconditions for “Advanced traffic management systems”. Note our convention for the direction of the relation: in this example the “Advanced traffic management systems” policy measure has the rest of the policy measures as its preconditions.

![Figure 9. Example policy measure and its preconditions](image)

6. Results

This section describes the results achieved so far in the development of the decision support system based on the proposed framework for policy formulation.

6.1. Generation and visualization of policy measure networks

Based on the specified preconditions, a graph structure was formed with policy measures as nodes (vertices) and the relations as directed edges between the nodes. Using the open source Graph Visualization Software (GraphViz) (Ellson et al., 2001), which uses the Dot plain text graph description language (Koutsofios & North, 1993), a network of the precondition relations among
policy measures was developed. Figure 10 depicts the resulting network of preconditions among policy measures (in figures 10 and 12 each node (circle) represents a policy measure).

Some of the results from the analysis are presented in the rest of Section 7.1 and will be expanded upon in the future. The flow in figure 10 is from left to right, which means the policy measures on the right hand side are preconditions to those in the left and thus should be implemented first.

In the next step of the analysis, policy measures were grouped into different clusters based on the information provided in the VIBAT project report. The main criterion for clustering was that the policy measures supporting the same overall goal should be grouped together. In the cases where significant differences existed among measures that related to a certain goal, measures were separated into smaller groups in order to reduce differences. Figure 11 presents the resulting clusters in the network of preconditions.
Figure 12 presents the same network with clusters creating a timeline for implementation (flow is left to right). Policy measures in the same column have the same implementation time.

![Clustered network of preconditions with a directional flow from left to right](image)

**Figure 12. Clustered network of preconditions with a directional flow from left to right**

This type of visualization provides insights on how to order the policy measures for implementation, when there are complex relations between the measures. In addition, the method can be used for observing the effect of clustering on the order of the measures, so changes on the order of implementation of the measures can be monitored and unintentional consequences avoided.

These are two important shortcomings of the method used to produce Figures 10 and 12: (a) the relations among measures are treated equally (as they are not weighted), and (b) the placement of nodes in the network depends on all their preconditions. This last item implies that all sink nodes are required for the implementation of the source node. Moreover, although each node has its own internal implementation timeframe, it has not been taken into consideration. This can have drastic effects on the order of implementation, especially for the placement of measures that have a long implementation time.
A closer look at the network of policy measures and their relations can provide useful information for the refinement of the relations and the evaluation of the policy.

The network is constituted by 122 nodes and 867 edges. The average number of connections to and from a node is 7.1; however, there is a large variation in the number of edges that connect to each node. Some measures act as foundations and their implementation plays an important part in the success of other policy measures, which makes them crucial for overall policy success. However, a large number of connections can also be caused by the existence of hierarchies among policy measures. This has been identified as a limitation in the VIBAT project, and the existence of hierarchies will be properly accounted in the DSS in the future.

Analyzing the nodes in terms of their input and output connections can also provide valuable information. Nodes with a large number of inputs should be implemented earlier, whereas nodes with a large number of outputs are harder to implement as they require more resources for implementation. Naturally, special attention should be paid to nodes that have a large number of both input and output connections as they are a precondition to a large number of nodes and require a large set of preconditions themselves. Moreover, nodes with the fewest number of outputs are also important since they are more flexible in terms of the implementation of the network.

For instance, nodes 46, 79, 80, 33, and 81 (car free planning, car free districts, car free housing, compact cities, and low emission zones respectively) have the maximum number of output connections and thus require the largest number of policy measures as preconditions. Examination of the nature of these measures confirms that the aforementioned nodes are policy measures with the broadest spectrum.

Nodes 99, 75, 17 and 98 (airport charges, taxes based on fuel consumption and weight, rail freight, and excess tax for aircraft fuel respectively) have a very low number of inputs. Thus, these nodes are not preconditions for many nodes and investigation of their nature confirms that they are isolated/special measures that do not affect many other ones.

Several other network features, such as robustness, eccentricity and graph colouring, should also be investigated for potential use in the refinement and evaluation of policy alternatives. In addition, multivariate statistical analysis should be explored to find correlations among measures in the network based on their internal properties and relations.
6.2. Generation of the policy tree

The next step in the development of the DSS was the generation of possible combinations of policy measures. A tree structure was utilized for exploring the space by generating different alternatives using policy measures as building blocks (Figure 6). A tree is formally defined as an acyclic connected graph where the node set can be divided into one root node, and an arbitrary number of inner and leaf nodes. The root node is in the topmost position of the tree, and it expands (grows) downwards (Cormen et al., 2001). The concept of hybrid tree is used in this work to combine targets, goals and policy measures in the same structure. As a result, two separate dimensions of the tree became engaged with each other, namely the goals of the system and the measures for achieving these goals.

