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Which policy first? A network-centric approach for the analysis and ranking of policy measures

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Abstract. In addressing various policy problems, deciding which policy measure to start with given the range of measures available is challenging and essentially involves a process of ranking the alternatives, commonly done using multicriteria decision analysis (MCDA) techniques. In this paper a new methodology for analysis and ranking of policy measures is introduced which combines network analysis and MCDA tools. This methodology not only considers the internal properties of the measures but also their interactions with other potential measures. Consideration of such interactions provides additional insights into the process of policy formulation and can help domain experts and policy makers to better assess the policy measures and to understand the complexities involved. This new methodology is applied in this paper to the formulation of a policy to increase walking and cycling.

Keywords: policy formulation, network analysis, multiple-criteria decision analysis, transport policy, walking and cycling

1 Introduction

Many policy problems are commonly referred to as ‘messy’ (Ney, 2009) or ‘wicked’ (Rittel and Webber, 1973) due to the inherent technical, institutional, and political difficulty of addressing them. As our understanding of the complexity of policy problems is increased, as experience is gained in trying to tackle them through various policy actions, and as the knowledge and experience is widely shared, policy makers are rarely short of options for ‘action’. Rather, policy makers more often might face the opposite problem, that of having too many avenues and options to explore.

Considering a rational policy maker (and putting aside the debate on the extent to which, if at all, policy making follows a ‘rational’ goal-oriented process, as questioned by Kingdon (1984), or an analyst advising the political decision maker on the best way forward to address a policy problem, the number of direct actions (policy measures in this paper) to take is considerable. With respect to transport policy, for example, the VIBAT-London study, (Hickman et al, 2009) identified over 120 individual measures to combat climate-change challenges in London; the Policy Scenarios for Sustainable Mobility project (POSSUM) (Banister et al, 2000) identified close to 100 measures to advance sustainable transport in Europe; the Visions-2030 project (see Tight et al, 2011) (used as a case study in this paper) identified 142 measures to promote walking and cycling (W&C) in cities.

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For policy makers, there is the real problem of not seeing the wood for the trees. What should be done and what should be done first is becoming an increasingly complex question given the options available, the information (empirical and/or theoretical) on each, and the various political and advocacy influences on policy making. Moreover, policy makers have bounded rationality[(1)] (Simon, 1957) and perhaps surprisingly, with all this information and opportunities for action, there is evidence for inertia and a lack of consideration of more than a few options (Kelly et al, 2008).

There are known to be no 'silver bullets' in policy making. What is needed to advance a certain policy objective successfully and efficiently is a package of policies (Banister et al, 2000; Feitelson, 2003; May and Roberts, 1995; OECD, 2007). A 'policy package' can be defined as "a combination of individual policy measures, aimed at addressing one or more policy goals. The package is created in order to improve the impacts of the individual policy measures, minimise possible negative side effects, and/or facilitate interventions' implementation and acceptability" (Givoni et al, 2010, page 4). Thus, the key for policy packaging is that more than one measure is included and the relations between the measures are mutually supporting and are explicitly considered. The need for multiple-measure policies is generally acknowledged, but while the importance of policy packaging is widely recognised, there is little guidance on how multiple measures should be chosen.

The decision on what to start with in addressing a policy problem or a policy goal is not straightforward. To facilitate this step a new methodology is proposed to assist policy makers in exploring a large number of different types of measures simultaneously, while examining both their own properties and their relations with other measures. The methodology is based on the previously proposed six-step policy-formulation framework (Taeihagh et al, 2009a) and brings together two established and well-researched concepts: network theory and multicriteria decision analysis (MCDA). The methodology aims to provide a tool for policy makers to explore a large number of measures by visualizing and mapping the relations between them and by ranking them. The aim is not to provide a result or suggest a 'solution', but only to aid policy makers in exploring a large field of options and in understanding why certain policy measures appear to be better than others given their intrinsic properties (eg, implementation cost) and their interactions with other policy measures in the policy package. The methodology is generic and is based on input from the user, be it the policy maker (the term adopted in this paper), stakeholders participating in the policy formulation process, or various experts.

The remainder of the paper is structured as follows. In section 2 a literature review of the use of network theory in the social science context is provided, together with a review of the use of MCDA approaches. Details of the methodology proposed in this paper are given in section 3 and then described in section 4 in the context of the case study used to illustrate it. The results of the analysis are provided in section 5, while in the last two sections some concluding remarks are made and issues to be explored in future research are listed.

2 The use of networks in policy making and decision making

In this paper, we are interested in the use of networks as a tool to improve our understanding of the interactions between policy measures and to streamline and improve the policy-formulation process. One of the problems in policy formulation is the appropriate and effective processing of the information available about each individual policy measure, especially in cases where the experts are faced with many policy measures and even larger combinations between them. This problem is further exacerbated by considering the multiple types of interactions that often exist between the policy measures and by constraints on

[(1)] Simon (1957) coined the term 'bounded rationality' as the limit to the rationality of individuals due to the limits to the information they can have, their cognitive limitations, and time limits for making decisions.

time and resources. Such problems can explain the tendency to explore a limited number of alternatives (Kelly et al, 2008).

Cost–benefit analysis (CBA) techniques and MCDA techniques are commonly used in the policy domain. Often, the merits of the available policy measures are assessed on the basis of a polyvalent set of criteria and their associated weights using MCDA techniques, such as the analytical hierarchical process (AHP) (Saaty, 1980) or the simple multiattribute rating technique (Edwards, 1977). These techniques have also been the traditional techniques used in transport policy decision making, with a recent shift from CBA to MCDA, for example, in Europe (Grant-Muller et al, 2001) and especially in the UK (Glaister, 1999; Price, 1999). General directives and guidelines are available to support the selection of evaluation criteria: for example, those proposed by Guitouni and Martel (1998) and Dodgson et al (2000). Traditionally these directives and guidelines have been used in transport policy decision making and are the ones used in selecting the criteria for our work.

Some new evaluation techniques have integrated network concepts with multiple-criteria decision making; examples include: a new approach that combines several MCDA methods using network structures introduced by Hanne (2001); a generic decision-making procedure and framework that integrates Bayesian belief networks with MCDA developed by Fenton and Neil (2001) and Watthayu and Peng (2004); and the reasoning map concept, which enables multicriteria evaluation of decision options using causal maps proposed by Montibeller et al (2008). Importantly, the analytical network process proposed by Saaty (1996) is a general form of AHP geared towards capturing the complexities that arise from the interdependence of the criteria between themselves and vis-à-vis alternatives, rather than towards the multiple forms of interdependence among alternatives. As a result, as the number of elements and their interactions increase, the use of the technique becomes more complex in a nonlinear fashion. An alternative proposed here is the use of a network-centric MCDA approach, which allows policy measures to be ranked according to explicit information drawn from their internal properties and the interactions with other policy measures.

3 The policy measures analysis and ranking methodology (PMARM)

Faced with a specific (transport) policy problem, policy makers have many options for action, far too many to be able to consider all systematically. Below, a methodology is proposed, and later tested, to assist policy makers to consider and rank a large number of policy measures systematically and to identify a measure, or a set of measures, to implement first. Such ranking is based on predefined criteria: the effectiveness of a measure in achieving (part of) the policy target(s), and its efficiency in doing so (accounting for the resources required to implement it, including overcoming any financial, technical, institutional, and acceptability obstacles). The proposed methodology, and its components and stages, is illustrated in figure 1.

