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# AFFECT-BASED APPROACH: QUANTIFYING USER COSTS RELATED TO INFRASTRUCTURE

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## Abstract

A key component of civil engineering life-cycle analysis is the consideration and inclusion of user costs. Currently, traffic delay user costs are assessed by formulating a constant valuation of the user's time. This approach fails to consider the evolution and reformation of society's expected performance throughout a given construction period. This paper develops an affect-based assessment approach from key psychology tenets to quantify how an individual constructs and refines their evaluation measures as they are exposed to a sequence of interactions. This affective assessment approach is then employed to analyze an individual's response to a three-week theoretical construction traffic modification. The traffic delay user costs are then redistributed in accordance to the individual's affective response, resulting in a more accurate representation of the individual's perceived costs.

## Keywords

User costs, constructive evaluation, affective assessment

## 1 Introduction

Infrastructure maintenance is driven by the interaction of three key elements: the infrastructure's deterioration state, the available maintenance funding, and the public's perception of the provided performance. As civil engineers, we are commonly asked to take a leading roll in formulating optimal maintenance plans. Our engineering training and professional experience has provided us the skills to calculate a given infrastructure's deterioration state, to formulate potential short and long-term maintenance methods, and to estimate the relative cost of each potential method. But when it comes to the third aspect, assessing the public's perception of the provided performance, we find ourselves beyond our realm of experience. We revert to employing static user cost assessment approaches rather

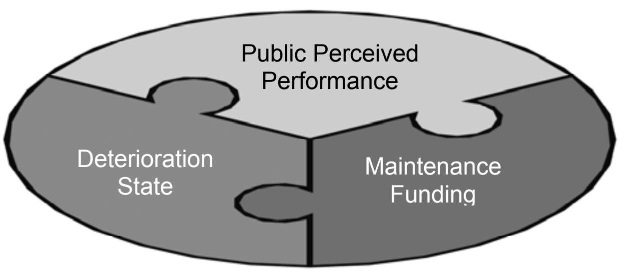


*Figure 1 Infrastructure maintenance: three key elements*

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than investigating the problem as the public does, by constructing a continually evolving evaluation tool moulded from and tempered by all previous and subsequent experiences. This article takes an essential step along this path by applying key findings from the field of psychology to develop an affect-based assessment approach to quantify an infrastructure user's perceived costs.

# 2 Life-cycle analysis

## 2.1 Current state of practice

During the past 25 years, numerous civil engineering life-cycle analysis and maintenance approaches have been developed to formulate optimal maintenance programs given an aging infrastructure and limited budget. These analytical approaches employ common design and inspection procedures to quantify the current and future levels of structural and user performances. These performances and the possible maintenance actions are then be represented in a common value, usually a monetary valuation, and the cost-benefit analysis is employed to evaluate the possible maintenance alternatives given the available funding. From this analytical process, the most "optimal" maintenance program is selected.

## 2.2 Assessing user costs

A key component of the life-cycle analysis is the consideration and quantification of user costs. User costs are the changing or additional costs incurred by the structure's users (the public) due to the structure's modified performance. The inclusion and quantification of user costs vary among structural management approaches but commonly include costs due to additional travel time and operating costs, but can also include secondary items such as the economic impact from inadequate traffic flow and direct and indirect accident related costs (QUADRO 2004). As an example, traffic delay user costs can be computed by multiplying the vehicle specific average daily traffic volume by the respective hourly operating cost and the additional incurred travel time (Radojičić 2002). While such succinct quantification methods can capture a definitive user impact, it is proposed that such static analytical methods fail to consider the reformation of society's expected performance within the changing traffic environment and resulting in a modified user assessed cost.

# 3 Constructive evaluation

For an engineer to evaluate the impact of a traffic change can, on the surface, appear to be a relatively simple task accomplished by measuring the current and modeling the future average vehicular speed and traffic volume prior to and following a given traffic change and computing the resulting user costs. But the true question remains: do users consciously assess this change and does this assessment directly correspond to the engineer's assessed user costs, and if not, how can the engineer's user cost assessment approach be modified to more accurately quantify user costs?