The tree has two main components:

1. The user-generated segment.

This segment is the starting point for the creation of the tree and deals, mainly, with the targets and goals. To avoid conflicts due to the presence of the same node in different branches of the tree, a unique identifier (ID) is assigned to any goal/measure that is added to the tree. Using the unique ID allows tracing back to the specific policy measure and makes it possible to have multiple instances of the same measure.

Figure 13 depicts the target and goals structure generated in Mathematica after the first step of the tree generation. In a future version of the DSS the goal structure will be more complex and multilayered; at this stage the focus was to create a structure as a proof of concept. The tree starts with the target as the root node. The two nodes connected to the target are G1 and G2, representing the goals for reducing emissions through decreasing transport usage and increasing transport efficiency, respectively. The leaf nodes in Figure 13, P1 to P9, represent nine subgoals related to G1 and G2. These subgoals were extracted from an analysis of the VIBAT report ((Banister & Hickman, 2006b). resulting in the identification of nine common goals throughout all the scenarios in VIBAT.
After creating the target and goals structure, the next step is to connect it with the policy measures, in effect, gluing the user and computer-generated sections of the tree. In order to establish the link between these two segments, relations were defined between the user-defined goals and the policy measures. Figure 14 illustrates the final view of the user-generated target and goals structure with the added layer of policy measures enabling the hybrid tree structure to grow automatically.

2. The computer-generated segment.

In this step the algorithm automatically grows the tree based on the relations defined among policy measures and the maximum allowed number of policy measures in a package. The algorithm starts by identifying the leaf nodes. The list of user-defined relations is examined for each leaf node, and the relations that had the reference policy measure as their source node were extracted.

The next step was to backtrack and check whether the sink node of each specific relation is present in the branch. Repetition of a node in the tree structure is not permitted as it results in the creation of cycles in the structure, which contradicts one of the fundamental features of the tree data structure, i.e. being acyclic.
Repeated nodes arise as a result of cycles in the network of relations between policy measures (more on cycles in the next section). If the sink node does not exist in the branch leading to the leaf node, the sink node in the relation is added to the tree and assigned a unique ID. The next level of the tree is generated when all of the current leaf nodes are processed (a breadth-first approach). Layers are added to the tree recursively based on the aforementioned algorithm. The termination criteria is attained when either the maximum number of policy measures is reached, or all relevant nodes in the database have been considered. The later happens when the sink node is already present in the branch leading to the leaf node, or when the leaf node has all of its possible nodes connected.

The resulting tree was checked manually and was found to be correct. Due to the size of the tree it is not computationally feasible to compare all of the possible policies (combinations of tree branches). In order to limit the size of the tree it might be beneficial to apply initially some of the criteria more stringently.

Figure 15 depicts the generation of the tree branch based on the methodology described. The level of complexity arising from generation of a single branch of the tree can be extremely high. The bottom tree in Figure 15 illustrates the point showing the full expansion of a single branch with 17 nodes.

Growth of the tree as described follows a breadth-first methodology, where all of the leaf nodes grow one level at a time with each iteration in the algorithm. It is also possible to use a depth-first methodology and grow the branches one at a time. In the final version of the DSS both methodologies will be available and a user will be able to apply them based on his/her preference.
The depth-first methodology can reduce the computational time and complexity of the tree structure if
the user decides to explore specific branches only. Tree visualisation can be carried out using a
variety of software. Mathematica has its own tree plotting function, TreePlot. Alternatively, the data
can be converted to a Dot language format for use with GraphViz, or with other visualisation software
using standards such as GraphML (Brandes et al., 2002), GML (Himsolt, 1996), etc.

6.3. Identification of Cycles

A large number of cycles consisting of five or more policy measures were identified in the network.
Two alternative methods for cycle identification were used. One was to record the list of nodes in a
branch when the termination criteria was reached due to repetition of a node, indicating the existence
of a cycle. In addition, the ExtractCycle function in the Combinatorica package of Mathematica can
be used to return a list of maximal edge-disjoint cycles in the network (Pemmaraju & Skiena, 2004).

Figure 16 illustrates an example cycle in the network of measures and their preconditions. In order to
favour modern urban design (“new urbanism”) in the development of cities, a precondition is to move
towards clustered land use and providing different functionalities in each district of a city. A
prerequisite for such development is the creation of low emission zones to attract residents to the
clusters, which in turn may be achieved by reducing car emissions e.g. through car-free planning. In
order to have successful car-free planning other means of transportation such as public transport,
cycling and walking need to be promoted. In turn, in order to have a successful switch towards the
use of bicycles and walking, cities should be compact so that travel distances are reduced. Lastly,
such compact cities can be created by moving towards a new urbanism approach in city planning.

