Managing Highways for Better Reliability - Assessing Reliability Benefits of Ramp Metering

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ABSTRACT

Reliability of travel time is increasingly becoming an important part of transport policies around the world. However, a recent review of policies in OECD countries shows that despite its importance, only few countries monitor reliability or explicitly incorporate reliability into transport policy making.

The role of the government may be crucial in delivering optimal levels of reliability. A number of policy options are available to improve reliability.

Active management of the network through ramp metering is recognized as an efficient way to control motorway traffic and field tests of ramp control strategies show benefits on average travel time.

Far less is said on reliability benefits of ramp metering. There are only few studies that specifically monitor improvements in travel time variability. In this paper we present findings on a case study of applying ramp metering on a French motorway A6W near Paris. We apply a number of indicators for travel time variability before and after introducing ramp metering.

In order to take into account reliability in policy impact evaluation, cost-benefit assessment provides consistent framework to assess the monetised benefits. We therefore also calculate monetary value of reliability benefits of ramp metering and finally discuss policy implications of our results.

We suggest that failing to unbundle time saving benefits of a project between average travel time and the variability in travel time is likely to lead to sub-optimal policy solutions. We also argue that managing existing capacity better can be a cost-effective way to improve both average travel time and the variability in travel time.

1. INTRODUCTION

Traffic congestion imposes cost on the economy and generates multiple impacts on urban regions and their inhabitants through increased travel times. Congestion has not only impact on average travel speed but also on travel time reliability. As traffic volumes increase and the road network approaches full capacity, the vehicle flow becomes unstable and much more vulnerable to incidents such as accidents, vehicle breakdowns, road works or bad weather. This in turn increases variability in travel times.

There is much evidence that the variability of travel times may be more important than the average travel speed in that users of the network can plan their travel accordingly if a road is constantly congested while unpredictable travel conditions impose the greatest frustration. Unreliable and extremely variable travel times impose the greatest challenge on road users (1).

This type of congestion-related unreliability has serious consequences as users of the transport network, trying to avoid delays, need to allow more time than otherwise needed by adding a “safety margin” or “buffer” above that of average travel time. Companies or logistic managers, in turn, try to adapt their operations and build in buffer stock of goods. Hence, in contemplating a journey, users consider not just the expected average travel time but also its variability in order to avoid delays, or worse, snowballing effects, affecting other activities in the logistic chain.

Adding extra time or keeping additional stocks “just in case” is not costless. Leaving earlier to ensure arriving on-time is time wasted from other, potentially more productive, activities. Keeping additional stocks of goods can be very costly way to ensure on-time delivery of goods. Not surprisingly, a recent study by the Joint Transport Research Centre of the OECD and the International Transport Forum suggests that costs of unreliability may rival those of congestion (2).

A number of countries are looking at ways of improving the reliability of travel time while reliability has become increasingly important part of national transport policies. An improvement in the reliability and predictability of travel times can rapidly reduce the cost associated with excessive congestion levels.

The role of the government may be crucial in delivering optimal levels of reliability. However, a recent review of policies in OECD countries shows that despite its importance, only few countries monitor reliability or explicitly incorporate reliability into transport policy making (2). Network and service reliability is not systematically incorporated in the transport planning process and thus is not reflected adequately in decision making.

A number of ways to monitor reliability are available but there are also several shortcomings. Existing indicators, if applied, tend to aggregate across users, monitor system performance rather the user perspective, show annual averages hiding shorter-term variations and provide partial view, normally that of network managers rather than the reliability perceived by the end-users (3).

A wide range of policy instruments are also available to improve reliability of transport and they can be distilled into four main options (2):

- Increasing capacity of infrastructure either by supplying extra capacity or improving quality of existing one.
- Better management of existing capacity.
- Charging directly for reliability.
- Providing information to users mitigating the adverse effects of poor reliability.

In this paper, we focus on better management of existing capacity. Management options can be further divided into two categories: *pro-active and active*. Pro-active management of infrastructure mainly includes identification of network vulnerability to recurrent and non-recurrent unreliability. Dynamic processes, in turn, focus on active management of network to intensify oversight of network use or react once a network incident arises; such management systems include traffic control, accident clearing teams and rerouting strategies.