## 3.1 Individual construct formation

By consulting the findings in the field of psychology, one can delve into the dynamic nature of the user cost evaluation process. From psychology, one can observe that when a person uses and interacts with a structure, they are continually assessing the interaction with their senses – sight, sound, touch and smell (Mahoney 2003). The individual defines their experienced world with ongoing sensorial assessments by formulating mental constructs – discrete relative mental concepts of their experienced reality (Kelly 1955). As the person experiences additional interactions, the individual compares and evaluates the current sensorial data against their pre-existing constructs. Where environmental changes occur, the person is unconsciously spurred to determine if the given change correlates with the pre-existing construct, whether the change is positive or negative, and if any unconscious or conscious action is warranted (Bargh and Chartrand 1999). The individual then employs these subsequent interactions, assessments and evaluations to refine or redefine, where warranted, their constructs to more accurately represent their experienced reality (Kelly 1955).

### 3.2 Framing and affect

Since an individual's evaluation tools are defined by their previous interactions, the sequence in which a person experiences a set of interactions can frame and alter their resulting evaluation (Kahneman 2002)(Frederick and Loewenstein 1999). Likewise, during and following a given interaction, the individual denotes the interaction with the respective evaluation or affect – the "positive or negative quality" of the interaction (Slovic et al 2002, p 397). The individual then employs this affective evaluation in the interaction decision process and in the post-interaction personal construct reformation. Lastly, when the individual refines their personal constructs, the most recent interactions and the interactions with the largest affective valuation have the most prominent impact on the refined construct (Kahneman 2000). The end result is an evaluation measure unique to each individual, comprised of the individual's constructs, which are a product of the quantity, range, and sequence of their respective environmental interactions (Glasersfeld 1996).

## 4 Quantifying constructive evaluation

In light of the dynamic evaluation findings presented above, it is proposed to employ an *affect-based evaluation approach* and the human temporal sensitivity documented by Brehmer (1970) to quantify the impact of a sequence of interactions. This affect-base evaluation approach differs in three key aspects from the previous works – the affective assessment is a direct function of the range of previous experience, both the perceived standard deviation and the perceived mean are weighted with the temporal depreciation factor, and the stimuli measurement units are assessed in speed (km/hr) rather than in time. This affect-based approach is applied in Section 5 to quantify the user impact of a given traffic flow modification and to formulate a more representative user cost distribution.

### 4.1 Affective assessment

The key component of this affective assessment is the evaluation of the current interaction against the individual's previous perceived experience. This calculation is conducted with Equation 1 and the result is graphed in Figure 2a.

$$AS_i = 2^{\left|\frac{S_i - p\mu_{i-1}}{p\sigma_{i-1}}\right|} \quad (1)$$

Where:

$S_i$ = the interaction i measured speed

$p\mu_{i-1}$ = the perceived mean speed for the previous interactions (1 to i-1)

$p\sigma_{i-1}$ = the perceived speed standard deviation for the previous interactions (1 to i-1)

$AS_i$ = the interaction i induced affect given the measured speed and the previous normal distributed perceived speed.

In equation 1, the previous perceived experience is represented by a normal distribution comprised of the sequential affective evaluation of all previous interactions. This weighted affect normal distribution is represented by its mean and standard deviation hereafter referred to as the perceived mean and the perceived standard deviation. In Figure 2a, one can observe that as the offset between the current interaction and the previous perceived mean increases, the resulting potential affect increases by a multiple of 2 for every additional perceived standard deviation. It is important to mention that in order to ensure computational stability, a minimum perceived standard deviation limit must be established to ensure that the perceived standard deviation does not become too small – thereby producing a hyper-sensitive individual.