Analysis of the relations between the individual policy measures helps in better understanding the
cycles. The knowledge gained through this analysis will be used to break the cycles in the most
appropriate manner, leading to a feasible order of implementation for the policy measures with
reduced overall cost and implementation time. In the hypothetical situation where all the measures
that form a cycle have the same strength, cost, implementation time, risk, etc. the order of
implementation does not matter (assuming that the measures do not have relations outside the cycle).
However, in a realistic scenario the degree of importance of the measures, cost, implementation time,
etc. differs, and through their appropriate scheduling significant gains can be made.
7. Current Limitations and Future Work

7.1. Current Limitations

The decision support system has a number of limitations. They can be assembled into four groups:

1. Data availability.

The VIBAT project report and its associated calculations were used as the primary source of data for the DSS. In cases where the data required was not explicitly given, the project reports were examined for implicit clues. If this examination did not yield satisfactory results, data was then generated through analysis of other available resources, and in the rest of the cases specified subjectively. This last approach has allowed us to explore and understand the problems facing the definition of the properties of the measures and the creation of the DSS structure. An incremental refinement of the data will take place with the support from experts.

2. Nature of the policy measures.

Policy measures used in the VIBAT project are assumed to be at the same level of abstraction, however, they range from being geared towards individuals to more generic measures covering a
broad spectrum. Additionally, the VIBAT project is not comprehensive in terms of behavioural measures, which in turn results in a lack of consideration for aspects such as public opinion, political climate, trends, etc. In due course, the abovementioned issues can also be considered with the help of transport policy experts.

3. Nature of the type of relations among measures.

Currently only one type of relation, i.e. precondition, exists among measures and it is assumed that it has the same level of importance for every pair of nodes, which is not realistic. The VIBAT project did not explicitly address the issue of relations among measures and thus the relations used in the DSS were the result of a subjective analysis. There needs to be a refinement and validation of these relations by transport policy experts. The first issue will be addressed through the definition of other types of relations, such as synergies and contradictions, and by switching to a weighted graph representation.

4. Network analysis.

The analysis of the network of preconditions is in its early stages. Aside from addressing the issues mentioned in the previous item, further development is required to perform a more inclusive and rigorous analysis of the network and its properties.

7.2. Future Work

Currently a third prototype is under development; it addresses items 1, 2 and 3 in Section 7.1. Furthermore, it focuses on the evaluation of the policy tree branches for the creation of policy packages and clusters, the comparison and visualization of the different alternatives, and the provision of sensitivity analysis capabilities. An agent-based modelling approach is being used for the development of the third prototype DSS. Moreover, integration of the DSS with third-party evaluation models, use of ontologies and the recording of decision rationale are also been explored.

1. Evaluation and comparison of alternatives.

The most important future development in terms of the system capabilities will be on the evaluation and comparison of policy alternatives at different hierarchical levels. This will result in creation of packages and clusters according to user-defined criteria. Multi-criteria decision analysis techniques will be studied and the best assessment method for the evaluation of different combinations of nodes for the creation of policy packages will be employed. At different stages of evaluation, results will be
compared with the baseline, which will be defined following the methodology developed in the VIBAT project (Banister & Hickman, 2005). Based on the assessments, one or several branches will be selected to form each package. The criteria for assessment will be related to the level of emission reduction achieved in each package, e.g. selection of a number of branches that will result in 0.5 million tonnes of CO$_2$ emissions reduction. Moreover, criteria such as shortest implementation time, minimum cost, etc. will also be considered. A similar procedure will be employed in the formulation of clusters.

Once the evaluation and comparison of the alternatives has finished the results need to be validated. There are three possible bases for comparing the results of a model during its validation: (1) with respect to the real system; (2) with respect to the results of another model; and (3) with respect to what would be expected by the experts in the specific field (North & Macal, 2007).

In case of policy formulation and design, it is not possible to compare the results with respect to the real system, as it would require the implementation of the policies beforehand. For instance, in the study undertaken, which deals with 60% reduction of emissions in transport sector by the year 2030, this would imply waiting for more than two decades to compare the predicted results from the DSS with a real system implementation. In this study, we intend to compare the results with those from the VIBAT study and seek the opinion of transport policy experts.

2. Development of an advanced visualisation system.

The visualization system will assist the user in the comparison of alternative policy hierarchies and examination of variations. The system will display, for each package, its degree of target achievement and its likely consequences and relative trade-offs in terms of implementation time, cost, etc. Where possible, this information will be complemented with details on the risks, uncertainties, and the constraints for implementation. In addition, providing editing capability of the tree structure through GUI is under consideration.