It is acknowledged that many of the policy options mentioned above are already in use as congestion mitigation policies. However, while remedial actions against congestion can also improve reliability, it is also important to separate the impacts as these two are not the same as will be demonstrated later on.

In order to ensure optimal strategies, policy makers face a number of challenges:

- To identify prevailing reliability levels by monitoring the existing variability in travel times.
- To assess the improvement in the variability of travel times after a policy intervention to ensure that the most cost-effective solutions are adapted first to improve reliability.
- To present these results in a way that is easy to communicate both for the decision makers and the users.

Until recently, improving travel time reliability has not been usually included into the assessment of management strategies. A recent study (4) has introduced measures for the variability in travel time when comparing effectiveness of alternative ramp metering strategies (ALINEA and coordinated method) at the A6W motorway in France (4). In addition to average travel time, the study included measures of standard deviation, coefficient of variation, buffer time and planning time.

In this paper we build on this analysis and apply a number of other indicators for travel time variability that have been advocated in a range of studies. In order to take into account reliability in policy impact evaluation, cost-benefit assessment provides consistent framework to assess the monetised benefits of different projects. We therefore also calculate monetary value of the reliability benefits of ramp metering and finally discuss policy implications of our results.

2. ACTIVE MANAGEMENT THROUGH RAMP METERING

Ramp metering is a specific active management measure which employs traffic lights at the freeway on-ramps to control the traffic flow entering the motorway mainstream. It consists in limiting, regulating and timing the entrance of vehicles from one or more ramps onto the main line. As with many other highway policy strategies, ramp metering was originally designed to mitigate congestion impacts. It is recognized as the most direct and efficient way to control and upgrade motorway traffic and a number of field tests of ramp control strategies in different countries are available showing benefits on average travel time (5).

Ramp metering is applied either on local or system level. Local control strategy is directly influenced by the main-line traffic conditions in the immediate vicinity of the ramp during the metering period. System control mode is a form of ramp metering in which real-time information on total freeway conditions is used to control the entrance ramp system (6).

The most efficient local ramp control strategy is ALINEA. It has been tested in many countries and proved its superiority when compared to other local strategies (7). ALINEA is based on a rigorous feedback philosophy (8) (9) (10). Since the main aim of ramp metering is to maintain the capacity flow downstream of the merging area, the control strategy for each controllable on-ramp should be based on downstream measurements. Therefore, ALINEA, which was developed by the application of the classical feedback theory, obtains the following form:

$$r_k = r_{k-1} + K(O^* - O_k) \qquad (1)$$

where r_k and r_{k-1} are on-ramp volumes at discrete time periods *k* and *k-1* respectively, O_k is the measured downstream occupancy at discrete time *k*, O^* is a pre-set desired occupancy value (typically set equal to the critical occupancy which separates fluid traffic from congested one) and K is a regulation parameter.

Ramp metering has been introduced mainly for reducing congestion and improving safety and the evaluation of impacts usually focuses on congestion related indicators, such as average travel time, duration of recurrent congestion, mean speed, fuel consumption and emissions (5) (7).

Far less is said on reliability benefits of ramp metering. There are only few studies that specifically monitor improvements in travel time variability. A recent study (4) compares different on-ramp strategies at the A6W Motorway near Paris. The study shows that ramp metering improves the variability of travel time more than average travel time (4). Therefore, it seems quite obvious that monitoring travel time variability, in addition to average travel time, and measuring network users' experiences are vital in making a robust assessment of the policy options to improve user experience of travel on any road network.

3. HOW TO MEASURE RELIABILITY

When monitoring reliability, it is important to distinguish between network operator perspective and user perspective. For the network operator, the focus is on network quality (what is provided and planned) while for the user, the focus is on how the variability of travel time is experienced.

Several definitions for travel time reliability exist and many different relevant indicators have been proposed. Here we use the same breakdown as presented in previous studies and divide these measures into four categories (11) (12):

1. Statistical range methods.
2. Buffer time methods.
3. Tardy trip measures.
4. Probabilistic measures.

Standard deviation (STD) and the *coefficient of variation* (COV) show the spread of the variability in travel time. They can be considered as cost-effective measures to monitor travel time variation and reliability, especially when variability is not affected by a limited number of delays and when travel time distribution is not much skewed (2). Standard deviation is defined as

$$STD = \sqrt{\frac{1}{N-1}\sum_N (TT_i - M)^2} \qquad (2)$$

while coefficient of variation is written as

$$COV = \frac{STD}{M} \qquad (3)$$

where *M* denotes the mean travel time, TT_i the i^{th} travel time observation and *N* the number of travel time observations.

