An Integrated Transport Planning Framework Involving a Combined Utility-Regret Approach

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ABSTRACT

Sustainable transport planning requires an integrated approach involving strategic planning, impact analysis and multi-criteria evaluation. This study aims at relaxing the utility-based decision-making assumption by newly embedding anticipated-regret and combined utility-regret decision mechanisms in an integrated transport planning framework. The framework consists of a two-round Delphi survey, an integrated land-use and transport model for Madrid, and multi-criteria analysis. Results show that (i) regret-based ranking has similar mean but larger variance than utility-based ranking, (ii) the least-regret scenario forms a compromise between the desired and the expected scenarios, (iii) the least-regret scenario can lead to higher user benefits in the short-term and lower user benefits in the long-term, (iv) utility-based, regret-based and combined utility-regret-based multi-criteria analysis result in different rankings of policy packages, and (v) the combined utility-regret ranking is more informative compared with utility-based or regret-based ranking.

INTRODUCTION

Planning sustainable transportation systems is a complex task involving a high degree of uncertainty due to the long-term planning horizon, the wide spectrum of potential policy packages, the need for effective and efficient implementation, the large geographic scale, the necessity to consider economic, social, and environmental goals, and the travelers' response to the various action courses and their political acceptability (*1*). The immense complexity necessitates the use of strategic tools (i.e., scenario development), impact analysis tools (i.e., transport models), and evaluation tools (i.e., multi-criteria analysis).

Although these tools have been extensively used over the past three decades, their combination has been employed only recently. Scenario development and transport models were used as an impact analysis tool for long-term planning (*2*). Ecological footprint models were utilized to explore alternative transport policy scenarios (*3*). Activity-based models were employed to analyze the effect of land-use (*4*) and transport policy packages (*5*). Scenario construction and multi-criteria analysis (MCA) were combined as an evaluation tool for selecting among policy scenario to promote a clean vehicle fleet (*6*). Scenario construction, transport models and MCA were combined to analyze scenarios via several macro-simulation tools for modeling energy, transport, and externalities (*7*), to examine scenarios for representing economics, transport, and environment (*8*), and to construct policy packages via expert-based methods within a regional study (*9*). Combining the tools is fundamental for a robust and transparent decision-making process towards transport planning (*9*).

The main limitation of the existing approaches is that all the tools are utility-based. Scenario construction largely incorporates the concepts of desirability or deliverability (e.g., *1, 9*), the fundamentals of transport models are utility-based decision models (e.g., *4*), and MCA relies on overall preference scores in agreement with the utilitarian approach (e.g., *6, 8, 10*). A cavity of the utility-based approach is that it disregards the feeling of regret due to a comparison between the chosen and the foregone alternatives. People experience regret when a choice outcome does not fulfill their expectations and the expected outcome of a foregone alternative is perceived to be better than the outcome of the chosen alternative. Regret is plausible in policy-making decisions because it is associated with important and complex decisions since it is associated with high-order cognitive processes such as contra-factual comparisons (e.g., *11*). Regret aversion has recently been associated with policy-makers' decisions on issues of climate change (*12*) and transportation (*13*). Choices based on anticipated-regret are essentially different from utility-based choices since regret-aversion tends to favor compromised or 'balanced' solutions rather than unbalanced 'optimal' solutions (*14*). Consequently, embedding regret in the integrated approach for transport planning is beneficial for increasing the robustness and the flexibility of the analysis.

This study embeds regret minimization and generalized utility combining utility and regret paradigm as an integral part of the integrated approach for expert-based scenario construction, model-based policy evaluation and optimization, and MCA. Chorus et al. (*13*) established regret-based decisions as plausible and more likely in the context of transport planning involving road pricing. The conditions underlying regret-based decisions, namely complex and important decisions for which decision-makers feel accountable, readily apply to policy decisions in transport (*13*). Moreover, the regret-based discrete choice model for politicians' choice of road pricing outperformed the utility-based model (*13*). In the context of integrated planning for sustainable transport, economic, social and environmental goals are combined. These policy goals are often conflicting and thus there are not clear 'no regret' policy options. Such decisions often require compromise solutions, which are associated with regret minimization (*14*). Moreover, the decision-making process in this study involves a group decision, in which the consensus alternative is attained through compromise and does not always comply with the views of all the policy-makers involved (*15*). Regret has been recently suggested as an alternative approach for ex-post analysis of choices among transport policies (*13*) and performing MCA in other policy decision contexts (*16*). This study is the first to embed regret both ex-ante and ex-post in the integrated transport planning framework based on a combined utility-regret approach. Moreover, the current study is the first to employ the generalized utility function combining utility and regret for scenario building and transport policy appraisal. The generalized utility combining utility and regret was proposed by Inman et al. (*17*) and applied to discrete choice models by Chorus et al. (*18*). The combined utility-regret mechanism is theoretically preferable compared to models based on utility or regret as sole decision paradigms because of its generality.

The proposed framework was applied to the case-study of the future implementation of travel demand management (TDM) measures in Madrid, the third largest metropolitan area in Europe. Decision-makers were requested to construct TDM policy scenarios. The TDM measures included cordon toll, parking fees, and bus frequency increase. Expert judgement was elicited regarding which measures are desired or expected, their timeframe and geographic scale. The integrated framework consisted of a combination of a two-round Delphi survey with the integrated land-use and transport model (LUTI) MARS for Madrid.

The remainder of the paper is organized as follows. The next section provides the case-study context, followed by the description of the proposed approach embedding regret. Then, the results of the analysis are presented and discussed. Last, concluding remarks are offered.

