

# Decision Support for Bicycle Route Planning In Urban Environments

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## SUMMARY

Over the last years, electronic route planners have become a common decision support tool especially for car drivers. Through the ongoing development of Location Based Service (LBS), electronic route planners are expected to be more frequently used by cyclists and pedestrians in the near future, too. For a user friendly design of route planners, the number of route selection criteria among which the user can choose is one of the key aspects. This paper describes and analyses observed route choice behavior of cyclists in urban environments and assesses the number of criteria the navigator considers for selecting the best route. In a desktop experiment, the testing subjects stated their preferred route among four given route suggestions on a paper map. The stated preferences were compared to the ranking found by self explicated preference analysis. The results show that the decision behavior of most users can be explained through a compensatory decision rule. We conclude that the user interface of a route planning support tool should provide the functionality to allow a navigator for stating his preferences for several route selection criteria, and not only for one single criterion.

**KEYWORDS:** Route selection, route planner, compensatory decision rule, decision support

## ROUTE SELECTION

### Route selection criteria

One of the shortcomings of current route planning software is the small set of route selection criteria that are offered to the user. The criteria are mostly restricted to fastest, shortest, or most scenic route (see Figure 1) and setting stopover points along the route. We claim that for many situations this will not suffice, and that the user wants to define his best route over additional route selection criteria and define the trade-offs between them. Current route planners, if allowing for selection between several route selection criteria, do not provide the functionality to weight criteria after their importance at all (Figure 1a), or they provide this functionality only for a part of the all offered route selection criteria (Figure 1b).

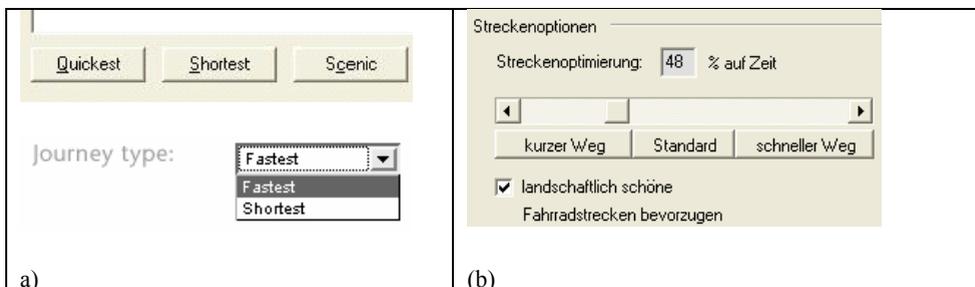


Figure 1: Prototypical set of available route selection criteria in route planners for cars (a), and cyclists (b)

For pedestrian navigation it has been shown that a single route selection criterion under-predicts the preference on paths selected (Golledge 1995). The hypothesis of this work is that cyclists also consider the performance of several route criteria in their route selection process, i.e., do not define the best route over only one route selection criterion. This hypothesis will be examined in an empirical desktop study.

One of the key questions for good design of route planners is which route selection criteria the human navigator will apply. Previous work on wayfinding has revealed a large number of route selection criteria for pedestrians (Golledge 1995), cyclists (Hyodo, Suzuki et al. 2000; Ehlers, Jung et al. 2002), and car drivers (Ben-Akiva, Bergman et al. 1984; Stern and Leiser 1987). The long lists of route selection criteria mentioned are not useable for straightforward implementation in route planners. One reason is the fact that a part of the mentioned route selection criteria overlap in their intention, i.e., describe similar effects. The other reason is that a classification of these route selection criteria into a cognitively perceptible number of classes is missing. For a user friendly design of route planning tools it will be important to classify attributes into a small number of disjoint attribute classes, where each class states a top level objective and contains one or more member attributes that support the objective of the corresponding class.

To gain more precise information about which route selection criteria cyclists actually apply in urban environments, an internet study was established. Participants were asked to take the role of a cycling tourist that wants to reach a given restaurant in an unknown urban environment. The participants should then state their route preferences in open text fields of the internet questionnaire. Within the 42 questionnaires that were filled, 35 different route selection criteria for cyclists were mentioned, the most stated being “use bike lane” (33), “sights” (25), “avoid heavy traffic” (20), and “short” (20) (see Figure 2). Similar to previous rankings of route selection criteria mentioned in the literature, the list gained from the internet study contains redundant objectives. Redundancy should be avoided in decision problems to avoid double counting of impacts (Keeny and Raiffa 1993). An example for redundant route selection criteria are “avoid pedestrian areas” and “avoid city center”, as one obvious objective of the latter is to avoid pedestrian areas. As the task of this work focuses on the number of route selection criteria considered within a route selection process, the problem of redundancy is excluded from the discussion.

