# FLEXIBLE TRAFFIC MANAGEMENT BASED ON
# BOUNDED RATIONALITY AND INDIFFERENCE BANDS

**Jaap Vreeswijk***
*Research and Development, Peek Traffic bv, Netherlands*
**Eric van Berkum**
*Centre for Transport Studies, University of Twente, Netherlands*
**Bart van Arem**
*Department of Transport and Planning, Delft University of Technology, Netherlands*

## ABSTRACT

**Constrained cognitive abilities cause imperfections in traveler's choice behavior which are largely systematic and predictable. This paper introduces the concept 'regulation flexibility' to build upon this knowledge, taking it as an advantage to increase the effectiveness of traffic network management rather than a threat. It assumes that within set boundaries, traffic management measures are perceived as acceptable by travelers, enabling road operators to have certain control over behavioral response and undesirable consequences. A conceptual framework for regulation flexibility is provided, following the three stages of the decision-making process: observation, evaluation and choice. Emphasis is on the processes underlying choice and behavior, to explain deviations from rational behavior, rather than the outcome itself. The notion of indifference bands reported in literature is taken as a starting point and applied in a broader context to specify regulation flexibility in all three stages. This paper debates that: (1) travelers' ability to detect changes in attributes of their trip or the performance of a traffic system is limited, (2) travelers make mistakes in estimating the value of changes, and (3) great diversity in applied choice patterns cannot be explained by observation and evaluation factors alone. In each of the three decision-making stages, multiple aspects are of influence to the perception of travelers and point toward the need for more empirical research. Future research will focus on travelers' ability to observe changes in attributes of their trip or the performance of a traffic system.**

*Keywords: Traffic network management, bounded rationality, indifference band, behavioral response,*

## INTRODUCTION

Explicit consideration of individual travelers and understanding of their interests and behavior is often regarded as troublesome by traffic engineers and road operators. They have to deal with imperfections in the abilities of individual travelers, but these imperfections also provide opportunities for effective operation of traffic network management. Traffic network management aims to minimize the total travel time in a network with consideration of constraints for traffic safety and air quality. On the other hand, individual road users are in particular interested in their own travel time. When reaching equilibrium state, these two situations are likely to be different, i.e. system optimum and user equilibrium [1, 2]. As traffic network management aims to reach the system optimum, its measures will not necessarily improve the situation of individual road users. Earlier research showed that the design of traffic management measures often overlook the interests and

benefits of individual road users [3]. Practical experience learns that traffic management measures with low acceptance are likely to lead to behavioral adaptation (e.g. red light running and rat run), possibly with undesirable and disproportionate outcomes.

This paper aims to find solutions for traffic network management which improve the efficiency of the total transportation system, without ignoring possible decline of individual situations. This paper introduces a concept called 'regulation flexibility' to assist road operators in activating stimulating or discouraging measures without those having undesirable consequences. This concept presumes that road operators are aware of the limits of acceptability as well as the thresholds of factors which influence behavioral response, and select their strategies accordingly.

This paper will first discuss the difference between modeling approaches based on standard and behavioral economics. Next, a conceptual framework for regulation flexibility based on behavioral economics principles is presented. The theoretical background of the framework is discussed in the following section. The final section discusses considerations for the setup of future empirical research and, concluding remarks.

## MODELLING APPROACHES

To what extent is travel choice behavior and behavioral response predictable? An important set of assumptions, derived from standard economics, often made in transportation modeling states that people are rational decision makers and above all perfectly informed about the available choice alternatives. It is assumed that they can calculate the value of the different options available, that they are able to derive the optimal choice, and that they are cognitively unhindered in weighting the implications of each potential choice [4-7]. In other words, people are presumed to be making logical and sensible decisions and quickly adopt their choice to changing conditions.