A further consideration to use the standard deviation as a reliability indicator derives from recent studies that recommend defining travel time reliability as the standard deviation of travel time when incorporating reliability into cost-benefit assessment (13) (14). As a result, standard deviation is used to measure reliability in few countries where guidelines for cost-benefit assessment include reliability (15) (16) (17).

Both standard deviation and coefficient of variation indicate the spread of travel time around some expected value while implicitly assuming travel times to be symmetrically (normally) distributed. However, symmetrical distribution probably only exists in the case of – trivial – time periods of free-flow conditions. Therefore, studies have proposed metrics for *skew* (λ^{skew}) and *width* (λ^{var}) of the travel time distribution (12).

The wider or more skewed the travel time distribution the less reliable travel times are. In general, the larger λ^{skew} indicates higher probability of extreme travel times (in relation to the median). The large values of λ^{var} in turn indicate that the width of the travel time distribution is large relative to its median value. Previous studies have found that different highway stretches can have very different values for the width and skewness of the travel time and propose another indicator (UI_r) that combines these two and removes the location specificity of the measure (12). Skewness and width indicators are defined as

$$\lambda^{var} = \frac{TT_{90} - TT_{10}}{TT_{50}} \tag{8}$$

$$\lambda^{skew} = \frac{TT_{90} - TT_{50}}{TT_{50} - TT_{10}} \tag{9}$$

$$UI_r = \frac{\lambda^{var} \ln(\lambda^{skew})}{L_r} \tag{10}$$

where L_r denotes the route length and TT_X is the Xth percentile travel time.

Other indicators, especially the *Buffer Index (BI)* appears to relate particularly well to the way in which travellers make their decisions (18). Buffer time (*BT*) is defined as the extra time a user has to add to the average travel time so as to arrive on time 95% of the time. It is computed as the difference between the 95th percentile travel time (*TT95*) and the mean travel time (*M*). The Buffer Index is then defined as the ratio between the buffer time and the average travel time

$$BI = \frac{TT_{95} - M}{M} \tag{4}$$

The Buffer Index is useful in users' assessments of how much extra time has to be allowed for uncertainty in travel conditions. It hence answers simple questions such as "How much time do I need to allow?" or "When should I leave?". For example, if the average travel time equals 20 minutes and the Buffer Index is 40%, the buffer time equals 20 × 0.40 = 8 minutes. Therefore, to ensure on-time arrival with 95% certainty, the traveler should allow 28 minutes for the normal trip of 20 minutes.

Planning Time (PT) is another concept used often. It gives the total time needed to plan for an on-time arrival 95% of the time as compared to free flow travel time. The *Planning Time Index (PTI)* is computed as the 95th percentile travel time (TT_{95} divided by free-flow travel time (TT_{free_flow})

$$PTI = \frac{TT_{95}}{TT_{free\_flow}} \tag{5}$$

For example, if PTI = 1.60 and TT_{free_flow} = 15 minutes, a traveller should plan 24 minutes in total to ensure on-time arrival with 95% certainty. Because these indicators use the 95-percentile value of the travel time distribution as a reference of the definitions, they take into account more explicitly the extreme travel time delays.

Misery Index (MI) calculates the relative distance between mean travel time of the 20% most unlucky travelers and the mean travel time of all travelers. It is defined as

$$MI = \frac{M|_{TT_i > TT_{80}} - M}{M} \tag{6}$$

where TT_{80} is the 80th percentile travel time.

Probabilistic indicators (Pr) calculate the probability that travel times occur within a specified interval of time. Probabilistic measures are parameterized in the sense that they use a threshold travel time or a predefined time window to differentiate between reliable and unreliable travel times. Probabilistic measures are useful to present policy goals, such as the Dutch target for reliability, according to which "at least 95% of all travel time should not deviate more than 10 minutes from the median travel time" (12). This can be presented by the following equation

$$\Pr\,(TT_i \geq \beta + TT_{50}) \tag{7}$$

which calculates the probability that travel times do not deviate more than β minutes the median travel time. Parameter β can be given any value. For example, β=10 minutes for routes less than 50 km in the Netherlands.