CASE-STUDY CONTEXT

Madrid is the third largest metropolitan area in the European Union with a population of 6.5 million in 8,030 km^2. The Madrid region consists of three concentric rings with Madrid as its core, the surrounding metropolitan area, and the outer regional ring. The average population density is 5,390 inhabitants/km^2 with the highest densities in the core. Due to the current sprawling trends of population and employment, a considerable growth is observed in the proportion of suburban trips versus radial trips, which increases car attractiveness. Indeed, the motorization rate is the highest in Spain with 529 per 1,000 inhabitants, with a 7% yearly growth rate. Among the 14.5 million daily trips, 45% are made by car and 40% by transit, while work trips are respectively at 35% and 32%.

The highway network of Madrid comprises four orbital highways (i.e., M-30, M-40 and uncompleted M-45 and M-50), eight radial highways (i.e., A-1 to A-6, A-42 and M-607) and four tolled radial highways (i.e., R-2 to R-5). The car use trends lead to increased congestion on the road network, with an average speed of 25 km/h in the area inside the M-40 highway. On the M-40 highway itself, the average speed is 60 km/h, half the intended design free-flow speed. The average speed in the city center is 9.6 km/h.

In this study, we propose car restriction measures (i.e., cordon toll, parking fees) and transit promotion (i.e., bus frequency increase) as TDM measures in the Madrid region. The measures are implemented during the morning peak-hour in Madrid because of the high congestion level. Both the cordon toll and the parking fees aim to regulate the car travel demand to the metropolitan core, while the improved bus service frequency aims at providing an attractive alternative to radial car travel. In terms of policy research questions, this study focuses on the long-term implementation of the proposed measures in terms of timeframe, geographic scope, and implementation intensity. The considered alternatives are implementation starting in the short-term (starting-year in 5 years), medium-term (starting-year in 10-15 years), and long-term (starting-year in 20-25 years). The duration is from the implementation starting-year until the end of the planning horizon, for example 2017-2034 for starting the implementation in the short-term. The considered geographic scopes are the Madrid metropolitan core, the area inside the M-30 highway, and the area inside the M-40 highway.

METHODOLOGY

Figure 1 presents the proposed innovative integrated framework for TDM design and assessment. The framework integrates the scenario building and policy evaluation by MCA on the basis of the Madrid LUTI model. Based on the defined objectives, the TDM scenarios were generated by a two-round Delphi survey among transport planners. With the optimization and evaluation of the TDM scenarios via the LUTI model, the proposed combined utility-regret approach based on the MCA was used to decide the 'best TDM scenario' towards the objectives. The following sections detail each element.

[Insert Figure 1 about here]

Scenario Building

The selected tool for scenario building is an expert-based Delphi survey (e.g., *19*) on the basis of the approach proposed by Shiftan et al. (*1*). The Delphi method essentially seeks to gain the most reliable consensus of opinion of a group of experts (*19*) as a legitimate source for designing creative yet realistic images of the future, because experts have the best knowledge of scientific progress, political, economic and social changes (*1*). Experts are also able to assess both the technical feasibility and the public acceptance of policies in an impartial manner (e.g., *9*). The Delphi method was modified to incorporate the combined utility-based decision paradigm via the interactive process involving experts, transport models and MCA.

The web-based Delphi survey included two-rounds. In the 1st-round, respondents were asked to rate on a 10-point Likert scale the importance level of the economic, environmental, and social objectives. They were also asked to rate on a 10-point Likert their level of anticipated-regret in the case these objectives would not be attained. In addition, the ability of the TDM measures to attain the objectives was elicited using a scale from -10 to 10, thus allowing negative, neutral and positive effects. For each TDM measure, the respondents were requested to state their opinion about the desired and the expected timeframe and geographical scope for implementation. Besides the predefined options, the respondents were provided with a 'no implementation' option. Then, the data about their desired frame and scope were fed forward to the next question and the respondents were requested to specify their level of regret if their non-desired frame and scope were implemented. For example, upon choosing the implementation of a congestion toll in the area inside the M-40 highway as the desired option, the next question was designed to elicit the regret level associated with the implementation within the M-30 highway and in Madrid city core. The desired alternative was associated with zero level of anticipated-regret, and the level of anticipated-regret was measured on a 0-10 scale where 10 was the highest regret level. The respondents were explicitly asked about their level of regret due to two reasons. Firstly, the feeling of regret is associated with engaging in contra-factual 'what if…' questions. Unless explicitly requested, the spontaneous engagement in contra-factual thinking is largely dependent on the choice situation, the decision-maker's intra-personal factors, and the assumed responsibility for the choice. Secondly, ranking alternatives with respect to the desirability or anticipated-regret largely differ, because the level of anticipated-regret depends not only on the desirability of the alternative, but also on the alternative satisfying the decision-maker's criteria thresholds.

In the 2nd-round, respondents were asked to state their degree of agreement with the scenarios generated from the results of the 1st-round according to the majority opinion. The generated scenarios included the implementation of all the policy measures implemented simultaneously as a policy-package, accounting for complementary and substitution effects. The respondents were asked regarding their level of agreement with the desired, expected and least-regret implementation, and were requested to identify potential drivers and barriers for the scenario implementation.