On the basis of these assumptions, current traffic models combine demand (i.e. travelers: trips and travel choice behavior) and supply (i.e. infrastructure and traffic management) and determine the performance of the transportation system by means of traffic assignment. Generally these models assume a fixed supply and an elastic demand which anticipates to changes in the

Basicweg 16, 3821 BR Amesfoort, Netherlands; Tel: +31 33 454 1724; Fax: +31 33 454 1740; E-mail: jaap.vreeswijk@peektraffic.nl

system performance. However, to understand the boundaries of regulation flexibility the question is how demand alters when traffic management measures change supply. In reality, people have limited knowledge and constrained cognitive abilities leading to prejudiced reasoning and certain randomness in behavior and choice outcomes [8]. In some cases, like random utility theory modeling, a random variable or error term is considered to somehow weaken the assumption of perfect rationality and knowledge. Nonetheless, many models based on standard economics fall short in considering the resulting imperfections of individual travelers.

Behavioral economics draw on the aspects of both (cognitive) psychology and economics, and studies the motives and behaviors that explain deviations from rational behavior [8, 9]. It is not just the behavior (i.e. choice outcome) that is of interest, but also the decision-making process behind such behavior. Irrational behavior is about human's distance from perfection. Recent studies provide evidence that these irrational behaviors are neither random nor senseless. They are systematic, consistent, repetitive, and therefore predictable [8, 9]. Prospect theory and regret theory are examples which have been derived from behavioral economics and applied in the transportation domain. Prospect theory assumes that decisions are context-dependent and that the evaluation of risky prospects involves identification of gains and losses with respect to some common reference point [10, 11]. Regret theory postulates that when choosing, people anticipate and try to avoid the situation where a non-chosen alternative outperforms the chosen one, which would cause post-decision stress [12]. In order to develop better descriptive models of travel choice behavior, and to validate theories derived from behavioral economics, empirical research is needed [3, 6, 8].

## REGULATION FLEXIBILITY

The concept of regulation flexibility builds upon the knowledge that travelers make mistakes as discussed earlier, and the notion of indifference bands. That is, travelers are only inclined to alter their choice when a change in the transportation system or their trip, for example the travel time, is larger than some individual-situation-specific threshold [6, 7]. Presumable, such thresholds arise at different moments in the decision-making process. Based on literature review, perceptual factors can be allocated to three successive stages: 'observation', 'evaluation' and 'choice'.

With sufficient knowledge on the thresholds and the behavioral response of travelers, the rationale of regulation flexibility is that ex-ante evaluation of the effects of traffic management measures can determine which measures are most effective and thus should be taken. As a result, the effectiveness of traffic management measures increases and the system performance will benefit.

The conceptual framework shown in Figure 1 summarizes the concept of regulation flexibility. For simplicity reasons, aspects relevant to perception as found in literature, such as risk attitude, inertia, habit, learning, information, reference point, individual characteristics and trips purpose/ importance, have been left out. Nonetheless, their influence is discussed in more detail in the following section.
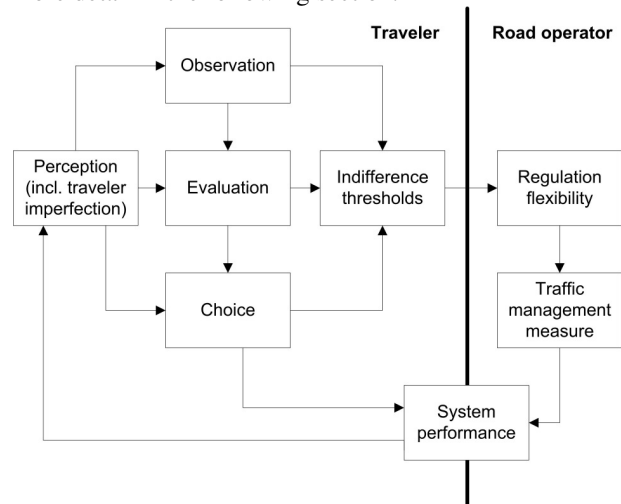


**Fig. 1:** Conceptual framework for regulation flexibility based on three stages: observation, evaluation and choices, which are affected by perception causing indifferences and leading to regulation flexibility.