The first step in the proposed methodology is to draw up a list of measures of various types (such as infrastructure, regulation, financial, and marketing) that can directly affect the policy target: that is, an inventory of primary measures. Next, the criteria against which to examine the measures are decided. As appropriate, given their nature and the information available

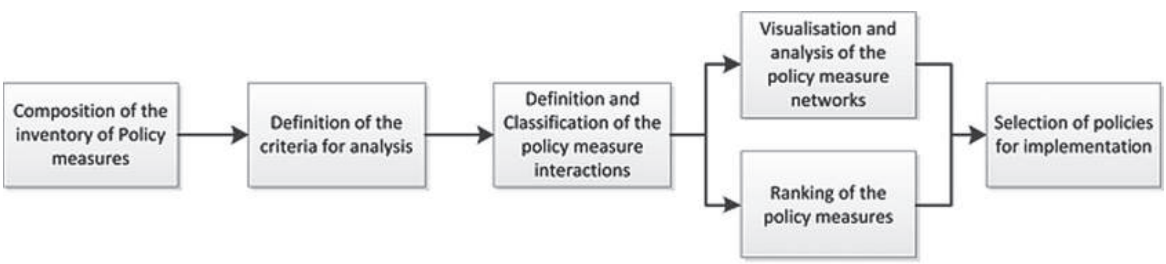

Figure 1. The proposed methodology, its components and stages.

for the specific circumstance, the criteria can be measured in a quantitative or qualitative manner. After the properties of each measure are assessed by the analyst, they are translated into scores [for example, ranging from 1 (low) to 5 (high)]. This stage of inputting the basic information for each of the measures in the inventory completes the preoperational stage.

The above initial stage follows standard MCDA practice and indeed can be used to generate a ranking of measures. However, the next steps in the proposed methodology provide additional and crucial information that produces more robust decision making and different results from those produced by the traditional MCDA approach. These steps are:
(1) definition and classification of the relations between policy measures;
(2) visualization and analysis of the networks of relations between policy measures;
(3) ranking and assessment of the policy measures.

3.1 Definition and classification of the relations between policy measures

Five types of mutually exclusive relations among policy measures are considered and defined: precondition (P), facilitation (F), synergy (S), potential contradiction (PC), and contradiction (C) (see table 1) (Taeihagh et al, 2009b). The five policy-measure interactions were deemed to be sufficient to capture the interactions between policy measures. For example, a policy measure is considered to have a facilitation effect if it makes another policy measure more politically acceptable. The methodology described is capable of handling additional types of interactions if the experts choose to define them.

Table 1. Five types of relations among policy measures.

Relation	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 facilitation relation is also a direct relation.
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.

The classification of the individual relations among pairs of policy measures is carried out by the domain experts (eg, policy maker or analyst) and stored in an adjacency matrix. In the specific case discussed in this paper, transport specialists and planners are considered to be domain experts. This task can be done individually or in a group setting. Using a collective decision-making procedure for identifying the relations is advantageous and is likely to increase the robustness of the analysis, since complex relations often exist between the policy measures and at times it can be difficult to distinguish the relation type clearly. We do not focus on the differences of opinion that various experts might have. In the case of this study, it was not difficult in a group setting of three experts to reach an agreement with regard to the relations. However, we acknowledge the importance of this issue and plan to carry out studies on the subject in the future.

To store the relations in a network consisting of *n* nodes, an *n* by *n* adjacency matrix is created in which each element represents a relation between the corresponding row and column nodes. In this study, the relations between policy measures (edges) are not weighted, yet this is an option for further development. Initially a multirelational adjacency matrix is used for storing the different types of relations among policy measures. The method requires the analysis of only two measures at a time, in total isolation from the other measures in the inventory, thus simplifying the task for the analyst. Still, when dealing with a large number of policy measures that often have complex relations, it is inevitable that inconsistencies will arise and that in some cases a precise identification of the relation among policy measures will be difficult to determine. For this reason, an iterative approach, where at least one iteration is performed for the identification of each type of relation, is important for the identification of inconsistencies and errors. The next step, the 'visualization' based on the defined interactions (edges) and policy measures (nodes), also serves as a final check on the integrity and validity of the defined relations.

3.2 Visualization and analysis of the policy-measure networks

Figure 2 depicts a sample multirelational adjacency matrix. An edge exists between nodes *a* and *b* if element (*a*,*b*) of the matrix is equal to P, F, S, PC, or C (see table 1), depending on the type of relation between the two nodes. Where there is no edge between *a* and *b*, the element (*a*,*b*) is equal to 0. In cases of undirected relations elements (*a*,*b*) and (*b*,*a*) both have the same value.

Figure 3 is the visualization of the sample multirelational adjacency matrix presented in figure 2. In this network, nodes 2 and 3 facilitate node 1, nodes 1 and 4 have a synergistic relation, nodes 2 and 4 potentially contradict each other, and nodes 2 and 4 are preconditions for node 3.[2]

When dealing with a large network, visualization of the data becomes difficult using a single multirelational network. Therefore, the multirelational adjacency matrix formed in the previous step is decomposed into individual adjacency matrices that only entail a single type of relation (in our case, five networks corresponding to the five relations defined in subsection 3.1). Once the separate network visualizations have been checked and the experts involved in the process are satisfied with the data, an analysis of the networks can be performed.

ID	1	2	3	4
1	0	F	F	S
2	0	0	0	PC
3	0	P	0	P
4	S	PC	0	0

Figure 2. Sample multirelational adjacency matrix. See table 1 for definitions.

[2] The direction of the arrows in figure 3 and in subsequent network visualizations may be counterintuitive, but is determined by the software used.

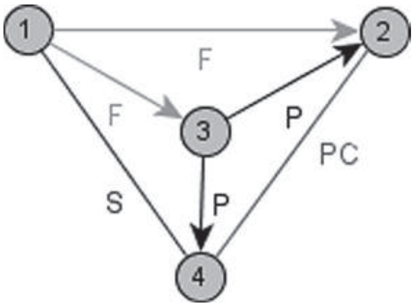

Figure 3. Network visualization of the sample data. See table 1 for definitions.

3.3 Ranking and assessment of policy measures

For the ranking of policy measures, we focus on the precondition relations; this approach is used for simplification in illustrating the proposed methodology. Full consideration of the other relations can be included when the methodology is developed further.

The precondition relations aggregate the nodal information of each criterion: for example, the total cost equals the sum of the cost of the policy measure and its preconditions. Other calculations and aggregations are made in the same manner following a traditional MCDA approach but also accounting for the precondition measures. In all the scoring calculations the following rules apply: (a) a policy measure will only work if its preconditions have been implemented; (b) it cannot be generically prescribed that all of the preconditions can be implemented concurrently (in parallel). Therefore, in the various calculations related to timescales (described below) the total time required for implementation is the sum of the implementation time of a policy measure and those of its preconditions.

4 Applying the PMARM: promoting W&C in cities

Transport, or mobility, is at the heart of our society. While it is very much the driving force of modern life style, economic growth, and globalization, it is also a major contributor to environmental degradation and, specifically, to air pollution and climate change. The approach currently advocated to improve the balance between the benefits and the costs of society's mobility needs is sustainable transport or 'sustainable mobility' (Banister, 2008). In this context, a main policy objective is to encourage the use of nonmotorized transport or 'active travel'. In other words, increase the levels of W&C [see, for example, Boarnet (2006) and Tight and Givoni (2010) in the special issues of the *Journal of the American Planning Association* and *Built Environment*, respectively].

The potential for increasing the use of W&C is substantial. In Britain, for example, 66% of trips are under 5 miles in length and 19% of trips are under 1 mile (DfT, 2009)—distances suitable for W&C. The use of both modes, however, has been in long-term decline. Cycle traffic in Britain declined from 23 billion to 5 billion passenger-km between 1952 and 2006 (DfT, 2007), despite the large increase in population, especially in cities, over the same period. Many other countries witnessed the same trend, but a few successfully reversed it, thus providing evidence that policies to promote W&C can succeed (Pucher and Buehler, 2010). In this context, the "Visions of the role of walking and cycling in 2030" research (Tight et al, 2011) seeks to develop and evaluate three alternative visions for the year 2030 in which W&C play a substantially more central role in urban transportation than is currently the case. In the research, almost 150 individual measures to promote W&C were identified. A combination of these measures is necessary to move from the situation in 2010 where W&C represent 26% of trips in urban areas, to a future situation in 2030 where W&C represent about 70% of trips in urban areas [see figure 4 for the visualization of scenarios and Tight et al (2011) for more details].