The Delphi method does not require the expert panel to be a representative sample for statistical purposes (*19*). The expert-based panel answers the necessary conditions (*19*) of being: (i) heterogeneous; (ii) not selected based on personal contacts; (iii) chosen based on work in the target area; (iv) interested and able to make a valid contribution; (v) able to represent a diversity of viewpoints; (vi) able to express current knowledge and impartial opinions. Conditions 1-3 are met by the selection process of the expert-panel. The 1st-round survey was administered via email during December 2012 through several channels including a list of participants in the national transport conference to a large pool of 220 transport professionals. The pool included a heterogeneous sample of transport decision-makers, operators, researchers and consultants in Spain. Conditions 4-6 are met by the sample composition: 99 experts completed the survey, representing an 85.4% response rate from the professionals who entered the survey. The respondents were aware of Madrid planning priorities: 52.2% live in the Madrid region, 37.4% travel to Madrid frequently, and 10.4% rarely visited Madrid. Among the respondents, 87.0% were transport consultants or researchers, 9.6% were decision-makers and 3.5% were transport operators. Thus, the experts have the appropriate knowledge and interest in the region and include both experts who reside in the region, and thus can consider the policies from both the user and the expert perspective, and experts who do not reside in the region and would not be directly affected by the policies. The 2nd-round survey was sent in March 2013 to the 81 experts who requested feedback.

MARS model

The framework for the MARS model and MCA-based optimization is provided in figure 2. The MARS model is a dynamic LUTI model for strategic planning, which combines forecasting, optimization and assessment (*20*, *21*) and was calibrated for Madrid (*22*). The land-use model consists of interrelated of sub-models of workplace, residential and housing development. The transport sub-model includes time-of-day and modal split, while demographic trends and motorization rates are forecasted as background scenarios. The system accounts for interactions between transport and land-use that are modelled by using time-lagged feedback loops between the transport and land-use sub-models until the planning horizon of 2034 in one-year intervals.

[Insert Figure 2 about here]

The MARS model includes a feedback loop between a simulation model and an MCA assessment that enables to optimize the implementation values (i.e., toll and parking price, bus frequency) of TDM scenarios and assess their derived effects on transport and land-use in the desired, expected and least-regret TDM scenarios. The optimization aims at obtaining the best implementation values by maximizing the value of the linear additive MCA objective function. While the MARS model can incorporate both cost-benefit analysis and MCA, as the two most prominent appraisal methods (*20*), the MCA was preferred in this study because of its clear advantages in the transport sustainability context (e.g., *6*, *10*): (i) the possibility to represent a holistic view incorporating multiple-criteria that are difficult to monetize; (ii) the possibility to involve stakeholders and account for their priorities in the decision-making process.

The MARS model was adapted for the needs of this study by: (i) tailoring the performance indicators to include economic, environmental and social performance indicators; (ii) providing the utility-based and regret-based weights for the MCA objective function and assessment on the basis on the survey; (iii) updating the background scenarios according to recent statistical data; (iv) incorporating the regret theory and the combined utility-regret theorem as elements in the MCA method for scenario assessment.

Utility and Regret-based MCA

Utility-based, regret-based and the proposed utility-regret MCA were applied. The MCA comprises an objective function of performance indicators weighted by their perceived importance. The weights were the utility-based and regret-based importance weights obtained from the 1st-round of the survey. The performance indicator values were obtained from the model results for the technically-optimal solution for each implementation scheme.

The MCA performance indicators relate to (i) transport efficiency objectives (i.e., travel time, car operating costs, mode share of car versus sustainable modes), (ii) social equity with respect to the opportunity space, the monetary burden of travel, and road safety (i.e., transport accessibility, transport11 affordability, accidents), and (iii) environmental conservation with respect to climate change, pollution and land depletion (i.e., CO_2, NO_x , PM_x, land-use consumption). Because of the different ranges of indicator values, the scales of the performance indicators were normalized to generate comparable units (*23*).

Utility-based MCA

The utility-based MCA is based on the method of multi-attribute utility analysis (MAUA), a structured methodology designed to handle trade-offs among multiple objectives in a rank ordered evaluation of alternatives that reflects the decision-makers' preferences (e.g., *6*, *10*, *16*, *23*, *24*). The basic assumptions of MAUA are that each alternative is characterized by a multi-attribute utility function, the alternative utilities are independent, and the attributes characterizing each alternative are independent (*16*). While numerous MAUA methods have been proposed for aggregating the individual utilities into a single scalar utility, the most widely used form is the linear-additive utility function (*24*). While MAUA is widely known, it is briefly described here for reasons of completeness.

To rank the constructed TDM scenarios from the most to the least preferred in terms of the performance criteria related to the three objectives, an aggregate linear additive utility of each alternative was calculated. Consider *n* alternatives $\{A_1,\ldots,A_n\}$ with *m* deterministic criteria $\{C_1,\ldots,C_m\}$, the alternatives are fully characterized by the decision matrix $\{U_{ij}\}$, where U_{ij} is the score measuring the deliverability of alternative A_i with respect to the criterion C_j. The weights $\{w_1, w_2,\ldots ,w_m\}$ account for the relative importance of the criteria. The additive utility of alternative A_i is given by:

$$U\left(A_{it}\right)=\sum_{t}^{t=m}\sum_{i}^{i=n}w_i u_{it}$$

where $U(A_{it})$ is the aggregate utility of alternative policy scenario A_i in year t, u_{it} is the score of policy alternative i in year t, and w_i is the weight of each criterion whose values reflect the relative contributions of changes in each of the scores, as the achievement of the objectives.