The impact of the memory and time depreciation phenomenon observed by Kahneman (2000) is incorporated in the affective-assessment by employing Equation 2 whose result is plotted in Figure 2b.

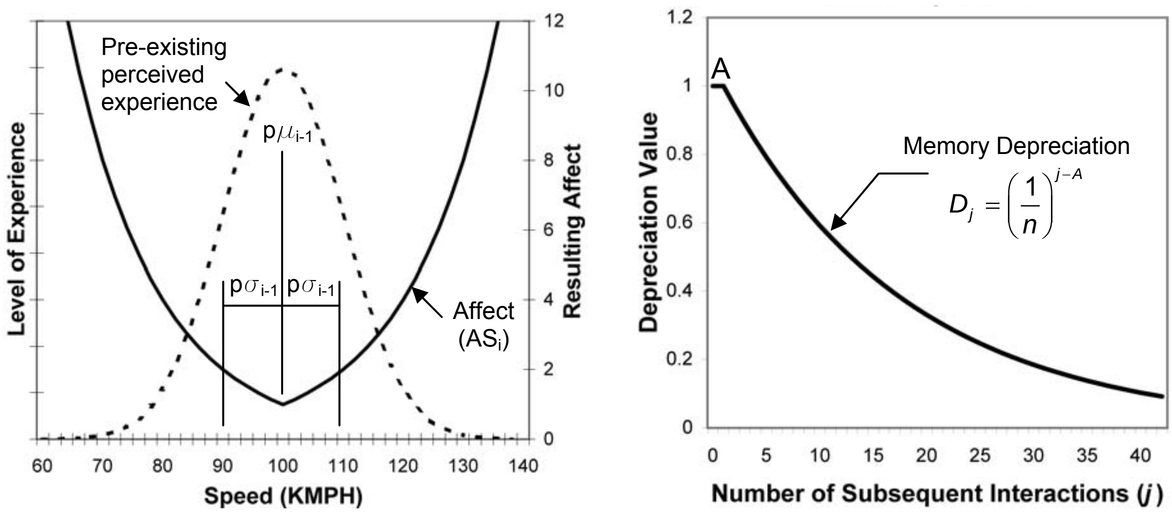


*Figure 2a) Potential affect given the pre-existing perceived experience, Figure 2b) Interaction affect depreciation as a function of the number of subsequent interactions.*

In Equation 2, *j* is the number of interactions between the considered interaction and the current interaction, *A* is the number of initial non-depreciated interactions currently set at 2, *n* is the memory depreciation rate currently set at 1.06, and $D_j$ is the depreciation for the considered interaction.

$$D_j = \begin{cases} 1 & (j \leq A) \\ \left(\frac{1}{n}\right)^{j-A} & (j > A) \end{cases} \tag{2}$$

The evolutionary experience of transitioning from interaction *i* to interaction *i+1* is shown in Figure 3. During this transition, a person reconstructs their previous perceived experience, shown in gray, by including the affective valuation of interaction *i*, denoted $AS_i$, for the measured speed $S_i$. The inclusion of $AS_i$ causes the weighted affect normal distribution to shift and dilate, modifying the affective evaluation measure for interaction *i+1*, graphed in black. (Please note that the shifting and dilation of the weighted affect normal distribution is graphically exaggerated for descriptive purposes).