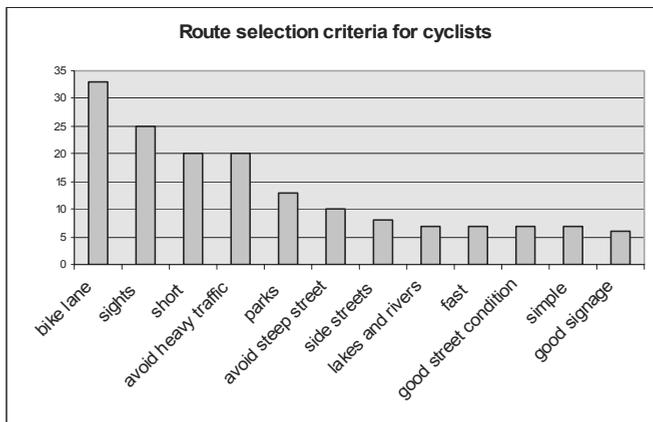


Figure 2: The 12 most often mentioned route selection criteria for a tourist cyclist in an urban environment

## Decision rules

A decision rule is a procedure for ordering alternatives from most to least desirable. According to the cognitive processing level two classes of multiattribute decision making rules can be distinguished, namely compensatory and non-compensatory (Malczewski 1999). Additive decision rules are the most popular in the context of GIS based decision making. They are called additive because the final appraisal score of a choice alternative is computed by summing up the part-worths of each attribute level for the choice alternative. In the compensatory approach a low performance on one attribute can be compensated by a high performance on another. Under the non-compensatory approach a poor criterion's outcome of an alternative can not be offset by another criterion's good outcome, and the alternatives are compared along the set of criteria without making intra-criterion tradeoffs. People tend to apply non-compensatory decision rules if the number of alternatives is large (Hartmann and Sattler 2002) or the decision maker is under time pressure (Stern 1999). In lexicographical ordering—one of the non-compensatory decision rules—the decision maker sorts the decision criteria after their importance and finally chooses the alternative that gives the highest desirability on the most important criterion.

If a route alternative A performs in all considered attributes as well as alternative B, and A in addition performs better in at least in one attribute, then alternative A is said to dominate alternative B. Both, compensatory and lexicographic decision rules can explain an agent's decision behavior for a given set of route alternatives where one alternative dominates all others (i.e., that the dominant route will be selected). The more realistic situation of the real world, however, is that a set of non-dominated route alternatives between two locations A and B will be found. For the design of route planners it is relevant, which decision rule humans actually apply in such situations: If navigators apply the lexical decision rule in their route selection process, a route planner that supports a function which allows for stating one's most important selection criterion will suffice. Contrary, for the case of compensatory decision making, the user should be provided a more detailed user interface, allowing for importance statements among several route selection criteria.

Compensatory decision rules, such as the simple additive weighting (SAW), have been implemented in GIS software (IDRISI, SPANS). The method can be operationalized in any GIS software with overlay capabilities. Malczewski (1999) presents a procedure for implementing SAW in GIS and provides an example of spatially-enabled SAW. Rinner and Malczewski (2002) combined the SAW approach with ordered weighting averaging (OWA) for a Web based decision support tool.

The study established in this paper focuses on route planners, i.e., reveals the need for compensatory user interface features for this specific type of geoinformation systems. We investigate empirically how often the subject's stated best route (i.e., when having an overview map) matches with the route that performs best on the stated most important criterion. For a set of non dominated alternatives, a high matching rate would mean that the decision maker applies the lexicographical decision rule. We expect the opposite, namely, that participants will consider the performance of several route selection criteria and apply a compensatory decision strategy.