To achieve the vision illustrated in figure 4, a well-designed policy package is needed. Such a package should, for example, promote W&C and in addition aim to reduce car use. With so many options for action (about 150 measures and combinations of them) policy makers cannot be expected to be able to consider them all systematically. To operate the proposed methodology three inputs are required from the analysts: a list of measures to consider (the inventory), the internal properties of each measure, and the type of relation between each pair of measures in the inventory.

To test the methodology and simplify its application and illustration, thirty-eight measures were selected for inclusion in the analysis. They were selected to represent different types of measures (such as infrastructure, regulation, and education) which are expected to affect the propensity to walk and cycle but in different ways (such as through pull and push factors, changes in W&C conditions, changing attitudes, and effecting the use of other modes). The selection process was performed by one of the authors who acted as the ‘expert’ for the analysis described in the paper. In practice, we propose that this stage of scaling down the inventory of measures should be done through internal consultation and discussion within the relevant organisation. The list of thirty-eight measures, which represent the inventory of *primary measures*, is presented in table 2. The policy measures were selected on the basis of overall impact (major interventions as opposed to small fixes) and variety (inclusion of policy measures of different types).

After selecting thirty-eight measures for the inventory, eight attributes for each measure were considered, representing two dimensions of measure characteristics, one with respect to its *performance* and the other with respect to its *implementation* (see table 2). The latter represents the ‘transaction costs’ related to implementing a measure, which may be

Figure 4. [In colour online.] Visualization of a current situation and three visions of future environments for walking and cycling (top left is the current situation) (source: Timms and Tight, 2010).

Table 2. Policy measures used in the study and their properties.

No.	Measure title	Measure properties							
		cost	effectiveness	timescale of implementation	timescale of lasting implementation effect	time from end of implementation to effect being felt	technical complexity	public (un)acceptability	institutional complexity
2	All public transport fully accessible	medium	low	medium	long term	immediate	low	low	low
3	Maintenance of W&C infrastructure	high	high	medium	medium	immediate	low	low	low
6	Regular public realm maintenance/ cleaning	medium	medium	short	short	medium	low	low	low
7	Widespread Sheffield stands	medium	medium	medium	long term	medium	low	low	low
8	Opt-out travel training for all school children	medium	low	medium	long term	long	medium	low	medium
10	Fine-grained provision of quality public space	high	medium	long	long term	medium	medium	low	high
11	Raised pedestrian crossings instead of dropped kerbs	medium	low	long	long term	immediate	low	medium/high	low
13	Tree planting/greenery	medium	low	medium	long term	medium	low	low	medium
21	Minimum cycle parking in new developments	low	high	short	long term	medium	low	low	medium/ low
26	Freight windows	low	low	short	long term	immediate	medium	medium/high	high
28	Strict liability legislation	low	medium/ high	long	long term	long	low	high	high
29	Workplace crèches	medium	low	long	long term	immediate	high	low	high
30	Flexible working hours	medium	low	long	long term	immediate	high	medium	high
31	Green belt	low	high	long	long term	long	high	high	high
33	Smart ‘oyster-style’ cards for all mobility	medium	low	medium	long term	medium	high	low	medium
34	Mandatory ring fencing of W&C funds	low	high	medium	long term	long	low	low	medium
36	All city parking for private cars to be pay and display or permit	low	low	medium	long term	immediate	low	medium	low
38	Removal of ‘rat runs’ for motorized vehicles	low	low	short	long term	immediate	low	medium	low

42	Velib-style cycle hire scheme (including ‘accessible’ bikes)	high	high	medium	long term	medium	medium	low	low
47	Dutch-style railway parking facilities	high	medium	medium/long	long term	medium	medium	low	medium
52	Community leisure walks and bicycle rides	low	low	short	medium	long	low	low	low
53	Walking buses to school for young children	low	medium	short	long term	long	low	low	medium
54	On-road cycle paths	medium	high	medium	long term	immediate	low	medium	low
56	Pavement widening	high	high	medium/long	long term	immediate	medium	low/medium	medium
57	Dutch-style segregated cycle paths	high	high	high	long term	immediate	high	low/medium	high
61	Mandatory ‘core’ W&C networks	high	high	high	long term	medium	high	low	medium
70	Widespread private car-sharing schemes	medium	low	medium	medium	medium	low	low	low
72	City-wide 20 mph speed limit	low	high	medium	long term	medium	low	medium/high	low
75	Limits on car advertising	low	low/medium	short	short	long	low	low	high
78	Contraflow bicycle lanes in one-way streets	low	high	short	long term	immediate	low	medium	low
79	Public fitness campaign	medium	low/medium	short	short	medium	low	low	low
86	Smart bicycle storage units	medium/ high	medium/high	medium/high	long term	immediate	medium	low	medium
87	Cycle traffic enforcement	medium	medium	short	long term	immediate	low	medium	low
94	Retrofitting cul-de-sacs for W&C connectivity	medium/ high	high	medium	long term	immediate	high	medium	medium
103	Private motor vehicle ownership restrictions	low	high	short	long term	medium	high	high	high
112	Car-free housing developments	low	high	high	long term	medium	low	medium	low
115	Consolidated neighbourhood goods delivery	medium	low	medium	long term	immediate	medium	low	medium
118	Orange NEV/HPV routes 20 mph	high	medium	high	long term	medium	high	medium	medium

W&C = walking and cycling; NEV = neighbourhood electric vehicle; HPV = human-powered vehicle.

considered as the cost of overcoming political and institutional barriers. Transaction costs can be defined as "the costs of deciding, planning, arranging and negotiating the action to be taken and the terms of exchange when two or more parties do business; the costs of changing plans, renegotiating terms, and resolving disputes as changing circumstances require; and the costs of ensuring that parties perform as agreed" (Milgrom and Roberts, 1990, page 60). Following Dodgson et al (2000), completeness, operationality, mutual independence, and other relevant factors were considered in the definition of the criteria.

The five 'performance' attributes considered were cost: the financial cost of implementing the measure; effectiveness: the effectiveness of the measure in affecting the policy target; timescale of implementation: time required to implement the measure; delay: the length of time from implementation of the measure to the time its effect is felt; and timescale of effect: the length of time during which the measure's effect will be felt after implementation. The three 'implementation' attributes considered were technical complexity: the degree of technical challenges for the implementation of the measure; public unacceptability; the likely degree of public opposition to the measure; and institutional complexity: which is related to existing institutional structure and practices that might hinder implementation, for example, issues related to jurisdiction over deciding and implementing a measure. These three additional properties have been used [eg, by de Bruin et al (2009)] to rank different measures to address climate-change policy. All of the eight criteria/properties were qualitatively assessed by the analyst using scores ranging from 1 (low) to 5 (high). The initial five performance attributes based on the properties of the policy measures were later streamlined into three properties for the assessment. The three implementation complexity attributes (the efficiency dimension) have not been streamlined.

Next, identification of the relation between each pair of measures is required. This process, while essential for the analysis and the main innovative aspect of the ranking methodology, is also useful in forcing the analyst to consider explicitly the nature of each measure and how it interacts with other measures. The task, while on the whole tedious and for certain measures difficult, is made easier by requiring the analyst to consider only two measures at a time. Eventually, a full matrix (38 × 38) representing all the interactions between measures in the inventory was produced. The value of the analysis using the proposed methodology depends very much on this stage and thus validation of the relations is crucial.

In order to compare and highlight the effect of the policy-measure relations on the ranking result, two approaches were used for analysis: the traditional MCDA and the network-centric MCDA. In both cases, ranking was based on the weighted summation of the score for each policy measure. Weights used for the criteria in each set were identical in both approaches.[3] In the traditional MCDA case, policy measures were ranked according to their scores based on their intrinsic properties and assuming independence between the policy measures. However, in the network-centric approach interactions with other policy measures were taken into account alongside the intrinsic properties of the nodes.[4]

The following calculations were performed to derive the score for a measure in the network-centric MCDA approach. Total implementation time equals the sum of the timescale of implementation and the delay for the policy measure and its preconditions. Total effect equals timescale of effect of the policy measure multiplied by the policy measure's effectiveness,

(3) The paper is more concerned with the method than with the results it provides and therefore some elements of the analysis, such as assigning weights to the criteria, were based on the authors' judgment and expertise. The weights used were as follows. Performance ranking: total implementation time 20%, total effect 40%, cost 40%. Complexity ranking: technical complexity 20%, public unacceptability 40%, institutional complexity 40%.