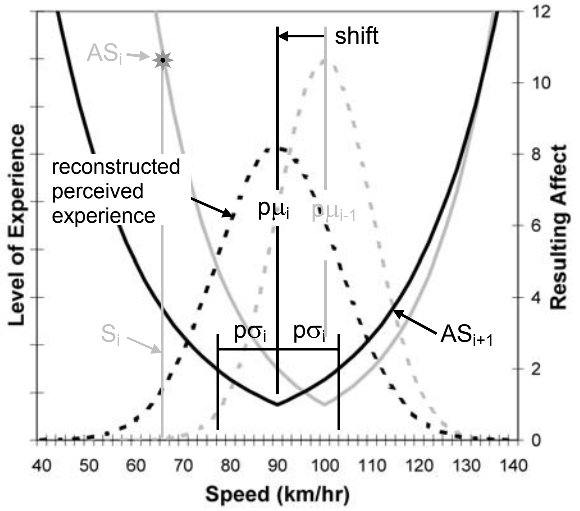


*Figure 3 Interaction i to interaction i+1, the reconstruction of the perceived experience*

# 5 Affective assessment case study

## 5.1 Case study overview

The following case study focuses on eastbound US Interstate I-26, the inbound Northwest highway access route for Charleston, South Carolina, at the US-52 and Ashley Phosphate Road junction, mile marker 209. This highway link is shown in Figure 4a and 4b and is denoted by the small black arrows. The data presented here was obtained from traffic monitoring site 0071-1 of the South Carolina Traffic Polling and Analysis System and was collected by an automatic traffic recorder (SCDOT 2006). This study addresses the hourly traffic data for the 42 working-day period between November 9, 2005, and January 10, 2006. It is assumed, the studied individual commutes along this section of highway each work day between the morning hours of 7:00 and 8:00 on all non-national holidays.

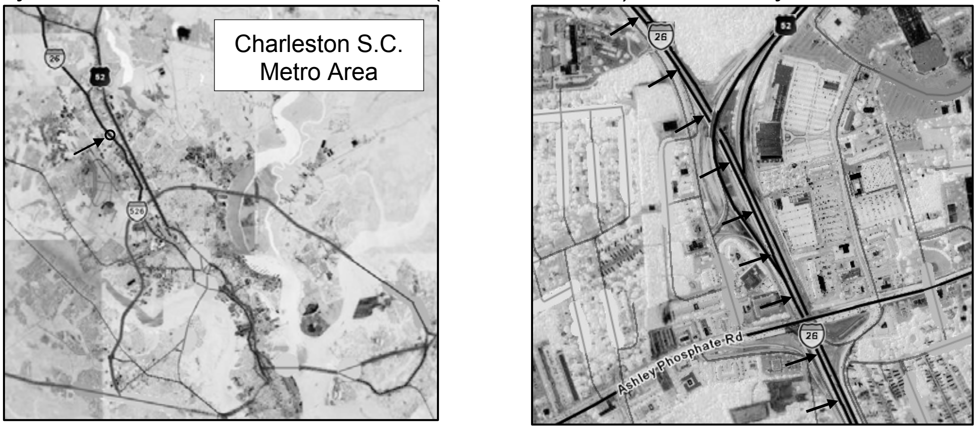


*Figure 4a) Charleston metro area, Figure 4b) Eastbound I-26 at US-52 and Ashley Phosphate Road junction (Google 2006).*

In Figure 5a, the average speed and volume for this section of roadway is presented. It can be observed that the volume peaks at 7:00, the beginning of the morning commute, and then exceeds the highway's capacity resulting in a drop of the average speed.