## EMPIRICAL STUDY: ROUTE SELECTION ON A PAPER MAP

The desktop experiment, in which 17 subjects participated, consists of two parts. In the first part participants stated their preference by ranking a given set of the route alternatives. In the second part we used self explicated data to derive the participant's preference behavior among these routes. Comparing the results of both parts we assessed the number of route selection criteria actually considered by the navigator in the decision making process.

### Part one: Stated preferences

We presented the participants a paper map that shows a part of an urban environment (Figure 3). The map includes four route suggestions (a-d) which lead from the starting point (P) to the destination (D). Besides the geometry of the street network the map shows bike-lanes (dotted lines), traffic lights, and a market place (cross-hatched area) located at a pond. It also highlights street segments with heavy traffic (bold

lines). We gave additional introductory information in text form to reduce the potential impact of unknown effects on the desirability of attribute levels between the respondents. For example, rainy weather as compared to sunny weather could decrease the desirability of the same route length. The textual introduction explained the purpose of the trip which has effect on weighting of route attributes (Bovy and Stern 1990). In the first part of the study, testing subjects were asked to rank the four given route suggestions and mark their preference value for each of the four routes on a continuous scale that reached from “unacceptable” to “most preferable”.

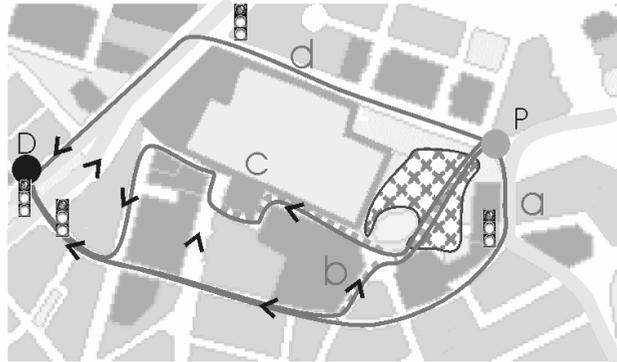


Figure 3: Paper map with test environment showing the four suggested routes a, b, c, and d

None of the routes dominated all other routes, i.e., there was no favorite that people would always select (independent from applying the lexical or the compensatory decision rule). For example, route c is the most scenic, but also the longest of all routes. And route d is the shortest, but at the same time the most dangerous route. This design aspect of avoiding dominant routes in the choice set was important for assessing which of the two decision rules would actually be applied.

To make sure that the respondents had enough information to make their decisions under certainty, the respondents were asked to rate for each of the four routes the amount of information given wrt. the decision task. The average value over all routes was 96 out of 100. Due to this high value and the textual introduction given we could make sure that the decisions were not influenced by other attributes than those that could be read from the paper map. This fact is an important pre-condition for achieving the second part of the experiment, namely to split a route into its ingredients, and present the route features piece by piece to the participant for evaluation.

Figure 4 visualizes the results from part 1 of the study. It shows for each of the four selectable routes the quartiles of the desirability values assigned by the 17 participants, as well as the minimum and maximum values. The 0 value denotes “unacceptable”, and 1 means “most preferable”. The boxplot shows that routes b, c, and d were considered as somewhat selectable by all participants, i.e., all subjective thresholds were satisfied by these routes. A small exception in this pattern is the evaluation of two participants that considered route a as unacceptable. Generally, the results of this study show that the selection of routes is not driven by knock-out criteria but over the performance of considered route attributes. However, the result does not give information about whether the participants apply a lexical or a compensatory decision rule.

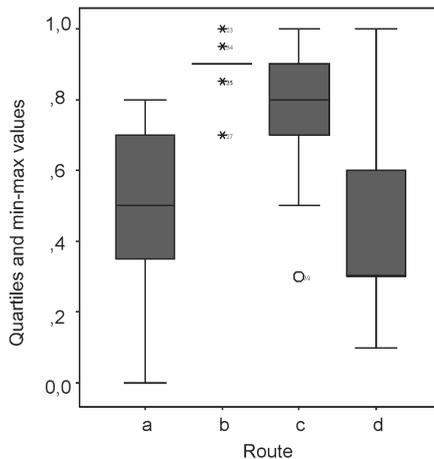


Figure 4: Quartiles and range of stated preference values assigned to routes a-d by all participants

## Part two: Self explicated analysis

The most popular methods for measuring subjects' preference structures are conjoint measurement (Green and Srinivasan 1978; Dijkstra and Timmermans 1997) and self-explicated approaches (Leigh, MacKay et al. 1984). It has been shown that the simpler and less expensive self-explicated studies are at least as good as conjoint (Sattler and Hensel-Börner 2000).