(4) We have performed extensive sensitivity analyses and Monte Carlo simulations, and used a much larger set of measures. These results will appear in a forthcoming paper.

in this case without considering the effect of the preconditions, since determining the extent to which a policy measure is more or less effective due to the implementation of its precondition measures is difficult to quantify. For public unacceptability, and technical and institutional complexities the value associated with the policy measure is the sum of the scores it has for the individual measure and all its preconditions.

All the criteria in each set were assigned positive weights and were fixed to a sum of ‘one’. Every individual criterion within each set falls into one of the two categories of desirable and undesirable. A criterion is desirable when a high score is considered better, for example, and is undesirable when a lower score is considered better (that is, cost, total implementation time, public unacceptability, and technical and institutional complexities). In the first set (performance criteria), a mix of desirable and undesirable criteria were present. By using the reciprocal of the values associated with undesirable criteria, the scores were transformed to desirable (Grunig and Kuhn, 2009). The scores obtained in both desirable and undesirable categories were then expressed as a proportion of the sum of all the scores for each criterion and then were multiplied by the weight assigned to that criterion. By adding the policy-measure scores across both desirable and undesirable categories, the performance score was then calculated. Hence, the policy-measure with the highest score in the first set was ranked as the top policy measure in terms of performance. As all the criteria in the second set (implementation criteria) were undesirable, the policy measures scores were summed up and the policy measure with the lowest score was the top ranked: that is, the one with the lowest transaction costs.

In the network-centric approach, facilitation and synergy relations can be used to discriminate between policy measures in cases where there was a tie in the overall score (rank). For instance, a measure that has facilitation or synergy relations with other measures is preferred to one that does not have these relations. It must be noted that it is difficult to estimate the magnitude of these positive effects a priori and thus it is not possible to compare policy measures quantitatively in terms of the number of facilitations or synergies they have and from this conclude which one is more advantageous.

5 Analysis of measures to promote W&C

The results of the analysis of the thirty-eight measures to increase W&C are presented below. The analysis is context specific and depends on the analysts performing it and their input; its only purpose is to illustrate the use and scope of the proposed methodology.

5.1 Analysis and visualizations of the policy-measure networks

Below, each network is visualized separately and independently from the others using the Fruchterman and Reingold (1991) algorithm, which places the most-connected nodes in the centre of the network.

Figure 5 visualizes the potential contradiction network. It provides graphic information on combinations of measures that should be avoided, or at least be considered carefully before implementation. The ‘on-road cycle paths’ (54) node in the centre of the network is in potential contradiction with four other measures in the inventory and this might be a reason to opt for segregated cycle paths. The literature on the subject of on-road versus off-road cycle paths is rich and generally undecided (Forester, 2001; Pucher and Dijkstra, 2000) so local circumstances would have to be accounted for before a decision is made. The contradiction network consists of only two measures and is not presented.

Figure 6 visualizes the precondition network, which is much more complex. Without the possibility to consider only two measures at a time and without the visualization, it is difficult to imagine that policy makers would be able to infer similar information with respect to the precondition relations between measures and their implications. On the basis of the information used in this case, ‘car-free housing development’ (112) is only possible if four other measures

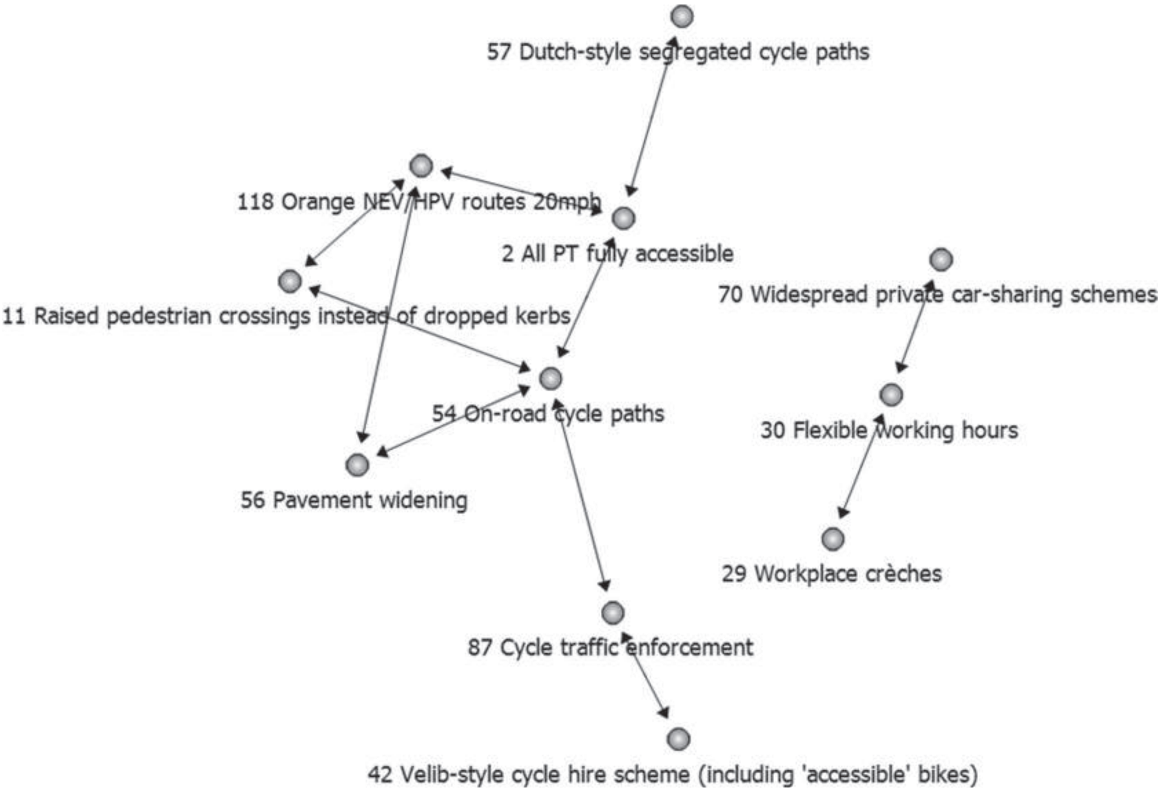

Figure 5. Visualization of the potential contradiction network. NEV = neighbourhood electric vehicle; HPV = human-powered vehicle; PT = public transport.

(2, 3, 61, and 70) are included in the package, and some of these measures have their own preconditions. For example, 'mandatory core W&C networks' (61) depends on 'mandatory ring fencing of W&C funds' (34). This does not necessarily mean that a measure such as 'car-free housing development' (112) should not be considered, only that its complexity must be recognized. The relations presented in figure 6 can also be interpreted as follows. 'Pavement widening' (56) is a measure which, if implemented, will enable the consideration of many other measures; thus it might be attractive to include it in a package of measures to increase W&C even if on its own it is deemed to have low effectiveness (although in this case it is judged to have high effectiveness). The centrality of a measure such as 'pavement widening' (56) might be overlooked without the visualization when considering a large inventory of measures and, at the same time, communicating the need for such a measure is made easier with the visualization. Interestingly, almost all the precondition network consists of measures related to infrastructure, implying the (perceived) importance of such measures.

Analyzing the facilitation and synergy networks shifts the focus from the implementation to the effectiveness aspect of measures to promote W&C. The level of complexity of the facilitation network is such that, in parts, it is difficult to make sense of its visualization (of course a larger image can solve the problem to some extent) and the limits of using visualization techniques for large networks should be recognised. Nevertheless, important information can be deduced. As in the case of the precondition network, two types of measures require special attention: measures that facilitate the effectiveness of many other measures (high in-degree)[5] and measures that are facilitated by many other measures (high out-degree). To assist in reading the facilitation network, table 3 provides the number of edges going out and into each measure in the network. Furthermore, the facilitation network can be visualized as two separate networks (figures 7 and 8) where nodes are scaled according to the number of links connected to them.