4. APPLICATION TO THE FRENCH A6W MOTORWAY

4.1. Test Site and Data

Within the framework of the European project EURAMP, traffic impact assessments of coordinated and isolated ramp metering strategies were carried out at a French test site (7).

The motorway section A6W of the French field test comprises 5 on-ramps which are fully equipped with signal lights and traffic flow, occupancy rate and speed measurement stations roughly every 500 meters (Figure 1). The total motorway length is around 20 kilometers. The controlled ramps include two measurement stations each. The upstream one is used to detect surface intersection blocking and the downstream one is used by the on-ramp metering strategy.

The main authority in charge of traffic management is the Direction Interdépartementale de l'Ile de France (DIRIF). The DIRIF motorway network covers 600 kilometres (motorways A1 to A13). The level of congestion on the "Ile de France" network (including Paris ring road) represents 80% of the total congestion on the whole of the French motorway network. The test site is considered the most critical area of the A6W motorway towards Paris. Morning and evening peak congestions are observed over several hours and several kilometers.

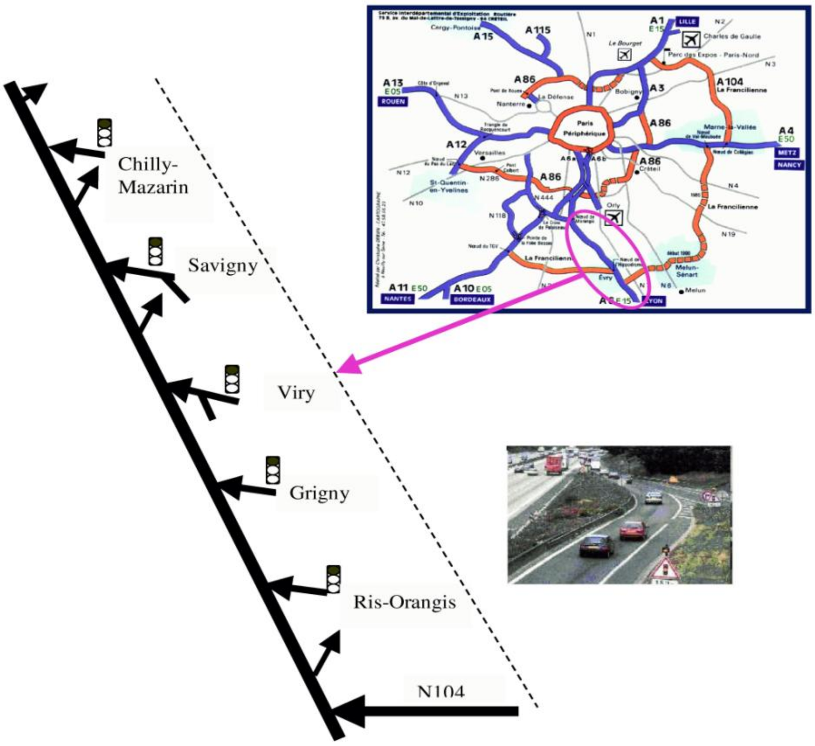

FIGURE 1 A6W Test site.

The predicted travel time of the main motorway section (20km) during the morning period (5h-12h) is computed based on data collected every 6-minutes. In order to point out in a comprehensive way the impact of the ramp metering for the decision makers and for the users, the travel time calculation is based on the application of the “floating car” algorithm. The travel time estimation is based on real data measurement and in particular the speed measurements.

Data collected was screened in order to discard days when there were major detector failures. Secondly, all days with atypical traffic patterns (essentially weekends and holidays) were discarded. Thirdly, in order to preserve comparability, all days including significant incidents or accidents (according to the incident files provided by the police) were also left out. This screening procedure eventually delivered data for 11 days for the No control and 10 days for ALINEA.

4.2. Findings

4.2.1. Reliability Indicators

Table 1 shows the variability in travel time according to different measures on the A6W motorway when active management by ramp metering is not in use (No control) and when ramp metering is used (ALINEA). Applying ramp metering strategy at the five accesses to the A6W motorway improves reliability by 26-52% depending on the indicator used. Results are consistent in the direction of change with, however, variation in the size of the impact.