For the design of the questionnaire that was used for the self-explicated analysis, the route attributes of the four routes to be evaluated (Figure 3) needed to be classified into a reasonable number of higher-level objectives (i.e., attribute classes). For this classification task, we adopted the results from another pre-test where 11 participants were asked to classify the 35 route selection criteria from the filled internet questionnaires. We did not give any class suggestions for this task, i.e., participants had to think of appropriate class names by themselves. Most classifications suggested by the respondents included four classes (36%). Among these classifications, in 75% of the cases, the four classes "Safe", "Fast", "Simple", and "Aesthetic/Attractive" were used. Among all classifications made, each classification used the classes "Safe" and "Fast", followed by "Simple" (73%) and "Attractive" or "Aesthetic" (73%).

We decomposed the 35 route selection criteria into attribute classes as suggested by the classification pre-test (Figure), yet strongly reducing the number of included route selection criteria. We included only those attributes, which could be read from the map, and which therefore could potentially have been considered by the testing subjects in the first part of the experiment. For example, the shape of the route has been included as route selection criterion in the questionnaire of the self-explicated analysis, whereas the criterion "good signage" has been omitted (as the quality of the signage along a route cannot be read from the paper map). We further restricted to the most important attributes, i.e., those that were mentioned frequently in the internet questionnaires. A (-) symbol in Figure 4 marks attributes that are negatively oriented. An example is "Open market place" which is assigned to two classes: The attribute prevents fast travel (-), but at the same time improves the aesthetics of the route (positively oriented).

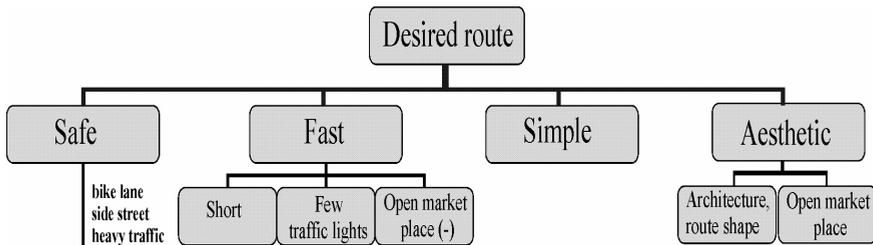


Figure 5: Classification scheme of route selection criteria for the self-explicated analysis of route choice

To get the part-worths of the actual attribute levels for each route alternative, the participant needed to rate the desirability of the given attribute levels of each route on a 5-tiered scale, which reached from „very bad“ to „very good“. This gave a discrete value function for each route attribute  $a_i$  with outcome scores between 0 and 1. In the self-explicated analysis, the desirability for levels of the attribute “Safe” for each route were gained through evaluation of four “safety profiles”, each describing the amount of bike lanes, side streets, and streets with heavy traffic of the corresponding route. Distance, frequency of traffic lights, and length of open market places along each route were presented as numerical values to the participant. Simplicity was described by the number of turns at intersections. As the route attributes “architecture” and “route shape” are hard to capture by numerical values, the levels of these attributes were presented as (rotated) sketch map of the corresponding route with some textual description of the buildings around.

Respondents were also asked to state the importance  $w$  for the four classes, and to state conditional weights for class members. The prominent route selection criteria “use bike lane”, “use side streets”, and “avoid heavy traffic” are attribute levels of the single attribute “Safe”, thus no separate weighting for these attributes was needed, and a single weight for the class “Safe” was sufficient. The preference value for each route alternative was calculated by the simple additive weighting (SAW) method, i.e., the final appraisal score  $v_i$  for each alternative  $i$  is computed by multiplying the  $j$ -th criterion importance weight  $w_j$  by the standardized outcome score of alternative  $i$  on criterion  $j$  (Eq. 1).

$$v_i = \sum_{j=1}^n w_j \cdot r_{ij} \quad \text{Eq. 1}$$

The assumption for using the simple additive weighting is that evaluation criteria are preferentially independent (Debreu 1960), i.e., that the preference structure for two attributes does not depend on the level of a third attribute. Even if this assumption does not strictly hold in the reality, an additive value function might provide a good approximation to the decision maker’s preferences (Russell and Norvig 2003). Figure 6 shows the results of the self-explicated analysis. The bars denote the quartiles and the maximum and minimum values of final scores that were computed with the SAW method.