[5] A high in-degree of a node indicates a large number of edges are directed towards it, and a high out-degree indicates a large number of edges are directed out of it.

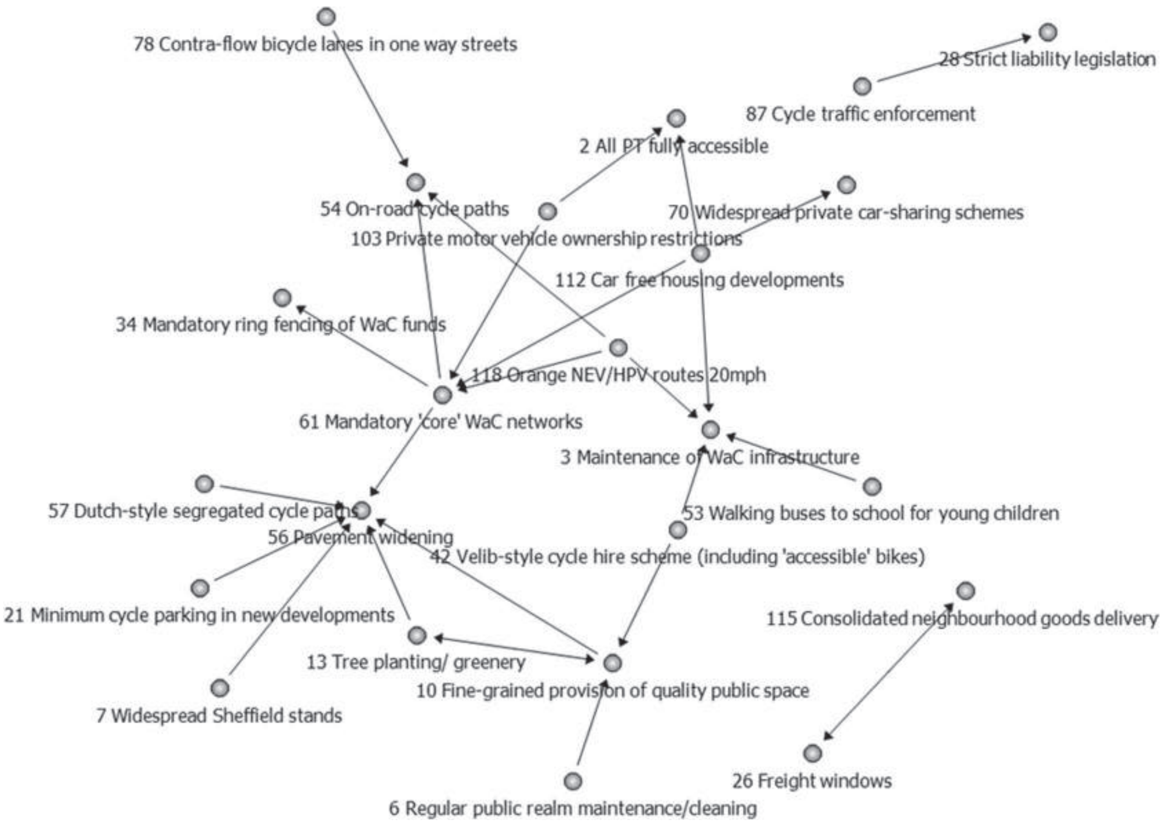

Figure 6. Visualization of the precondition network. PT = public transport; WaC (= W&C) = walking and cycling; NEW = neighbourhood electric vehicle; HPV = human-powered vehicle.

Measures that facilitate many other measures (high in-degree value in table 3 and many arrows pointing to them in figure 7) are of more interest to policy makers. ‘Mandatory core W&C networks’ (61) and ‘Mandatory ring fencing of W&C funds’ (34), (see figure 7) are both such measures that upon implementation facilitate the effectiveness of nine other measures each. Therefore, it will be important to try to include these measures in a package, after considering also their internal characteristics such as perceived effectiveness in contributing to W&C and their cost. It is important to remember that the relation between these two measures was defined as a precondition (34 is a precondition to 61) suggesting both should be included in a package and, if only one can be included (eg, for budget reasons), then it must be measure 34.(6)

The other side of the facilitation network (out-degree column in table 3, and figure 8) illustrates the extent to which a certain measure’s effectiveness can be enhanced by the implementation of other measures. Here, it is important to emphasize that facilitation is not defined as a restriction, but nevertheless it might be seen as a soft restriction. ‘Velib-style cycle hire scheme’ (42) stands out as the measure that more than any other measure can be made much more effective with the support of other measures (14 in total). While a measure which makes much sense when promoting cycling is a policy objective, it is clear that its success is facilitated, but not necessarily dependent, on a wide range of other measures. It might be that as more experience and knowledge is gained in this type of intervention some of the relations defined here would have to be changed to precondition relations. Similarly, the facilitation network also suggests that relatively ‘simple’ and cheap measures such as ‘community leisure walks and bicycle rides’ (52) and ‘walking buses to schools for young children’ (53) might

(6) In this case the interpretation is only partially applicable since measure 34 aims to deal with the budget constraint.

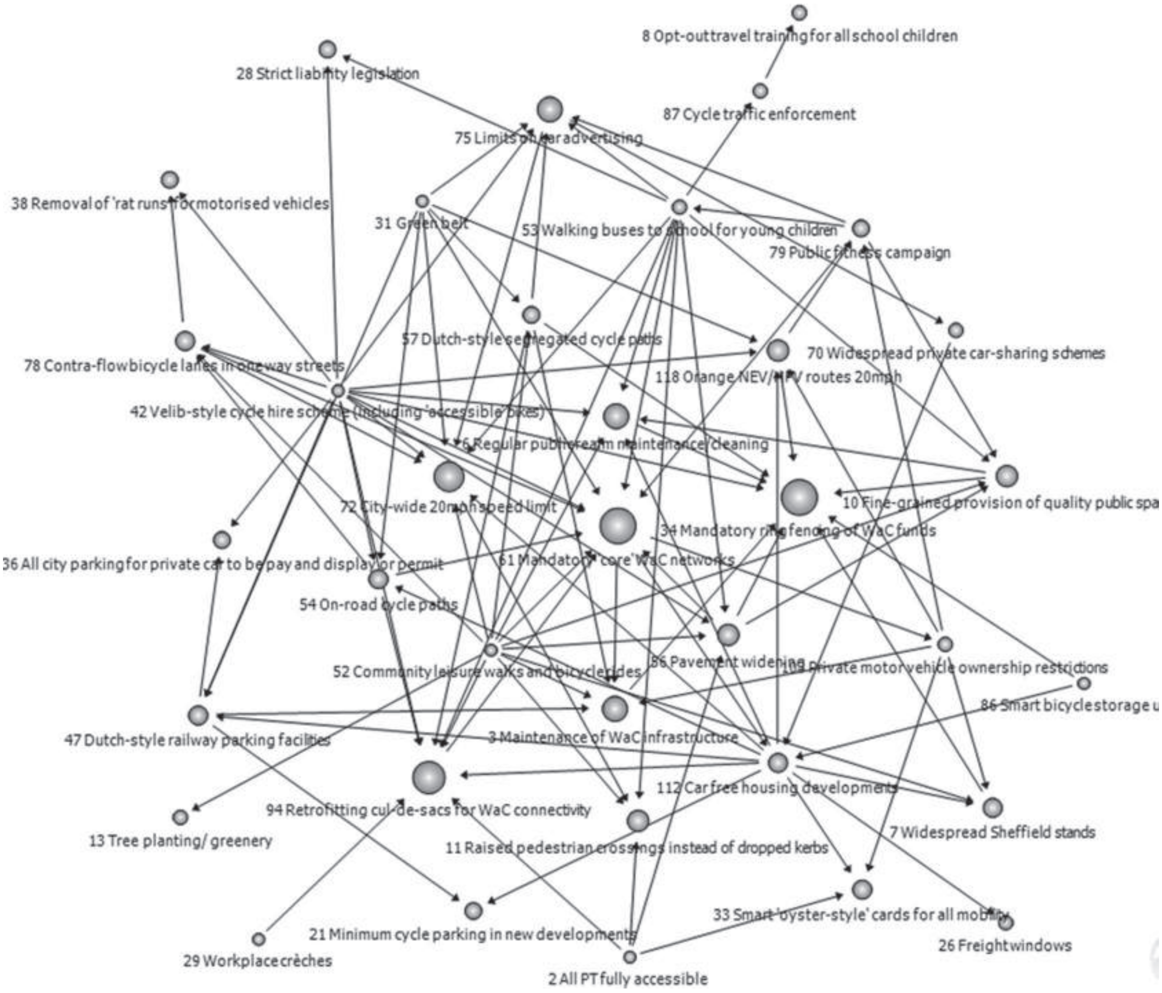

Figure 7. Visualization of the facilitation network scaled based on in-degree values. NEV = neighbourhood electric vehicle; HPV = human-powered vehicle; WaC (= W&C) = walking and cycling; PT = public transport.

have a real impact only when other measures have been implemented. The importance of considering a measure in the context of its relations with other measures is apparent.