The wider the travel time distribution, the less reliable travel times are. As shown in Table 1, overall the spread or variation (*STD* or *COV*) of the travel time distribution becomes smaller (and more reliable) when using the ramp metering.

Generally, during congestion, unreliability is predominantly proportional to λ^{var} while during congestion onset and dissolve unreliability is predominantly proportional to λ^{skew}. Our analysis suggests that ramp metering has nearly the same impact on both indicators, suggesting that ramp metering improves reliability both at the onset and dissolve of congestion as well as during congestion itself.

The Misery Index (*MI*) indicates that 20% of the most unlucky travellers experienced a travel time 76% worse than the average travel time when ramp metering was not in use. The index was reduced to 53% when ALINEA was applied.

Probability index (*Pr*) shows that without active management 28% of users experience more than 10 minutes of delay as compared with the median travel time. Again, ramp metering reduced this to only 18% of users.

TABLE 1 Results for Travel Time Variability by Different Statistical Indicators

Category	Acronym	No control (%)	ALINEA (%)	Gain (%)
Statistical range	*STD*[(a)]	706	463	34
	COV	46	35	25
Skewness	λ^{var}	137	96	30
	λ^{skew}	270	199	26
	UI_r (/km)	7	3	52
Buffer Index	*BI*	98	62	37
	PT	377	270	28
Tardy Trip	*MI*	76	53	31
Probabilistic	*Pr(TT>TT50+10min)*	28	18	35

(a) *STD* in seconds. Gain in % may differ from actual numbers due to rounding errors.

For the policy maker, the variation in findings presented above can be problematic. The choice of the "right" measure will remain a subject to debate. Hence, without further analysis, we cannot make any deeper going conclusions on the impact of ramp metering on travel time variability, other than it seems to reduce variability in general.

The results are also difficult to communicate to decision makers or users of the network. While the operator view on reliability is still important, measures like these are likely not to relate particularly well to the way in which travellers make their decisions. A traveller is more accustomed in making decisions based on time (minutes) rather than in terms of percentages.

In the following, we therefore present results on the average Travel Time *(TT)*, Buffer Time *(BT)* and Planning Time *(PT)* in minutes. Table 2 shows that a user who plans to arrive on time to his destination during the long morning peak period on A6W with 95% certainty, has to take into account the mean travel time of 25 minutes and add another 25 minutes as a "buffer" to ensure on-time arrival (when ramp metering is not in use). Hence the actual travel time during the morning peak is doubled due to uncertainty and variability in travel time.

On the contrary, when introducing active management through ramp metering (ALINEA), user planning time is reduced by more than 14 minutes for the trip. The total time needed for the trip declines from 50 to 36 minutes. The main improvement from the user perspective comes indeed from reduced variability in travel time (buffer time reduced by 11 minutes) while the mean travel time only improves by 3 minutes.

TABLE 2 Travel Time, Buffer Time and Planning Time

	TT (min)	Gain (min)	(%)	BT (min)	Gain (min)	(%)	PT (min)	Gain (min)	(%)
No-Control	25.4			25.0			50.4		
ALINEA	22.3	-3.1	-12.2	13.8	-11.2	44.8	36.2	-14.2	28.2

Figure 2 shows the difference between congestion and reliability by time of day. As the morning peak starts at around 6am, travel time increases sharply from around 17 minutes to over 35 minutes by 6:42am. It remains at this level until 9am starting then slowly to decline until at around 10am it has reached nearly the pre-peak levels.

At the congestion onset, also the unreliability of travel time increases rapidly and the buffer time grows from 4 minutes at around 6am to 14 minutes by 6:42am. However, in contrary to travel time, the buffer time continues to increase (although slowly) all the way until 10am, finally reaching nearly 22 minutes. This may be explained by the fact that during peak congestion travel is consistently slow whereas as congestion dissolves travellers are faced with more variable speeds affecting travel time distribution including extreme observations at the tail end of the distribution.