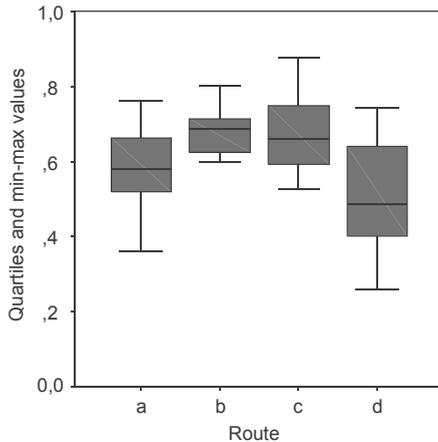


Figure 6: Quartiles and range of preference values computed from self explicated analysis

## RESULTS AND INTERPRETATION

Figure 7 shows the final result obtained from both parts of the study. The plotted curve compares the stated best route (experiment part one) with the highest scoring route found by the SAW approach (experiment part two) for a varying number of attributes considered.

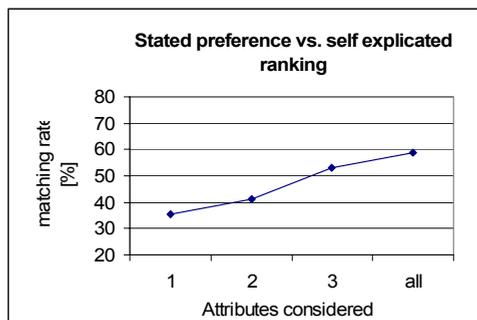


Figure 7: Matching between best routes found through stated approach and self explicated analysis

Considering the stated most important criterion only in SAW (which corresponds to the lexicographical decision rule) gives the left most data point and a matching rate of 35% between the best routes found. That is, in 65% of the trials, taking the route that performs best on the most important criterion does not yield the best stated route. The matching rate increases if the two most important (41%), three most important (53%), and finally all attributes (59%) are included in the compensatory computation by SAW. The curve indicates that the wayfinder considers the performance of more than just one attribute to find the best route, i.e., uses a compensatory decision rule. This in turn supports the hypothesis that user interfaces of route planners should provide the user the possibility to select among a higher number of route selection criteria, between which the user can state his subjective importance.

Despite an increasing matching rate for an increasing number of attributes included in the SAW, the curve in Figure 7 **Error! Reference source not found.** does not reach the 100% level. This fact means that the route characteristics perceived in the stated approach (part one) are not perfectly mapped to a set of route attributes used in the questionnaires of the self explicated approach. Thus, some aspects which make a route desirable were not captured by the questionnaires. From interviews with the participants

after the studies it was for example found that some people consider traffic lights—if located at intersections of heavy traffic roads—to improve the safety of the route (which was not taken into account in the questionnaires) besides the effect of increasing travel time (which was included).

Figure 8 shows, which SAW computed routes (study part 2) yield higher preference values than another route that was stated best (study part 1). These modeling errors of route attributes cause the matching curve in Figure 7 not to reach the 100% level. The size of each bar in Figure 8 shows how often the first of the two indicated routes was stated to be the best (study part 1), but then yielded a smaller SAW value in the self-explicated approach (study part 2) than the second route. These errors correlate with differences in the preference values between corresponding routes gained with both methods. That is, the improvement of the performance of route a as compared to b through SAW (2nd bar in Figure 8), a to d (6th), c to b (7th), and d as compared to b (9th) can also be observed in shifts of the value ranges and quartiles between **Error! Reference source not found.** and Figure 6.