Although it is one network, it is useful to present the facilitation network of relations between measures in two ways: one highlighting those measures which facilitate many other measures; that is, measures with many arrows pointing *to* them (measures which appear as a large nodes in figure 7, such as measure 61) and the other highlighting those measures that are facilitated by many other measures: that is, measures with many arrows pointing *out* of them (measures which appear as large nodes in figure 8, such as measure 42). This makes the facilitation network more legible and, more importantly, it clearly distinguishes between the two types of measures, The first types of measures are those will likely support—that is, facilitate the effectiveness of—other measures (the measures will large nodes in figure 7). The second types are measures that need support: that is, facilitation to increase their effectiveness (the measures with large nodes in figure 8). In other words, measure 61 is attractive since in addition to its own potential influence on W&C it can also influence W&C through its effect on all the measures it facilities; shown in table 3 and figure 7: 9 in total. At the same time, if policy makers consider implementing measure 42 they should consider the implementation of many other measures alongside it to increase its effect on W&C; table 3 and figure 8 show there are fourteen such measures.

Table 3. Representation of walking and cycling facilitation network.

Policy measure (ID from the original study)	Out-degree [a]	In-degree [b]
All public transport fully accessible (2)	4	0
Maintenance of W&C infrastructure (3)	1	5
Regular public realm maintenance/cleaning (6)	1	5
Widespread Sheffield stands (7)	1	3
Opt-out travel training for all school children (8)	0	1
Fine-grained provision of quality public space (10)	2	4
Raised pedestrian crossings instead of dropped kerbs (11)	0	4
Tree planting/greenery (13)	0	1
Minimum cycle parking in new developments (21)	0	2
Freight windows (26)	0	1
Strict liability legislation (28)	0	2
Workplace crèches (29)	1	0
Green belt (31)	7	0
Smart ‘oyster-style’ cards for all mobility (33)	0	3
Mandatory ring fencing of W&C funds (34)	0	9
All city parking for private cars to be pay and display or permit (36)	0	2
Removal of ‘rat runs’ for motorized vehicles (38)	0	2
Velib-style cycle hire scheme (42)	14	0
Dutch-style railway parking facilities (47)	3	3
Community leisure walks and bicycle rides (52)	12	0
Walking buses to school for young children (53)	10	1
On-road cycle paths (54)	3	3
Pavement widening (56)	3	4
Dutch-style segregated cycle paths (57)	4	2
Mandatory ‘core’ W&C networks (61)	3	9
Widespread private car-sharing schemes (70)	1	1
City-wide 20 mph speed limit (72)	1	7
Limits on car advertising (75)	2	5
Contraflow bicycle lanes in one-way streets (78)	3	3
Public fitness campaign (79)	4	2
Smart bicycle storage units (86)	2	0
Cycle traffic enforcement (87)	1	1
Retrofitting cul-de-sacs for W&C connectivity (94)	1	8
Private motor vehicle ownership restrictions (103)	5	1
Car-free housing developments (112)	10	3
Orange NEV/HPV routes 20mph (118)	2	4

Note. W&C = walking and cycling; NEV = neighbourhood electric vehicle; HPV = human-powered vehicle.
[a] Out-degree represents the number of policy measures that facilitate the individual measure.
[b] In-degree represents the number of policy measures that the individual measure facilitates.

The last visualization shows the network of synergy relations (figure 9) where nodes are scaled based on the number of links connected to them. ‘Private motor vehicle ownership restrictions’ (103) immediately stands out as an important measure for inclusion in a policy package to increase W&C since it has synergy with twelve other measures. This measure does not address W&C directly and thus illustrates the significance of considering a mix of measures including some with only indirect effect on the policy objectives. In formulating a W&C policy, such a measure might not appear so important without the use of visualization.

Each of the visualization networks provides essential additional information when considering the ranking of policy measures and deciding which measures to implement.

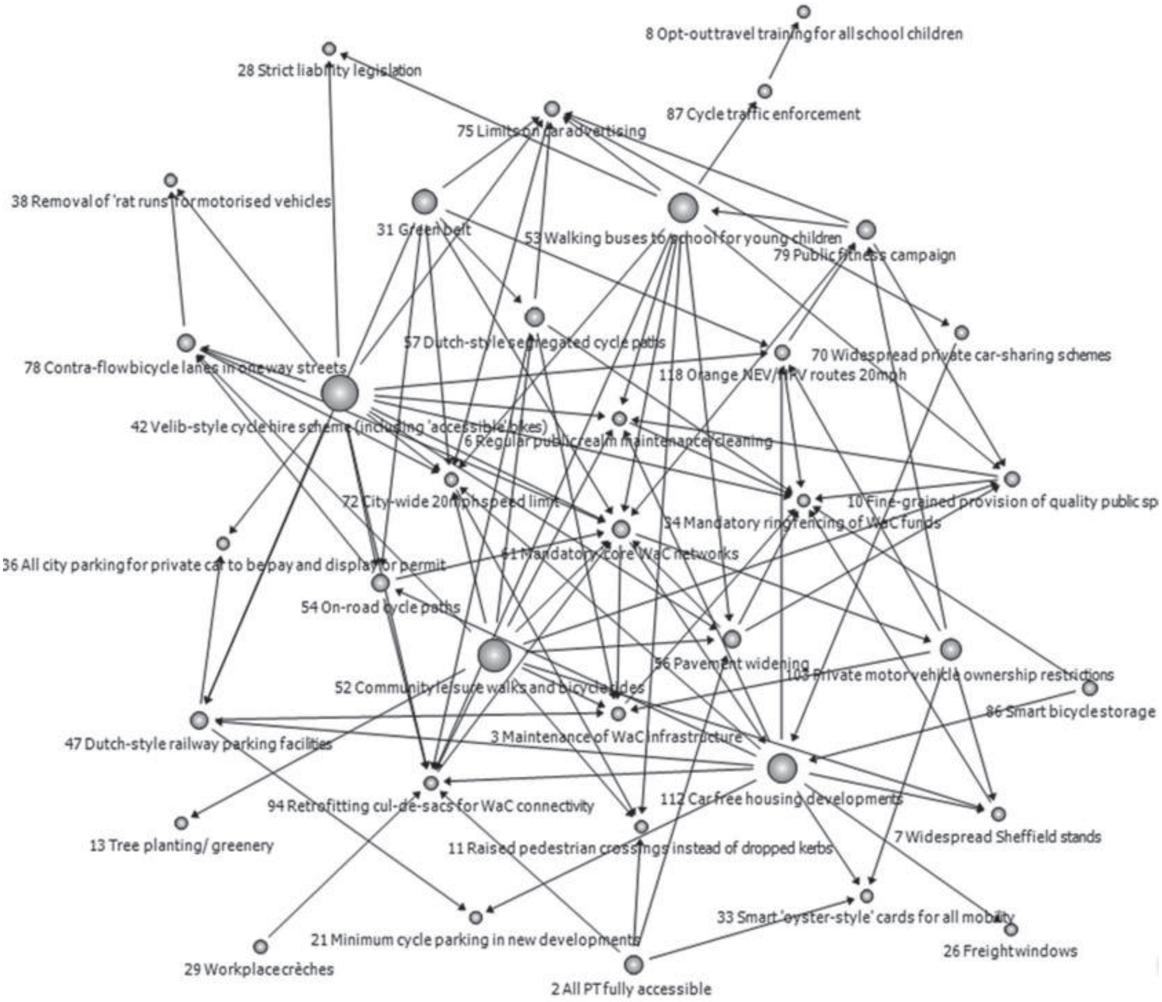

Figure 8. Visualization of the facilitation network scaled based on out-degree values. NEV = neighbourhood electric vehicle; HPV = human-powered vehicle; WaC (= W&C) = walking and cycling; PT = public transport.