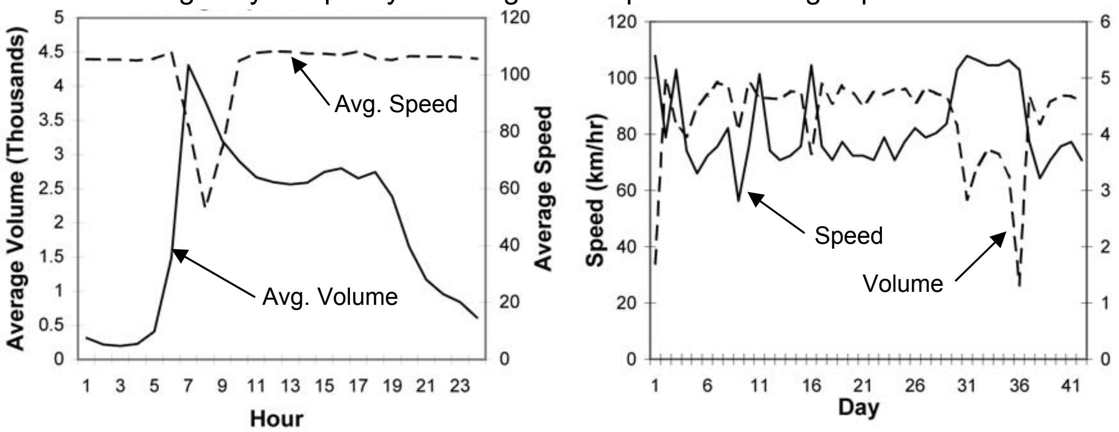


*Figure 5a) Average hourly speed and volume, Figure 5b) 7:00 traffic speed and volume.*

The 7:00 traffic speed and volume for the studied 42-day period is presented in Figure 5b. From Figure 5b, it can be seen that the speed and volume are relatively inversely correlated, with the speed reaching maxima when the volume is at minimum and vice versa. Of particular interest are days 30 to 36 which are the working days between December 22 and January 2, the Christmas and New Year holiday time. It is during this period that the traffic volume drops and the traffic speed achieves free-flow conditions.

## 5.2 Affective analysis of traffic data

The traffic speed data was analyzed with the affective analysis approach introduced in Section 4 and the results for the 7:00 traffic data is presented in Figure 6. This analysis employs the average traffic speed, shown in bold, to sequentially define the perceived mean and perceived standard deviation which are in turn employed to evaluate the subsequent commuting speeds. In this analysis, it is assumed that the given individual's experience is limited to this study, therefore the interaction on day 2 is completely framed by the interaction on day 1. This framing results in a large affective response, for the interaction on day 2 is significantly beyond the individual's previous experience. This experience shift induces the individual to redefine and reconstruct their evaluation measure (their perceived mean and perceived standard deviation). As the individual's interactions transpire, their evaluation measures respond and evolve, sometimes at a slow rate as on days 13 and 21, sometimes at a rapid rate as on days 9, 11 and 16. This analytical process, as in the psychological process, results in a dynamic evaluative measure.

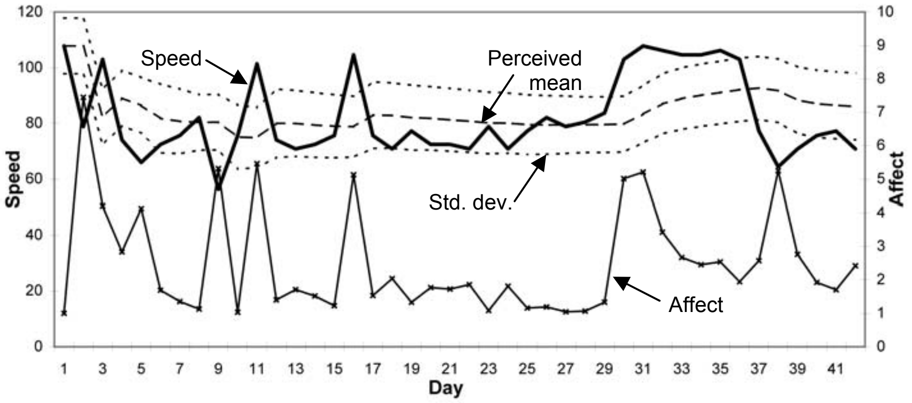


*Figure 6 Affective analysis of 7:00 traffic speed*

What is of particular interest is the individual's Christmas holiday commuting interactions, days 30 to 36. It is during this time that the individual experiences free-flow traffic conditions for an extended period of time. Initially this traffic change has a significant affect, for the individual is accustomed to the constrained traffic conditions. As the individual's experience with the free-flow traffic conditions broadens, the novelty and the affect diminish, for the individual's evaluative standards have evolved to accept and even anticipate these free-flow conditions. As a direct result, when the individual once again experiences constrained traffic conditions, on days 37 and 38, the affect of these standard and sub-standard traffic conditions is amplified.