Regret-based MCA

Loomes and Sugden (*25*) proposed regret-theory as an alternative to utility-theory. The theoretical foundations of regret-theory are explained by Zeelenberg (*11*). Discrete choice models based on regret theory were recently developed and applied to transport planning decisions (e.g., 13,14,18). Chorus (*26*) provided a detailed overview of the random regret minimization model properties and empirical evidence. Utility-based MCA methods do not consider anticipated-regret, although anticipated-regret is an important consideration in decision-making under uncertainty (*16*). In particular, because MAUA assumes independence across alternative utilities, it does not consider regret due to further consideration of foregone alternatives, while most people can anticipate or imagine the feeling of regret associated with choosing an alternative from a choice set when a foregone alternative possesses one or more desirable attribute values (e.g., *16*, 17). Therefore, while utility-based MCA assume the decision-makers aim at choosing the "best alternative" that maximize their utility, regret-based models assume that decision makers would prefer a "balanced alternative" that minimizes their regret (*16*, *17*, *18*). To overcome this cavity of the utility-based MCA, Kujawski (*16*) proposed the Reference-Dependent Regret Model (RDRM) as a regret-based MCA. The RDRM is an additive difference model summing the pairwise differences between criteria utility scores across alternatives. According to the RDRM, the regret value associated with the choice of alternative A_i over a foregone alternative A_j is expressed by:

$$R\left(u_{ik,}u_{jk}\right)=\begin{cases}G\left(1-u_{ik}\right)-G\left(1-u_{jk}\right) & ,u_{ik}<u_{jk}\\ 0 & otherwise\end{cases}$$

where R(u_{ij},u_{ik}) it the anticipated-regret, u_{ij} and u_{ik} are classical utility scores with respect to the *k-th* criterion, and *G(x)* denotes the regret-building function. The regret function *G(x)* used in the RDRM model is:

$$G\left(x\right)=\begin{cases}\dfrac{1}{1+\left(B/x\right)^{2*S*\left(B+x\right)}} & ,\mathrm{x}>0\\ 0 & otherwise\end{cases}$$

where the parameters *B* and *S* characterize the shape of *G(x)*. When *S* is larger, *G(x)* is steeper and approaches unity faster. *G(x)* is convex when the regret value is below *B*, and concave when the regret value is above *B*. In this study, the chosen values are *B*=0.5 and *S*=4 in agreement with previous studies (*16*). Therefore, the chosen alternative with criterion utility below 0.5 is judged as very painful when there is another alternative with a corresponding criterion utility over 0.5. The regret value of choosing alternative A_i from a set of *n* alternatives (n ≥ 2) with *m* criteria is:

$$R_i^s=\left(\frac{1}{n-1}\right)\sum_{k=1}^{m}w_k^{'}\sum_{j=1}^{n}R\left(u_{ik},u_{jk}\right)$$

where w'_k is the regret-based weight of each criterion.

Generalized utility based MCA combining utility and regret-based evaluation

Inman et al. (*17*) proposed a generalized expected utility theory that extends expected utility theory by considering both chosen and foregone alternatives as the basis for alternative evaluation. Thus, the generalized expected utility theory proposes a combined utility-regret valuation which includes both notions simultaneously. Namely, it assumes that the choice of an alternative depends both on the overall value of the utility, and the utility difference between the chosen and foregone alternatives. The utility-regret paradigm is preferred over a sole utility or regret-paradigm because of its generality, but the application of this paradigm is still in its nascent stage with the models proposed by Muermann et al. (*27*) and Laciana and Weber (*28*), who also called it regret-theoretical-expected-utility, for decisions under uncertainty, and Chorus et al. (*18*) being the first to employ it in discrete choice models in transport and to show its practical value in terms of goodness-of-fit. We propose to embed such a generalized expected utility function in the MCA. The model associates each TDM policy scenario with a generalized utility fuction $A_i=GU(U_i, R_i^s)$, where U_i represents the aggregate expected-utility of alternative A_i, which is calculated by MAU, and R_i^s is the anticipated-regret value computed using RDRM that compares with the other alternatives. The proposed combined utility-regret function is expressed as follows:

$$\mathrm{GU}\left(U_i, R_i^s\right) = \sum_{k=1}^{m} w_k u_{ik} - R_i^s = \sum_{k=1}^{m} w_k u_{ik} - \left(\frac{1}{n-1}\right)\sum_{k=1}^{m} w_k' \sum_{j=1}^{n} R\left(u_{ik}, u_{jk}\right)$$

where w_k and w'_k are the utility-based and the regret-based weights, respectively. The generalized utility function collapses to a utility-based paradigm in case the value of zero regret weight, and to a sole regret-based paradigm in case of a zero utility weight.

RESULTS

1st-round Survey Analysis

The first survey round was analyzed with the aims of evaluating the relative weights of the economic, environmental, and social objectives, evaluating the potential of the TDM measures towards achieving the specified objectives, and generating the desired, expected and least-regret scenarios.

The average utility-based importance scores were 0.353 (SD = 1.29) for transport efficiency, 0.334 (SD = 1.43) for social equity, and 0.314 (SD = 1.85) for environmental conservation. The average regret-based importance scores were 0.351 (SD = 2.44) for transport efficiency, 0.337 (SD = 2.39) for social equity, and 0.312 (SD = 2.63) for environmental conservation. The results of the utility-based and regret-based importance scores were similar in their average values, but the regret-based scores showed higher variance.

Table 1 shows the proportion of experts who perceived each implementation scheme as desired or expected, and the level of regret associated with each scheme. The results show a wide agreement across respondents with respect to the desired and expected implementation schemes for each TDM measure, albeit the proportion of respondents who agreed with the desired implementation is much higher than the proportion of respondents who agreed with the expected scenario. The majority of the respondents thought that the cordon toll should be implemented in the short-term and in a relatively large area inside the M-30. The respondents expected a later and smaller scale implementation of the cordon toll in 5-10 years in the Madrid city center. Regarding parking fees, the majority of the respondents thought that the desired implementation is in the next five years and in the area inside the M-30 ring. The respondents thought that the desired implementation is also the expected one, although they were more in consensus about the expected scheme than the desired scheme. The vast majority of the respondents thought that the bus service frequency should increase in the next five years in the area within the M-40 ring. They expected however to be implemented only in 10-15 years and in the smaller area within the M-30 ring.