## THEORETICAL BACKGROUND

*Observation*

Research on the impact of learning shows that the awareness among travelers of changes in the transport system is limited and grows over time as a result of direct experience and indirect learning [6]. A change could involve an improvement or decline of an existing alternative or the introduction of a new alternative, and concern for example the waiting time at traffic lights, the average speed or the travel time. In general, the larger, the more likely, the more important and the more negative a change, the sooner a traveler is expected to notice the change [6, 13]. However, when a change is within the natural variation of a traffic situation with respect to an average, it seems unlikely that travelers are capable to detecting the change at all. For example, the waiting time at a traffic light with average 30 seconds and variation 15 seconds, means that measures shifting the average within the range of 15 to 45 seconds are hardly distinguishable from the natural variation. Derived from cognitive sciences, change blindness is the inability to detect and report changes to objects from one instant to the next that are obvious once pointed out [14]. Experiments have shown that participants are surprisingly bad at detecting even large changes, sometimes leading to change blindness in 88.5 percent of all cases. Change blindness increases when the changed item is not relevant for the task, when the magnitude of the change increases, and when the change is outside the visual periphery [14].

Different studies confirm that the decisions and actions of travelers not always correspond with their (perceived) observations. In one study only 12% of the drivers was able to correctly perceive their experienced travel times, and reversely, 12% perceived the opposite of their experience [13]. This led to three types of behavior: (1) logical behavior that reflects drivers choosing better perceived routes (perceive route A better and choose route A), (2) cognitive behavior reflecting drivers choosing a route in spite of not perceiving a difference between both routes; to reduce mental working load (perceive no different, choose any route), and (3) irrational behavior that reflects drivers choosing worse perceived routes (perceive route A better and choose route B). For the last type, cognitive scientists use the term 'choice blindness' to explain such failures to detect mismatches between intention and outcome of a simple task [15]. Most surprisingly is that in a choice blindness paradigm, participants still offer arguments why their choice was the most logical. An interesting insight on this aspect is that travelers are better in perceiving travel speeds than travel times and that perceived travel speeds seem to influence choice outcomes more than perceived travel time [13].

*Evaluation*

When travelers have been able to detect a change, the central question in the evaluation state is whether they value it properly or not? In a rational way, people have little feeling of how much things are worth. They focus on the relative advantage of one thing over another rather than the absolute difference, compare them locally to the available alternative, and estimate value accordingly [9].

Previous experiences serve as an anchor in the memory of travelers and strongly affect choice behavior, in particular when bad experiences are involved [9, 10]. Loss aversion refers to the fact that people treat gains and losses differently as they tend to be more sensitive to decreases in wealth than increases, while people become less sensitive for every marginal gain or loss [16, 17]. In general, bad experiences involving loss, weigh two times a similar size good experience which involves gain [8]. Figuratively, good experiences create a certain 'acceptability-buffer', for which much less bad experiences (e.g. unacceptable traffic management measures) are needed to empty again. Clearly, the reference point in the mind of the traveler determines for a large extent how things are valued. Earlier research concluded that the perception of the reference point in the mind of the traveler is vague and fuzzy rather than crisp; they may not necessarily consider their actual experience to be the reference point [10].

To value a choice option or a change in any of its attributes, the option and/or its attributes need to be within the area of interest of an individual. As a result of traveler's bounded rationality there are multiple factors which narrow this area of interest and make travelers appear indifferent concerning the evaluation of alternatives. For example habitual behavior, which evolves in trips that are often repeated and causes cognitive processes to reach automaticity and eventually results in making choices in a more or less mindless fashion [6, 18]. Besides, travelers tend to be near-sighted which means that experiences of the previous day as well as short-term gains dominate choice processes [4]. Satisfying behavior, states that people are happy with a good solution instead to find the best solution, is regarded as a major cause for travelers' indifference [4, 6]. It means that humans tend to minimize their cognitive efforts, and follow simple heuristics to reach decisions which are both satisfactory and sufficient, especially under uncertainty and time constraints [7, 13]. Empirical research on the indifference band discussed earlier showed that travelers may be uninterested in other choice options until their current situation worsens by 22 percent (e.g. extra travel time), or a choice alternative improves by 22 percent [7].