In addition to development of the evaluation and comparison and visualization modules, the ability to use sensitivity analysis to observe the effects of change will be developed. The feature could be used, for instance, in cases such as delays in implementation of a measure, replacement of a measure with a new measure, and failure of a policy measure. The effect of such occurrences could be analyzed on other policy measures and on the overall policy and the robustness of the envisaged alternatives with regards to such occurrences could then be examined.
4. Use of agent-based models

An agent-based model is a system for the simulation of the interactions between autonomous entities and thus allows the exploration of the overall effects of the individuals on the whole of the system. In the implementation being developed each policy measure has a set of interests which will result in cooperation with likewise measures or adaptation to the conditions, resulting in the creation of policy packages. With a multi-layered approach, the same behaviour will result in the creation of policy clusters.

8. Conclusions

The purpose of the research is to facilitate the design of policies and improve the resulting policies by using knowledge gained in other fields that address design issues, mainly from process design and synthesis. The focus has been directed towards the similarities between process and policy design with the specific aim of introducing a new framework and systematic thinking to the problem of policy formulation. A working prototype decision support system has been developed; it facilitates the design of transport policies that aim to achieve environmental targets. In particular, the software will help decision makers in selecting appropriate policy measures to achieve a reduction in transport related greenhouse gas emissions. This research constitutes the first step towards the development of a general family of computer-based systems that support the design of policies to achieve environmental targets – not only for the transport sector, but also for areas such as energy, biofuels/food security, water, etc.

A six-step framework and a decision support system based upon it have been proposed to achieve the overall objective. The details and rationale behind the developed framework and the DSS were described in Sections 4.2 and 5, and some of the results achieved were presented in Section 6. In particular: (a) an interface to define the targets, goals and preferences, and a library of policy measures; (b) the specification of precondition relations among policy measures and the generation of the resulting network; (c) the identification an analysis of a large number of cycles in the network; and (d) a simple method to determine the order of implementation and clustering of policy measures. In addition, combinations of policy measures for the development of policy packages were generated and represented in a tree data structure.

The proposed method and computer implementation is fundamentally different from the tools commonly used in the transport sector and intended to assist (not replace) transport policy makers, and complement (not substitute nor compete with) existing mathematical modelling tools. It should be emphasised that the decision support system described in this document is intended for the
generation of different alternatives and their initial screening and not for their evaluation (e.g. via simulation).

The results from the research will be a fresh contribution to the methodological development of policies (with transport as a case study) and the results have the potential to:

1. Accelerate the design of new transport policies and the update of existing ones.
2. Improve the chance of policy success through the exploration of more alternatives for target achievement by supplying provision in the generation, representation and evaluation of alternatives and supporting the evolutionary nature of the design by incremental operation.
3. Facilitate the specialisation of transport policies for different regions and points in time and provide support in the integration of different systems, tools and information for decision-making.
4. Improve the adequacy and effectiveness of transport policies by explicitly accommodating the diversity of preferences from different types of stakeholders.
5. Enhance the communication between different stakeholders (policy makers, experts, etc.).
6. Automate some of the tasks such as documentation, evaluation, control, etc.

A trend in decentralization is apparent in the medical field with the introduction of tailor-made diagnosis and treatment solutions, in the energy sector through the introduction of small-scaled decentralized power generation units, and in the policy realm by empowering the city councils and local authorities in decision-making. Use of DSS systems can help decentralized decision-making. The case of VIBAT-London project in the transport sector (VIBAT, 2008) is an example of how local authorities can take the initiative in examining emission reduction possibilities and coming up with tailor-made localized solutions. A DSS system can have national/international goals set by experts from the government and legislative bodies and provide localized solutions for different regions and cities according to their specific conditions and resources.

9. Acknowledgments

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### 10. Glossary

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<tr>
<th>Acronym</th>
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<tr>
<td>AHP</td>
<td>Analytical Hierarchical Process</td>
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<tr>
<td>API</td>
<td>Application Programming Interface</td>
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<tr>
<td>CBA</td>
<td>Cost-Benefit Analysis</td>
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<tr>
<td>CDP</td>
<td>Criterium DecisionPlus</td>
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<tr>
<td>CRUD</td>
<td>Create, Read, Update and Delete</td>
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<tr>
<td>DSS</td>
<td>Decision Support System</td>
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<tr>
<td>GIS</td>
<td>Geographical Information Systems</td>
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<tr>
<td>GraphViz</td>
<td>Graph Visualization Software</td>
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<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
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<td>ID</td>
<td>Identifier</td>
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<td>JDBC</td>
<td>Java Database Connectivity</td>
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<td>JPA</td>
<td>Java Persistence API</td>
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<td>MCDA</td>
<td>Multi-Criteria Decision Analysis techniques</td>
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<td>MCS</td>
<td>Monte-Carlo Simulation</td>
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<td>SMART</td>
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<td>VIBAT</td>
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### 11. References


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