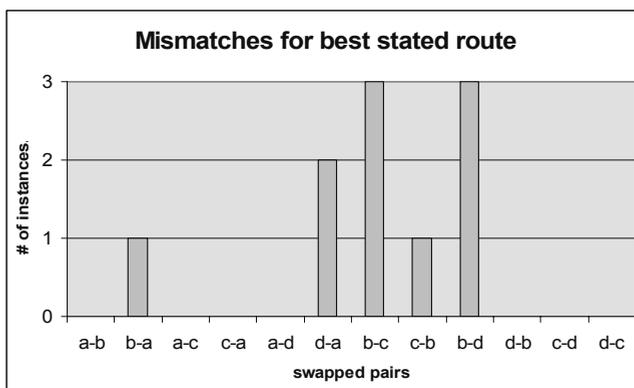


Figure 8: Stated best routes and mismatches with SAW computed routes

As an example we give a possible interpretation for one of these modeling errors, which is the deterioration of the (stated) best route b with respect to route c in the self-explicated analysis (bar 7). We defined the simplicity of a route over the number of turns to be made at an intersection along the route. In the questionnaire, the simplicity of route b was therefore characterized as a route with two turns (one after the pond, and one when turning right into route a), and route c with three turns respectively. However, the complicated shape of route c caused by additional bends off intersections (i.e., along the park), lets participants consider this route to be even more complex when perceiving it, which causes participants to abandon selecting this route in the stated preference method. Thus, the abstract description of the simplicity of a route just by the number of turns at intersections was obviously an oversimplification. Further parameters might have led to improvement of the characterization of “Simple” for the design of the self-explicated analysis part. Despite these oversimplifications in the second part of the study, the task of demonstrating the decision makers’ use of compensatory decision rules in route selection has been successfully demonstrated.

## CONCLUSIONS AND FUTURE WORK

The presented work aimed at finding which decision rule humans apply when selecting routes on a map. The desktop experiment gives evidence that the best route—at least for the given test scenario—is defined over the performance of several route selection criteria. However, this behavior may change under extreme situations, such as pressure of time. The first part of the study observed stated preference behavior for route alternatives, whereas the second part of the study computed the participants’ preference behavior through self-explicated analysis using the SAW method. A comparison of both results showed that with a higher number of attributes included in the SAW the matching of the best routes found by both

methods increased, i.e., that the decision makers' preference behavior can be described as compensatory decision making. This holds at least for situations where none of the routes in the choice set dominates the others, and where each route in the choice set satisfies all knock-out criteria. User interfaces of route planning tools should respond to this fact accordingly: The user should be given the possibility to state his preference for more than one single attribute and set the trade-off between those attributes. Thus, options such as "fastest route" OR "simplest route" OR "scenic route" (as realized in most current route planners) will not suffice to correspond to the navigator's demands. The basic message of this work can be applied to car navigation systems, too. Although the route selection and their classification may be different for the car transportation mode than for the cyclist mode, the user's desire to express the best route over several preferred route selection criteria will remain.

A goal for the future work is to find which trade-off functionality between preferred route selection criteria is the most intuitive, and how much trade-off functionality will be required at all. This is a challenging task, as the level of attribute classes (such as fast, scenic, or safe) and member attributes (e.g., amount of bike lanes) either have different units or cannot be expressed as number at all. Breaking down trade-off functionalities to the level of numerically scaled route attributes bears the danger of too complex user interactions. A related aspect of future work is to develop appropriate interactive elements for user interfaces of route planners besides the traditional checkboxes and track bars. If we take a situation of four conflicting route selection criteria, an appropriate basic geometric feature could be a tetrahedron, where each of the tetrahedron's corners expresses a desired route selection criterion. With such feature, the navigator can with his pointing device set a marker inside the tetrahedron, where the nearness ( $d_1$ ,  $d_2$ ,  $d_3$ , and  $d_4$ ) of the marked position to each of the four corners denotes the importance of the corresponding criterion (Figure 9).

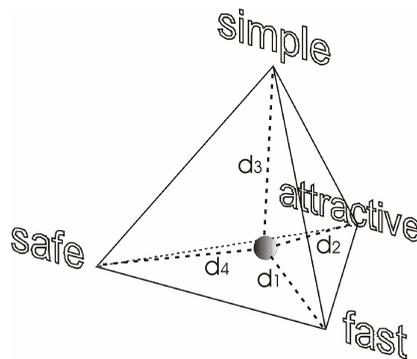


Figure 9: Tetrahedron as potential user interface feature for a route planning tool

Another relevant step for future work will be to find the best sequence of user interactions in the route selection process, i.e., if and when exactly the tradeoff functionality should be presented to the navigator, and which route selection criteria should actually be presented for selection. Current route planners let the user enter start and destination as well as the desired route characteristics simultaneously. In a subsequent step, the "best" route is computed. An alternative would be an approach where after the user's entering of start and destination a set of reasonable routes is computed first, and in a second step the tradeoff functionalities that are tailored to the set of precomputed routes from step one are presented to the user for making his preference statements.