*Choice*

Changes in traffic conditions may be observed and correctly valued or not, but do they provide sufficient motive to affect the choice outcome? Generally, studies on choice behavior focus on choice outcomes, apart from few exceptions which shifted interest to the analysis of underlying cognitive mechanisms. Such studies for example showed that travelers think much more strategically than usually presumed [19, 20]. Based on the analysis of verbal reports at least four decision strategies can be considered: the comparison strategy, the exploitation strategy, the exploration strategy and the anticipation strategy [19]. Great diversity in applied strategies proves that a certain level of awareness and acceptance of changes affect choice decisions. Another study showed that route switching occurs more frequently when the traffic conditions fluctuate randomly than when it is systematic [7]. This type of behavior is largely influenced by risk attitude (i.e. risk aversion and risk seeking) which determines the amount of risk somebody is willing to take. Many factors such as travel purpose, length of the trip and preferred arrival time have a big impact on a traveler's risk attitude and choice outcomes [e.g. 4]. In terms of choice outcomes, roughly four route choice patterns can be distinguished: fixed choice, single trial, preferred switching and random switching [18].

## CONCLUSION AND FUTURE RESEARCH

Clearly, it is uncertainty in the mind of the traveler, rather than variability in the system which influences behavior [11]. If a change is detectable, and observed by the traveler, then the traveler might be able to use value indicators to come to a decision and make a choice. However, what may be regarded as predictable by one person may seem completely arbitrary by somebody else. To increase the effectiveness of traffic network management measures, regulation flexibility can be

useful in two ways. First, to use knowledge about the limits of acceptability and thresholds of behavioral response, providing certain flexibility in traffic management as discussed in this paper, in order to come close to a system optimal state. Secondly, to make sure that travelers notice the impact of measures or presence of information in case their aim is to influence behavior or choice. In this context, 'choice architecture' could help individuals to overcome cognitive biases, and to highlight the better choices for them, without restricting their freedom of choice [8]. In either case, a behavioral economics perspective is preferred, but to reach better descriptive models for ex-ante evaluation of travel choice behavior, more empirical research is needed. To the best knowledge of the authors there is yet no related work that shows practical application of the philosophy discussed in this paper. However, road operators' interest in finding synergies between human factors and dynamic traffic management recently started increasing [21] .

Before designing an experiments, it is important to note that due to the analytical similarity of the perspective of limited awareness and the existence of indifference bands, it is impossible to empirically distinguish these two appearances, based on observed choice alone [6]. It is impossible to derive from the observation that a traveler repeatedly responds to a change or not, whether this results from the inability to observe the change or from indifference and disinterest to act upon it. To anticipate to such limitations and enrich choice-data it is recommendable to collect participants' cognition in different sections of an experiment by means of a questionnaire or verbal protocols [6, 13, 19].

Future research will involve a field study at a series of controlled intersections to determine relevant factors with respect to regulation flexibility and their relative importance empirically. The study will focus on questions related to travelers' ability to observe changes in waiting time and travel time, as well as travelers' perception related to these. In particular the correlation between subjective data from questionnaires and objectively measured data will be studied. First results from two exploratory experiments are currently being analyzed and reported [22, 23].

## ACKNOWLEDGEMENTS

## REFERENCES

[1] Roughgarden, T. (2003). The price of anarchy is independent of the network topology. *Journal of Computer and System Sciences,* 67**,** 341-364.

[2] Youn, H., Gastner, M. T. & Jeong, H. (2008). Price of anarchy in transportation networks: Efficiency and optimality control. *Physical Review Letters,* 101.

[3] Vreeswijk, J. D., Van Berkum, E. C., Van der Vliet, H. A. & Van Arem, B. (2010). Effective strategies for energy efficient network management. *Proceedings of the 13th International IEEE - ITS Conference.* Madeira

[4] Bogers, E. A. I., Viti, F. & Hoogendoorn, S. P. (2005). Joint modeling of advanced travel information service, habit, and learning impacts on route choice in laboratory simulator experiments. *Transportation Research Record,* No. 1926**,** 189-197.