## 5.3 Affective analysis applied to user cost distribution

With this insight into the dynamic nature of an individual's affective valuation, it is only natural for it to be applied to the quantification of user costs. For an example case study, the Interstate I-26 traffic speed data is extended for an additional three weeks to include a theoretical 15-day construction period to accommodate the theoretical rehabilitation of an overpass. The traffic data for the additional three weeks is developed by assuming the construction traffic speed directly corresponds to the three week period between days 12 and 26 but is reduced by a constant speed of 20 km/hr.

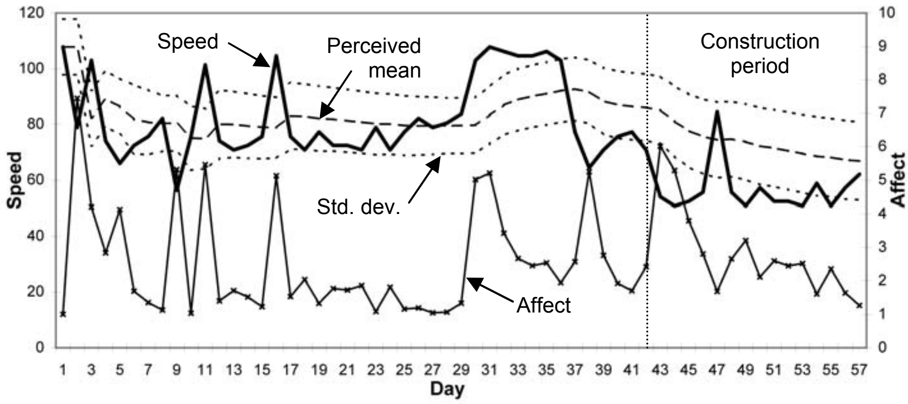


*Figure 7 Affective analysis of 7:00 construction traffic speed*

The original 42-day traffic data and the additional 15-day construction traffic data for all 24 hours were then analyzed with the affective analysis approach. The results for hour 7:00 are presented in Figure 7. It can be observed that the initial 42 days of data frames this three-week construction period, providing a pre-established evaluative measure. Therefore when the 20 km/hr speed reduction is introduced, the response is initially significant, but as the individual experiences this speed reduction, their evaluative measures adjust to this new condition and the affective valuation reduces. By day 57, the end of the 3-week construction period, the individual's evaluative measures have adjusted to and compensated for the construction conditions and therefore the affective valuation is substantially reduced.

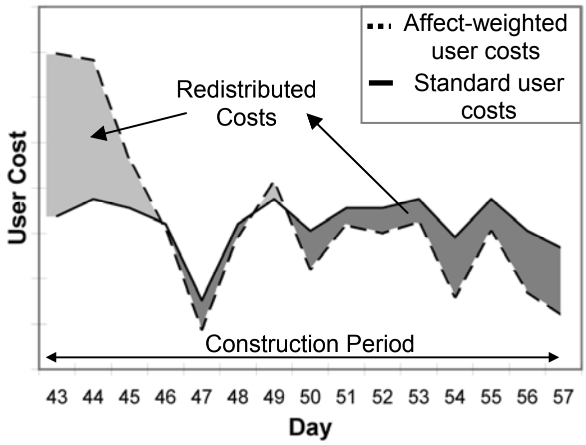


*Figure 8 Standard and affect-weighted user costs during the construction period*