[Insert Table 1 about here]

While the desired implementation option was in most cases associated with the least-regret, the regret scores were similar for the majority opinion and the dominant minority opinion, and both were lower than the anticipated-regret associated with the option preferred by the small minority opinion. Notably, the anticipated-regret expressed in the 1st-round only served for generating a least-regret scenario, and not for the evaluation of the desired or expected scenarios.

Optimization Results

The optimization process via the MARS model generated the optimal starting-year and end-year values for the implementation intensity of the desired, expected and least-regret combinations of cordon toll, parking charges and bus frequency increase. The three measures were considered simultaneously as a TDM policy-package in the model runs. The optimal implementation values are presented in table 2.

[Insert Table 2 about here]

In the expected and the desired TDM policy-package scenarios, the model results show a substitution effect between the cordon toll and the parking fees, and a complementary effect between the cordon toll and the bus frequency increase. The parking fees were much lower than the cordon toll and approached zero in the least-regret scenario. The results are reasonable when considering a substitution effect between the two measures because both impose a fee on car travelers to the city center, and both can be designed to affect local and non-local residents to a different extent. Likely, the model did not differentiate between the two measures. The complementary effect between the cordon toll and bus frequency increase is evident from the results because the higher the optimal cordon toll, the higher was the optimal bus frequency. Notably, the cordon toll and parking fee values in the desired and expected scenario derived from the tradeoff between transport efficiency and social equity in the MCA objective function.

Comparing the desired and the expected scenarios, in the former travelers will enjoy lower cordon toll costs and higher bus frequency, in both the medium-term and the long-term. This means that the experts' desired scenario is also superior from the perspective of the single traveler, and thus may be associated with higher political acceptability.

Comparing the least-regret scenario and both the desired and expected scenarios, the user in the least-regret scenario will enjoy lower cordon toll fees and higher bus frequency in the short-term, and will suffer higher cordon toll fees and lower bus service frequency in the long-term.

2nd-round Survey Results

From the 81 e-mails that were sent in the 2nd-round, 41 (39.5%) respondents entered the survey page and 32 completed the questionnaire. Table 3 shows the respondents' level of agreement with the survey results and the model output, showing higher agreement with the desired scenario compared to the expected and least-regret scenarios. The results agree with the first survey round, in which high proportion agreed on the compared to the expected TDM implementation scheme.

[Insert Table 3 about here]

Respondents were invited to provide their comments regarding the main drivers and barriers for implementation of the TDM measures. Environmental concern was mentioned as a driver for policy implementation, while imposing higher transport fees in times of financial austerity were mentioned as policy implementation barriers. The respondents were unsure about the reduction of parking fees and cordon toll in the long run, possibly because it is difficult for human decision-makers to fully consider the tradeoffs in the MCA objective function. These results indicate the need for the complementary use of expert judgment and transport models, and the need for a transparent modelling and evaluation process.

Combined Utility-Regret MCA

Table 4 presents the utility-based, regret-based and combined utility-regret-based MCA calculated by using the model output regarding the performance indicators, and the utility-based and regret-based importance weights. The desired scenario performed better in terms of transport efficiency and environment, while the expected scenario had better social equity scores, and the least-regret scenario was clearly a compromise solution balancing transport, efficiency, social equity and environmental conservation. Considering utility as a sole measure for an overall evaluation, the desired and the least-regret scenarios were almost the same with a slight advantage to the compromise solution. Considering regret as a sole evaluation measure, the desired scenario generated the least-regret when considering the model output of performance indicators. Considering the combined utility-regret measure, the desired scenario performed best, followed by the least-regret scenario as the second-base solution.

[Insert Table 4 about here]

CONCLUSIONS

This study proposes an innovative integrated framework for planning sustainable transportation systems, which combines scenario building, impact analysis and multi-criteria evaluation on the basis of a generalized utility approach combining simultaneously utility and regret. The integrated approach, combining expert-opinion and transport modelling on the basis of utility-based, regret-based and combined utility-regret MCA offers a robust and transparent decision-making process. The proposed methodological advances were demonstrated in the design and assessment of TDM measures in Madrid.

The results demonstrate the practical importance of considering regret-based and combined utility-regret-based approach in the integrated framework. In the scenario construction stage, the regret-based importance scores are similar in their average values to the utility-based scores, but show higher variance, indicating that utility-based and regret-based importance trigger a different type of thinking. The difference is possibly due to the need for justifiability that is associated with regret-minimization (*11*). In addition, the experts associated a high level of regret to their non-chosen alternatives, which indicates that expert decision-makers have strong opinions both in the majority and minority expert groups. Thus, the least-regret scenario is important as a compromise solution between the majority and the minority opinions in agreement with Iverson (*15*). In the scenario evaluation stage, the desired-scenario performs better in terms of transport efficiency and environment, while the expected-scenario is preferred from the social-equity perspective and the least-regret scenario is a clear compromise in terms of the performance indicator scores. Moreover, the least-regret as a compromise solution is associated with higher user benefits in the short-term and lower user benefits in the long-term, likely leading to the higher political acceptability of this scenario in the short-term. Thus, considering a generalized utility combining both utility and regret in the evaluation process could be informative to decision-makers by considering the impact of different MCA models under uncertainty (*16*). Consequently, the proposed assessment of policy-packages are more robust and transparent compared to the existing approaches solely based on utility-maximization.