Bringing together the information provided in each network with the information relative to the performance and implementation criteria of each individual measure is achieved through two separate rankings, as explained in the next subsection. The relative importance of these two rankings is left to the analyst's judgment.

5.2 Ranking of policy measures

Using the methodology described in section 3, two ranking lists can been generated (table 4): a *performance*-based ranking where measures are ranked according to their cost, effectiveness, and time-related properties, and an *implementation*-based ranking where the ranking reflects the technical and institutional complexity of the measures as well as their public (un)acceptability. The philosophy of MCDA suggests that weights can be put on the performance and implementation rankings to produce one set, but this was avoided to prevent the dilution of the information that would result from merging the two different dimensions. We propose to consider first the performance of various measures before paying attention to the barriers for their implementation, since implementation barriers can often be overcome with supportive (additional) measures. For each of the two ranking sets two further sets are presented based on (1) a traditional MCDA ranking and (2) a network-based MCDA ranking, where the precondition relations are accounted for.

On the basis of their intrinsic performance attributes (the traditional MCDA) the three top-ranking measures are: 'contraflow bicycle lanes in one-way streets' (78), 'minimum

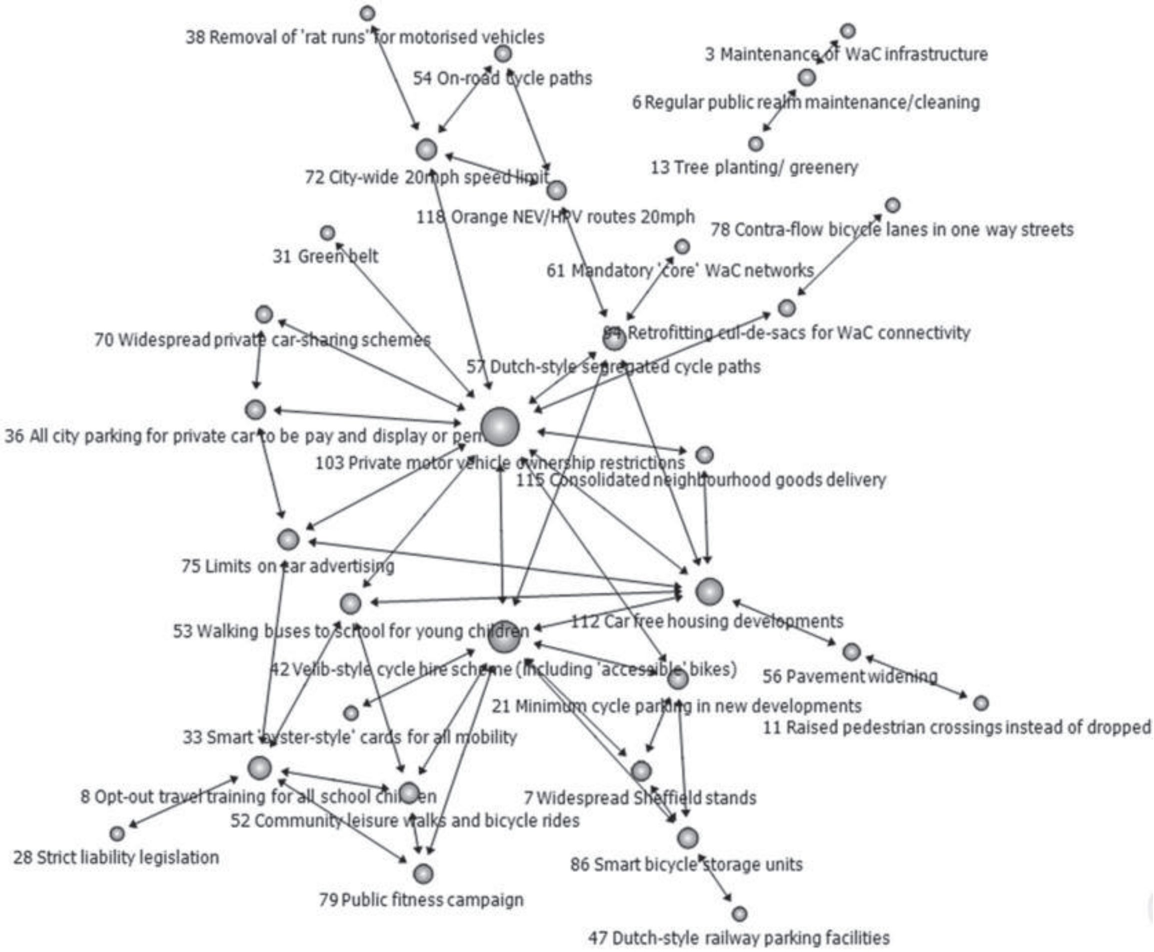

Figure 9. Visualization of the synergy network (nodes scaled based on their degree). WaC (= W&C) = walking and cycling; NEV = neighbourhood electric vehicle; HPV = human-powered vehicle.

cycle parking in new developments' (21), and 'private motor vehicle ownership restrictions' (103). When accounting for the fact that these measures all have precondition measures (see figure 6) their ranking changes to 11th, 14th, and 17th, respectively, in the network-centric MCDA. Assuming the precondition relations have been identified correctly, not accounting for them would result in a misguided choice of policy measures. For example, both measures 'limits on car advertising' (75) and 'public fitness campaign' (79) are ranked twelve places higher in the network-centric ranking than in the traditional MCDA ranking because they have no preconditions attached to them. Whenever preconditions are present they must be implemented to allow successful implementation of their supporting policy measure. This increases the costs, and given the high weight assigned to cost (40%) in this analysis the existence of preconditions is seen as undesirable. In the other direction, and due to the presence of preconditions, the ranking of the measure 'freight windows' (26)—the restriction on delivering freight into the city to certain hours only—is dropped twenty-four places from being a relatively attractive measure (ranked 9th using traditional MCDA) to being one of the least attractive in terms of its performance (ranked 33rd using network-centric MCDA). This same measure (26) has only one precondition, 'consolidated neighbourhoods goods delivery' (115), but the performance attributes of both together make measure 26 unattractive. Such information could not have been inferred directly from the visualization of the networks.

On the basis of the network-centric MCDA ranking, the three most effective measures in the inventory are: 'city-wide 20 mph speed limit' (72), 'mandatory ring fencing of W&C funds'

Table 4. Ranking of measures to promote walking and cycling based on their 'performance' and 'implementation' attributes.