The claim of this paper is not to overload a route planner with too much trade-off functionality or a high number of route selection criteria. It rather claims that these features, if they are necessary for defining the optimal route, should be provided by the route planner. The test scenario presented in this paper was an example for such situation, where one single route selection criterion alone leads hardly ever to the optimal route.

## AUTHOR NOTES

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## BIBLIOGRAPHY

- Ben-Akiva, M., Bergman, U. M., Daly, J. A. and Ramaswamy, R. (1984). Modeling Inter Urban Route Choice Behavior. *Ninth International Symposium on Transportation and Traffic Theory*, VNU Science Press.
- Bovy, P. H. L. and Stern, E. (1990). *Route choice: Wayfinding in transport networks*. Dordrecht, Kluwer Academic.
- Debreu, G. (1960). Topological methods in cardinal utility theory. *Mathematical Methods in the Social Sciences*. K. J. Arrow, S. Karlin and P. Suppes. Eds. Standford, CA, Standford University Press.
- Dijkstra, J. and Timmermans, H. J. P. (1997). Exploring the Possibilities of Conjoint Measurement as a Decision-Making Tool for Virtual Wayfinding Environments. *2nd Conference on Computer Aided Architectural Design Research in Asia (CAADRIA '97)*. Y.-T. Liu. Ed. Hsinchu, Taiwan, Hu's Publishers Inc., Taipeh: 61-72.
- Ehlers, M., Jung, S. and Stroemer, K. (2002). *Design and Implementation of a GIS Based Bicycle Routing System for the World Wide Web (WWW)*. Spatial Data Handling 2002, Ottawa.
- Golledge, R. G. (1995). Path Selection and Route Preference in Human Navigation: A Progress Report. *Spatial Information Theory (COSIT'95)*. A. U. Frank and W. Kuhn. Eds. Berlin, Springer. 988: 207-222.
- Green, P. E. and Srinivasan, V. (1978). Conjoint analysis in consumer research: issues and outlook. *Journal of Consumer Research* 5: 103-152.
- Hartmann, A. and Sattler, H. (2002). *Preference Measurement in Marketing Research Practice*. 31. Annual Conference of the European Marketing Academy, Braga, Portugal.
- Hyodo, T., Suzuki, N. and Takahashi, K. (2000). *Modeling of Bicycle Route and Destination Choice Behavior for Bicycle Road Network Plan*. Annual Meeting of Transportation Research Board.
- Keeny, R. L. and Raiffa, H. (1993). *Decision Making with Multiple Objectives: Preferences and Value Tradeoffs*. Cambridge, UK, Cambridge University Press.
- Leigh, T. W., MacKay, D. B. and Summer, J. O. (1984). Reliability and Validity of Conjoint Analysis and Self-Explicated Weights: A comparison. *Journal of Marketing Research*: 456-462.
- Malczewski, J. (1999). *GIS and Multicriteria Decision Analysis*. New York, John Wiley.
- Rinner, C. and Malczewski, J. (2002). Web-enabled spatial decision analysis using Ordered Weighted Averaging (OWA). *Geographical Systems* 4(4): 385 - 403.
- Russell, S. J. and Norvig, P. (2003). *Artificial Intelligence - A Modern Approach*. London, Prentice-Hall International, Inc.
- Sattler, H. and Hensel-Börner, S. (2000). A comparison of Conjoint Measurement with Self-Explicated Approaches. *Conjoint Measurement: Methods and Application*. A. Gustafsson, A. Herrmann and F. Huber. Eds. Berlin, Springer: 121-133.
- Stern, E. (1999). Reactions to congestion under time pressure. *Transportation Research Part C* 7(2-3): 75-90.
- Stern, E. and Leiser, D. (1987). Levels of Spatial Knowledge and Urban Travel Modeling. *Geographical Analysis* 20(2).