The proposed approach is practice-ready. Expert-based scenario building, LUTI models, and MCA are well-established tools for transport planning (e.g., *1*, *9*). The MARS model is applied to 14 cities across continents (*21*). The Delphi is a quick and cost-effective method to gather expert-based information for long-range planning (e.g., *1*, *19*). Similar to Shiftan et al. (*1*), this study reveals a high response rate to the questionnaire, reasonable and diverse answers, convergence of the results of the two rounds, and modest costs due to the web-based application that allowed the participants to complete the survey at the location and time of their convenience without requiring transportation or accommodation costs required in focus group techniques. While the current study uses a large number of participants, a smaller expert-panel can be used (e.g., *1*, *19*). The approach can be extended to public-participation in scenario building, in order to increase the public acceptability of future transport policies.

REFERENCES

1. Shiftan, Y., S. Kaplan, and S. Hakkert. Scenario building as a tool for planning a sustainable transportation system. *Transportation Research Part D: Transport and Environment*, Vol.8, No.5, 2003, pp.323-342.
2. Chatterjee, K., and A. Gordon. Planning for an unpredictable future: Transport in Great Britain in 2030. *Transport Policy*, Vol.13, No.3, 2006, pp.254-264.
3. Browne, D., B. O'Regan, and R. Moles. Use of ecological footprinting to explore alternative transport policy scenarios in an Irish city-region. *Transportation Research Part D: Transport and Environment*, Vol.13, No.5, 2008, pp.315-322.
4. Shiftan, Y. The use of activity-based modeling to analyze the effect of land-use policies on travel behavior. *The Annals of Regional Science*, Vol.42, No.1, 2008, pp.79-97.
5. Malayath, M., and A. Verma. Activity based travel demand models as a tool for evaluating sustainable transportation policies, *Research in Transportation Economics*, Vol.38, 2013, pp.45-66.
6. Turcksin, L., A. Bernardini, and C. Macharis. A combined AHP-PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet. *Procedia Social and Behavioral Sciences*, Vol.20, 2011, pp.954–965.
7. Fedra, K. Sustainable urban transportation: a model-based approach. *Cybernetics and Systems: An International Journal*, Vol.35, No.5-6, 2004, pp.455-485.
8. López E., A. Monzón and P.C. Pfaffenbichler, Assessment of energy efficiency and sustainability scenarios in the transport system. *European Transport Research Review*, Vol.4, 2012, pp.47-56.
9. Hickman, R., S. Saxena, D. Banister, and O. Ashiru. Examining transport futures with scenario analysis and MCA. *Transportation Research Part A: Policy and Practice*, Vol.46, No.3, 2012, pp.560-575.

10. Macharis, C., L Turcksin, and K. Lebeau. Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use. *Decision Support Systems*, 2012, in press.
11. Zeelenberg, M., and R. Pieters. A theory of regret regulation 1.0. *Journal of Consumer Psychology*, Vol.17, No.1, 2007, pp.3-18.
12. Bulkeley, H. No regrets? Economy and environment in Australia's domestic climate change policy process. *Global Environmental Change*, Vol.11, 2001, pp. 155-169.
13. Chorus, C.G., J.A. Annema, N. Mouter, and B. van Wee. Modeling politicians' preferences for road pricing policies: A utilitarian and a regret-based perspective. *Transport Policy*, Vol.18, No.6, 2011, pp.856-861.
14. Chorus, C.G., and M. Bierlaire. An empirical comparison of travel choice models that capture preferences for compromise alternatives. *Transportation*, Vol.40, No.3, 2013, pp.549-562.
15. Iverson, T. Communicating trade-offs amid controversial science: Decision support for climate policy. *Ecological Economics*, No.77, 2012, pp.74-90.
16. Kujawski, E. A reference-dependent regret model for deterministic tradeoff studies. *Systems Engineering*, Vol.8, No.2, 2005, pp.119-137.
17. Inman, J.J., J.S. Dyer, and J. Jia. A generalized utility model of disappointment and regret effects on post-choice valuation. *Marketing Science*, Vol.16, No.2, 1997, pp.97-111.
18. Chorus, C.G., J.M. Rose, and D.A. Hensher. Regret minimization or utility maximization: It depends on the attribute. *Environment and Planning Part B*, Vol.40, No.1, 2013, pp.154-169.
19. Powell, C. The Delphi technique: myths and realities. *Methodological Issues in Nursing Research*, 2003, pp.376-382.
20. Pfaffenbichler, P., G. Emberger, and S. Shepherd. The integrated dynamic land use and transport model MARS. *Networks and Spatial Economics*, Vol.8, No.2, 2008, pp.183-200.
21. Pfaffenbichler, P., Modelling with systems dynamics as a method to bridge the gap between politics, planning and science? Lessons learnt from the development of the land use and transport model MARS. *Transport Reviews*, Vol.31 No.2, pp.267-289.
22. Guzmán, L.A., D. De la Hoz, and A. Monzón. Optimal and long-term dynamic transport policy design. Seeking maximum social welfare through a pricing scheme. *International Journal of Sustainable Transportation*, Vol.4, 2012, pp.107-136.
23. Keeney, R.L., and H. Raiffa. Decisions with multiple objectives: preferences and value trade-offs. Cambridge University Press, UK, 1993.
24. Costa, B.E., and A. Carlos. The use of multi-criteria decision analysis to support the search for less conflicting policy options in a multi-actor context: Case-study. *Journal of Multi-Criteria Decision Analysis*, Vol.10, No.2, 2001, pp.111-125.
25. Loomes, G., and R. Sugden. Regret theory: An alternative theory of rational choice under uncertainty. *The Economic Journal*, Vol.92, No.368, 1982, pp.805-824.
26. Chorus, C. Random regret minimization: An overview of model properties and empirical evidence. *Transport Reviews*, Vol.32, No.1, 2012, pp.75-92.
27. Muermann, A., O.S. Mitchell, and J.M. Volkman. Regret, portfolio choice, and guarantees in defined contribution schemes. *Insurance: Mathematics and Economics*, Vol.39, No.2, 2006, pp.219-229.
28. Laciana, C.E., and E.U. Weber. Correcting expected utility for comparisons between alternative outcomes: A unified parameterization of regret and disappointment. *Journal of Risk and Uncertainty*, Vol.36, No.1, 2008, pp.1-17.