Measure title	Performance		Implementation	
	traditional	network	traditional	network
All public transport fully accessible (2)	28	20	1	1
Maintenance of W&C infrastructure (3)	24	15	1	1
Regular public realm maintenance/cleaning (6)	30	37	1	**23**
Widespread Sheffield stands (7)	23	30	1	**21**
Opt-out travel training for all school children (8)	37	31	19	10
Fine-grained provision of quality public space (10)	26	35	29	33
Raised pedestrian crossings instead of dropped kerbs (11)	31	26	19	10
Tree planting/greenery (13)	31	38	10	**33**
Minimum cycle parking in new developments (21)	2	**14**	9	**23**
Freight windows (26)	9	**33**	34	30
Strict liability legislation (28)	8	5	34	25
Workplace crèches (29)	31	26	30	**19**
Flexible working hours (30)	31	26	34	25
Green belt (31)	7	3	37	**27**
Smart 'oyster-style' cards for all mobility (33)	31	26	25	**15**
Mandatory ring fencing of W&C funds (34)	5	2	10	6
All city parking for private car to be pay and display or permit (36)	15	6	10	6
Removal of 'rat runs' for motorised vehicles (38)	9	4	10	6
Velib-style cycle hire scheme (including 'accessible' bikes) (42)	17	18	8	**28**
Dutch-style railway parking facilities (47)	25	21	19	10
Community leisure walks and bicycle rides (52)	19	**8**	1	1
Walking buses to school for young children (53)	11	**25**	10	18
On-road cycle paths (54)	12	7	10	6
Pavement widening (56)	16	12	28	**17**
Dutch-style segregated cycle paths (57)	17	16	33	30
Mandatory 'core' W&C networks (61)	20	19	25	**37**
Widespread private car-sharing schemes (70)	38	32	1	1
City-wide 20 mph speed limit (72)	4	1	19	10
Limits on car advertising (75)	21	**9**	25	**15**
Contraflow bicycle lanes in one way streets (78)	1	**11**	10	**22**
Public fitness campaign (79)	36	**24**	1	1
Smart bicycle storage units (86)	22	13	19	10
Cycle traffic enforcement (87)	13	**23**	10	**29**
Retrofitting cul-de-sacs for W&C connectivity (94)	14	10	31	**20**
Private motor vehicle ownership restrictions (103)	2	**17**	37	36
Car-free housing developments (112)	5	**22**	10	**33**
Consolidated neighbourhood goods delivery (115)	28	33	19	**30**
Orange NEV/HPV routes 20 mph (118)	26	**36**	31	37

Note: When the difference in ranking between the traditional multiple criteria decision analysis and the network-centric MCDA is more than 10 places, the network-centric rank is emphasized (bold numbers). W&C = walking and cycling; NEV = neighbourhood electric vehicle; HPV = human-powered vehicle.

(34), and ‘green belt’ (31), the restriction of city development to within a ‘belt’ surrounding it. When two measures share the same ranking (received the same score) they can be further discriminated by also considering the facilitation and synergy relations they have with other measures. This is not done in this study.

The ‘implementation’ ranking provides information on potential barriers to the implementation of various measures (technical, public unacceptability, and institutional barriers, see section 3). Seven measures with the least implementation barriers are ranked first (measures 2, 3, 6, 7, 52, 70, and 79) and five of these remain ‘best’ measures based on the network-centric MCDA ranking, since they have no preconditions attached to them. The measures ‘regular public realm maintenance/cleaning’ (6) and ‘widespread Sheffield stands’ (7), the provision of metal bars for bicycle parking, drop to the 23rd and 21st rankings when considering their precondition measures. Perhaps not surprisingly, the measures which have relatively few implementation barriers have a relatively poor performance ranking.

The measures ‘mandatory ring fencing of W&C funds’ (34) and ‘removal of rat runs for motorized vehicles’ (38) are both ranked high in terms of performance (2nd and 4th) and in terms of implementation (both 6th) making them relatively attractive to implement first. Measure 34 also appeared central in the facilitation network (table 3). Also the measure ‘city-wide 20 mph speed limit’ (72), which is considered to be highly effective (ranked 1st) and has no particular implementation barriers (ranked 10th) (low technical and institutional complexity but medium/high public unacceptability) appears as an attractive measure to include in a package of measures to promote W&C. In contrast, the measures ‘green belt’ (31) and ‘strict liability legislation’ (28) which are ranked 3rd and 5th in performance appear as very problematic to implement, ranked 27th and 25th, respectively, in the network-centric MCDA implementation ranking. It is the institutional complexity of implementing such measures that makes them relatively unattractive. Similarly, the measure ‘private motor vehicle ownership restrictions’ (103) which has synergies with many other measures (figure 9) and is ranked 2nd on performance in the traditional MCDA ranking (but only 17th in the network-centric ranking) is not so attractive considering it is almost the most complicated measure to implement (ranked 37th and 36th in the traditional and network-centric MCDA implementation ranking, respectively).

6 Future research

The current methodology has several limitations, which further research will aim to overcome. The main limitations and avenues to explore to improve the methodology are as follows.

Originally, about 150 measures to promote W&C were identified but only thirty-eight of them were selected for the case study. The extent to which the methodology can be utilized in a useful way for a larger inventory of measures needs to be examined and any implication for a possible need to limit the size of the initial inventory accounted for. In addition, a more formal and structured way to build the initial inventory (150 measures in our case) and then reduce it (to 38 in our case) can be developed. The analysis above suggests the methodology is probably useful when dealing with up to about fifty measures, which already represent a much larger decision space than is otherwise considered.

Currently, the methodology is ideal for cases when policy makers have no numbers, just (expert) judgment on the measures. At present, the extent to which a measure is implemented (eg, the size of the area covered by a new bicycle-hire scheme or the level of a tax or subsidy) is not accounted for although it will affect the level of effectiveness or the implementation complexity. Moreover, currently the analysis assumes a single objective. Dealing with multiple objectives, where measures might contribute (or adversely affect) various objectives in a different fashion is an important issue to include.

7 Conclusions

The 'messy' and complex nature of many policy problems requires the development of new methods to assist policy makers in making policy choices and decisions. The requirement stems primarily from the number of options and the volume of relevant information that need to be assessed to make an informed decision. In this paper, a methodology for the analysis and ranking of policy measures is proposed and applied to the policy to promote W&C. The methodology allows policy makers to consider systematically a large number of measures in dealing with a specific policy objective and to gain a better understanding of the potential effectiveness and implementation complexity of each measure, on its own and when considered together with other measures within a policy package. The methodology relies on the application of network theory and MCDA approaches but has several advantages compared with the traditional MCDA approach, thus facilitating policy design and policy effectiveness.

The main innovative aspect of the methodology is the definition and identification of five types of relations between policy measures and their application when selecting measures for implementation. In addition, the methodology allows policy makers, or policy analysts, to consider and input data in a systematic way for pairs of measures; this is especially important when a large number of measures is considered. It also provides a visualization of the network of relations between all measures and a ranking of policy measures to assist in their analysis and selection for implementation and to improve the understanding of the alternatives within a much larger decision space. Emphasis is placed not only on the expected effectiveness of one or more measures but also on their implementation attributes. Overall, the methodology allows the consideration of information (relations between measures and implementation attributes), additional to that traditionally considered, while simplifying the analysis (through visualization and ranking). A large amount of vital information can be gleaned from the visualization of the policy-measures network; information which might be overlooked otherwise simply due to the difficulty in grasping the multiple links between policy measures. Moreover, the use of the policy-measures network has been demonstrated in the formulation of policies in agent-based modelling systems (Taeihagh and Bañares-Alcántara, 2010). Finally, the methodology can increase the understanding of the analysis and its results and thus the level of 'knowledge utilization' in the policy process (Landry et al, 2001).

The methodology is based entirely on the analysts' expertise and is generic in nature, making it relevant for any policy circumstances (eg, local, regional, and national) and policy domain (eg, transport, energy, and water). It is seen as an essential first step in the formulation of policy packages. In no way is the methodology replacing the policy makers, who still need to 'bring together' the understanding gained from considering separately each of the networks and combining this with information on the characteristics of each measure as reflected in its rank and with respect to the performance and implementation dimensions. The application of the methodology in the case study around the policies to promote W&C demonstrated its capabilities and advantages, but its usefulness in the field remains to be tested.

The complexity of most policy problems suggests they can only be dealt with appropriately through a range of different measures (ie, a policy package). This, however, requires the consideration of numerous options for policy action and the processing of a vast amount of information. To consider a large decision space and to fully utilize the knowledge and the experience of policy makers, the use of computers is essential. Such use, which supports but does not substitute the policy maker, in analyzing and selecting individual policy measures has been proposed in this paper. As a future step, a methodology based on the same principles for the consideration and selection of policy packages, rather than individual measures, is envisaged.

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