[5] Avineri, E. & Prashker, J. N. (2004). Violations of expected utility theory in route-choice stated preferences. *Transportation Research Record,* No. 1894**,** 222-229.

[6] Chorus, C. G. & Timmermans, H. J. P. (2009). Measuring user benefits of changes in the transport system when traveler awareness is limited. *Transportation Research Part A: Policy and Practice,* 43**,** 536-547.

[7] Srinivasan, K. K. & Mahmassani, H. S. (1999). Role of congestion and information in trip-makers' dynamic decision processes experimental investigation. *Transportation Research Record***,** 44-52.

[8] Avineri, E. (2010). 'Choice Architecture' and the Design of Advanced Traveler Information Systems (ATIS). *Proceedings of the 13th IEEE - ITS Conference - Workshop on Traffic Behavior, Modeling and Optimization.* Madeira

[9] Ariely, D. (2009). *Predictably Irrational - Revised and expanded edition,* London, HarperCollingsPublishers.

[10] Avineri, E. & Bovy, P. H. L. (2008). Identification of parameters for a prospect theory model for travel choice analysis. *Transportation Research Record,* No. 2082**,** 141-147.

[11] Bonsall, P. (2004). Traveller behavior: Decision-making in an unpredictable world. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations,* 8**,** 45-60.

[12] Chorus, C. (2011). Regret aversion, risk aversion, and their impact on route choices and traffic equilibria. *91th annual meeting of the Transportation Research Board.* Washington D.C.

[13] Tawfik, A., Rakha, H. & Miller, S. (2010). Examining drivers experiences, perceptions, and choices in route choice behavior. *Proceedings of the 13th IEEE - ITS Conference - Workshop on Traffic Behavior, Modeling and Optimization.* Madeira.

[14] Martens, M. (2011). Change detection in traffic: where do we look and what do we perceive? *Transportation Research Part F: Traffic Psychology and Behaviour,* 14F, 240-250.

[15] Johansson, P., Hall, L., Sikström, S., Tärning, B. & Lind, A. (2006). How something can be said about telling more than we can know: On choice blindness and introspection. *Consciousness and Cognition,* 15**,** 673-692.

[16] Kahnemann, D. & Tversky, A. (1979). Prospect theory: an analysis of decision under risk. *Econometrica* vol. 47, no. 2**,** pp. 263-291.

[17] Tversky, A. & Kahnemann, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty,* vol. 9**,** pp. 195-230.

[18] Tawfik, A., Rakha, H. & Miller, S. (2010). Eliciting drivers cognitive trends, examing driver learning, and capturing aggregate evolution in route choice. *Proceedings of the 13th IEEE - ITS Conference - Workshop on Traffic Behavior, Modeling and Optimization.* Madeira

[19] Senk, P. (2010). Route choice under microscope: Process oriented analysis of decision making. *89th annual meeting of the Transportation Research Board.* Washington D.C.

[20] Razo, M. & Gao, S. (2010). Strategic thinking and risk attitudes in route choice. *89th annual meeting of the Transportation Research Board.* Washington D.C.

[21] Harms, I. M., Lambers, M. & Westerman, M. (Year). The synergy between human factors and traffic management (In Dutch). *In:* 9th Dutch Symposium on Dynamic Traffic Management, 2011 Rotterdam.

[22] Van der Bijl, B., Vreeswijk, J. D., Bie, J. & Van Berkum, E. C. (2011). The perception and acceptance of waiting at signalized intersection by car drivers. *In preparation for the 14th International IEEE - ITS Conference.* Washington D.C.

[23] Vreeswijk, J. D., Do, M., Middag, W. & Martens, M. (2011). Travelers' ability to observe changes in traffic intensities and traffic light settings. *In preparation for the 14th International IEEE - ITS Conference.* Washington D.C.