LIST OF FIGURES AND TABLES

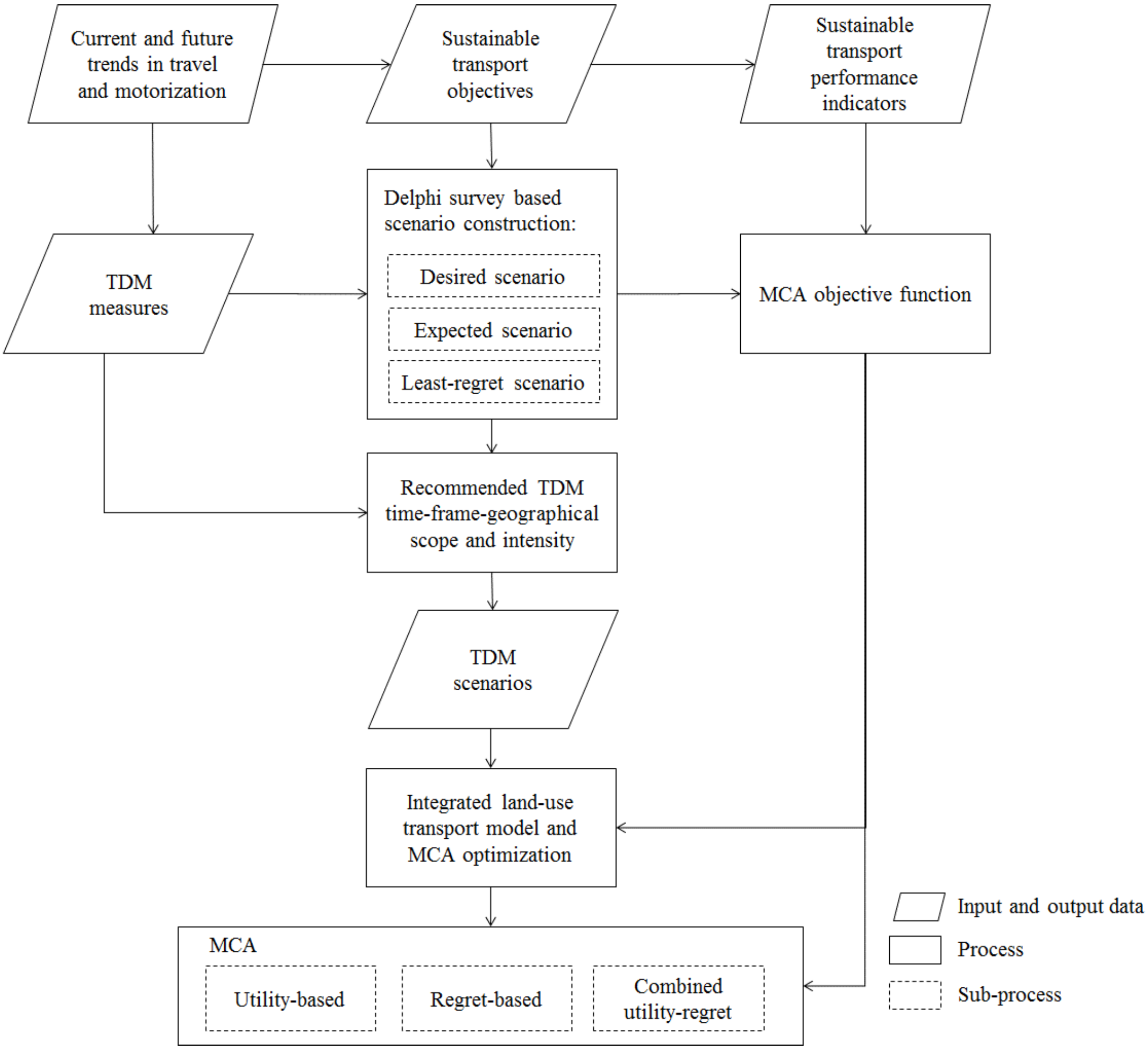

FIGURE 1 Integrated framework for TDM measures design and assessment.