When this affective assessment is applied to weight and redistribute the standard traffic delay user costs, the result is apparent. The affect-weighted individual user costs per day for the 7:00 to 8:00 traffic period are presented against the standard user costs in Figure 8. The standard user costs were calculated by multiplying the additional time delay for each day introduced by the 20 km/hr construction speed reduction, by the number of users considered, one, and the user constant time valuation factor, x. The affect-weighted user costs were calculated by multiplying the affective valuations presented in Figure 7 by the respective standard user costs and the total 15-day user costs and dividing by the 15-day affective valuation and user cost summations. (For non-hindsight calculations it is proposed to employ previous construction zone traffic performance data in parallel with statistical construction traffic modeling to calculate the future traffic performance, the standard user costs, and the associated affective assessment.) By studying Figure 8, one can observe that by affectively weighting the user costs, 16% of the total user costs are redistributed over the first three days, the first 20%, of the construction period. These aligned and redistributed construction user costs more-closely model the dynamic and evolutionary nature of user valuation as compared to the standard static user cost assessment approach.

## 6 Conclusions

This paper addresses the dynamic evaluation measures individuals employ to valuate a sequence of events: 1) An affective assessment approach is formulated to quantify the construction and adaptation of an individual's evaluative measure. 2) This approach is then successfully applied to affectively analyze highway performance during construction and non-construction periods. 3) The individual's construction period affective response is then employed as a benchmark against which the standard static user costs are aligned and redistributed. 4) This affective response user cost redistribution more closely models the individual perceived costs by capturing the dynamic and evolutionary nature of user cost evaluation.

It is essential to note that the presented data is solely representative of an individual who has experienced the set and sequence of interactions presented here, for as this set and sequence of interactions changes, so will the resulting affective valuation. Further development steps for this affective assessment approach include the documentation of individual interaction exposure probabilities, the assessment of affective valuation sensitivity due to a changing interaction exposure, and the application of this framework to address additional primary and secondary user costs. In closing, this case study considers only interaction-driven affective valuation in response to an abrupt traffic change. Methods, such as actively publicizing construction schedules and potential service impacts, should be employed to initiate the affective evaluation measure modification and adaptation prior to the abrupt traffic change, thereby reducing the post-traffic change affective valuation and affect-weighted user costs.

## Notations

The views expressed here reflect the views of the author alone and do not reflect the views of the South Carolina Department of Transportation.

## References


Bargh, J.A., Chartrand, T.A., 1999, The unbearable automaticity of being, American Psychologist, 54, 462-479.

Brehmer, B., 1970, Note on the effect of velocity on perceived duration, Scandinavian Journal of Psychology, 11, 157-160.

Glasersfeld, E., 1996, The conceptual construction of time, International Symposium on Mind and Time, Neuchâtel, Switzerland.

Google, 2006, Google earth beta version 3, http://earth.google.com/.

Frederick, S., Loewenstein, G., 1999, Hedonic adaptation, Well-Being: The Foundations of Hedonic Psychology, New York, United States of America,302-329.

Helson, H., 1964, Adaptation-Level Theory, New York, United States of America.

Kahneman, D., 2000, Evaluation by moments: past and future, Choices, Values and Frames, New York, United States of America, 693-708.

Kahneman, D., 2002, Maps on bounded rationality: psychology for behavioral economcis, The American Economic Review, 93, 1449-1475.

Kelly, G., 1955, The psychology of personal constructs, New York, United States of America.

Mahoney, M., 2003, Constructive Psychotherapy, London, Great Britain.

QUADRO, 2004, Economic assessment of road maintenance – the QUADRO manual, Department of Transport, London, Great Britain.

Radojičić, A., 2002, Models for identification of cost effective interventions on existing structures, Ph.D. thesis, EPFL Lausanne, Switzerland.

SCDOT, 2006, South Carolina traffic polling and analysis system, http://dbw.scdot.org/Poll5WebAppPublic/wfrm/wfrmViewDataNightly.aspx, South Carolina, United States of America.

Slovic, P., et al, 2002, The affect heuristic, Heuristics and Biases: The Psychology of Intuitive Judgement, New York, United States, 397-420.