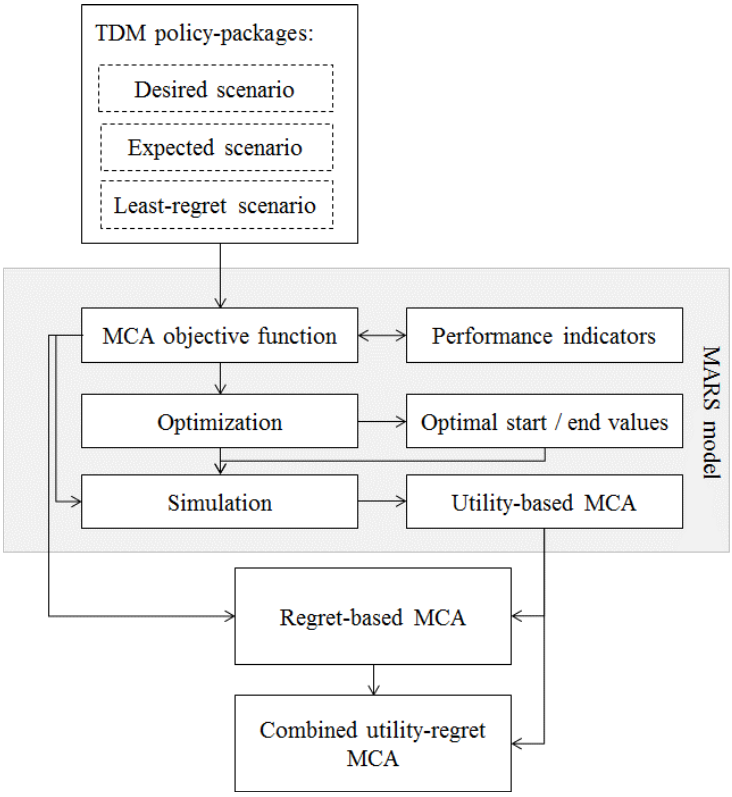

FIGURE 2 Integrated land-use transport model and MCA optimization.

TABLE 1 1st-Round Survey Results: Timeframe and Geographic Scope of TDM Measures Implementation

		Cordon toll		
Starting-year	**In 5 years**	**In 10-15 years**	**In 20-25 years**	**No implementation**
Desired	**60.0%**	17.4%	2.6%	20.0%
Expected	27.0%	**45.2%**	10.4%	17.4%
Level of regret*	**5.52**	5.87	6.03	
Geographical scope	**City Center**	**Inside the M-30**	**Inside the M-40**	
Desired	31.5%	**56.5%**	12.0%	
Expected	**63.0%**	30.4%	6.5%	
Level of regret*	5.72	**5.66**	6.31	
		Parking fees		
Starting-year	**In 5 years**	**In 10-15 years**	**In 20-25 years**	**No implementation**
Desired	**63.0%**	14.8%	2.8%	19.4%
Expected	**75.0%**	16.7%	0.9%	7.4%
Level of regret*	4.27	4.24	5.71	
Geographical scope	**City Center**	**Inside the M-30**	**Inside the M-40**	
Desired	31.4%	**54.7%**	14.0%	
Expected	32.2%	**64.4%**	3.4%	
Level of regret*	**5.45**	5.50	6.84	
		Bus frequency increase		
Starting-year	**In 5 years**	**In 10-15 years**	**In 20-25 years**	**No implementation**
Desired	**71.4%**	15.2%	0%	13.7%
Expected	19.0%	**40.0%**	7.6%	33.3%
Level of regret*	**1.6**	3.3	6.4	
Geographical scope	**City Center**	**Inside the M-30**	**Inside the M-40**	
Desired	2.2%	29.7%	**68.1%**	
Expected	22.2%	**43.3%**	34.4%	
Level of regret*	6.4	**4.2**	5.2	

*Note: * average regret score on a 10-point Likert scale.*

TABLE 2 MARS Model Results for the Desired, Expected and Least-Regret TDM Policy-Packages

Base year 2012	**Policy package**	**Survey results**		**Model output**	
		Implementation			
		Geographical scope	Timeframe	Optimal starting-year value	Optimal end-year value
Desired TDM policy scenario	Cordon toll	Inside the M-30	2017-2034	4.0 €/vehicle*	2.9 €/vehicle
	Parking fee	Inside the M-30	2017-2034	2.5 €/hour	0 €/hour
	Bus frequency	Inside the M-40	2017-2034	52%	34%
Expected TDM policy scenario	Cordon toll	City center	2022-2034	5.2 €/vehicle	3.7 €/vehicle
	Parking fee	Inside the M-30	2017-2034	2.5 €/hour	0 €/hour
	Bus frequency	Inside the M-30	2022-2034	36%	27%
Least-regret TDM policy scenario	Cordon toll	Inside the M-30	2017-2034	1.1 €/vehicle	6.0 €/vehicle
	Parking fee	City center	2022-2034	0 €/hour	0 €/hour
	Bus frequency	Inside the M-30	2017-2034	50%	22%

*Note: *Single entry to the cordon area during peak-hour*

TABLE 3 Respondent's Agreement with the Survey Results and Model Output

	Agreement with the survey results			
	Highly agree	**Partially agree**	**Partially disagree**	**Highly disagree**
Desired	37%	37%	23%	3%
Expected	12%	44%	38%	6%
Least-regret	9%	50%	32%	9%
	Agreement with the model optimization output			
	Highly agree	**Partially agree**	**Partially disagree**	**Highly disagree**
Desired	26%	37%	29%	9%
Expected	6%	33%	48%	12%
Least-regret	9%	35%	41%	15%

TABLE 4 Performance Indicators, Utility, Regret and Combined Utility-Regret MCA

Scenario scores	**Desired**	**Expected**	**Least-regret**
Transport system efficiency	26.59	17.25	21.59
Car modal share	8.62	-18.87	-7.83
Motorized trip time	45.65	41.46	43.25
Operation car costs	25.58	29.22	29.42
Social Equity	21.23	44.50	37.75
Accessibility	43.04	43.36	42.89
Accidents	20.35	40.94	34.41
Transport cost affordability	4.35	48.72	36.65
Environment	47.89	28.79	37.92
CO_2 emission	29.31	-4.00	11.81
Air pollution	15.83	5.57	10.71
Land consumption	91.62	91.67	91.54
Utility-based MCA	32.05	29.68	**32.14**
Regret-based MCA	**6.20**	12.17	9.80
Combined utility-regret MCA	**25.85**	17.50	22.33