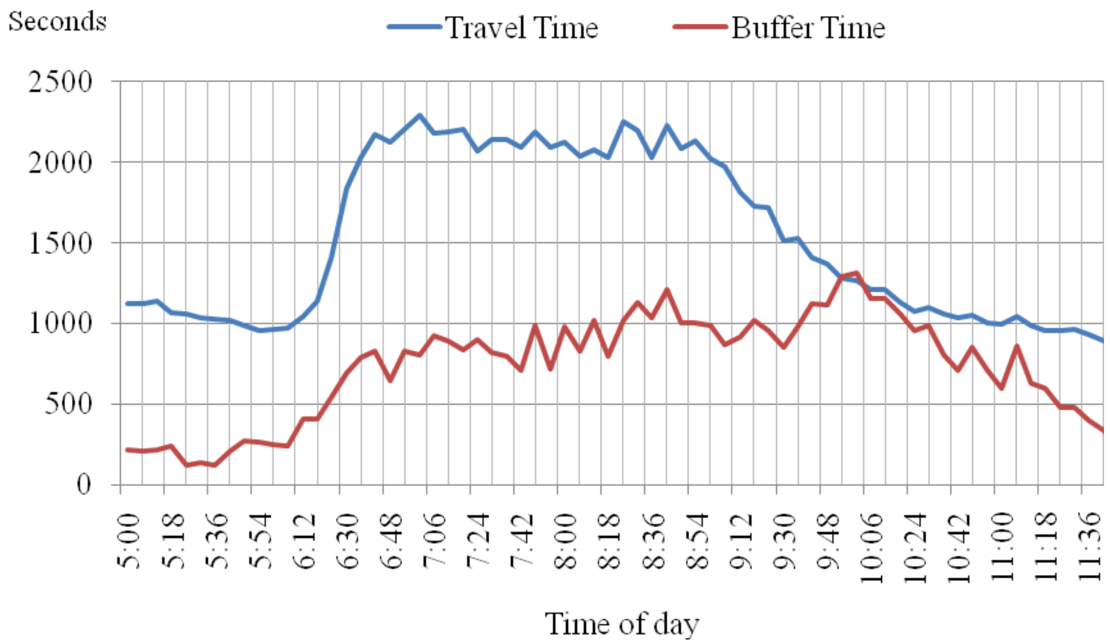

FIGURE 2 Congestion and reliability.

4.2.2. Monetary Value of Time Savings Benefit

Indices such as the Probability Index seem rather practical ways to present reliability from the network management point of view. The Probability Index allows for setting targets for reliability against the median travel time, such as is done in the Netherlands. However, while this type of targets may be useful in benchmarking desired performance standards, they are often arbitrarily set. The cost of achieving such levels may unintentionally exceed the benefits derived.

Without (monetised) quantitative criteria, the impact of a policy measure on travel time variability will remain a matter of debate. Especially for policy maker, the challenge is to identify policy options that deliver an improvement in reliability for the lowest cost. In order to take into account reliability in policy impact evaluation, cost-benefit assessment provides consistent framework to assess the monetised benefits of different projects.

At present, reliability is generally not taken into account when evaluating a project. However, recent findings have provided valuable information on how to value and measure unreliability of travel time and a number of studies are underway to estimate the value of reliability based on stated and revealed preference research (14) (2) (19). Although these methods are still under development, more practical approaches are already proposed and used for incorporating reliability into project evaluation (19).

The standard deviation of travel time distribution can be with relatively little difficulty applied in the cost-benefit assessment (2). In few cases where reliability is formally incorporated into the project appraisal, the country guidelines indeed suggest that travel time variability is measured by the standard deviation of travel time (15) (16) (17).

Most available country guidelines refer to the use of the so-called reliability ratio (*RR*) for valuing reliability. This ratio is defined as the ratio of the value of one minute of standard deviation (*i.e.* value of reliability) to the value of one minute of average travel time. These ratios are mainly derived from international case studies, and more specifically from a workshop of international experts convened by AVV, the transport research centre of the Dutch Ministry of Transport. At this meeting, some consensus regarding reasonable reliability ratios for passenger transport was reached – 0.8 for cars and 1.4 for public transport (20) (21).

While we acknowledge that the value of reliability (and value of time) is user-, location, and time-specific, we use the approach presented above as the best practise estimation of the reliability benefits of ramp metering on the M6W motorway.

To simplify, traditionally the money value of time savings benefit (*TSB*) arising from a project can be written as

$$TSB = \Delta TT * VOT \tag{11}$$

where the average number of minutes of time savings (ΔTT) is multiplied by the value of time (VOT), typically differing by user group. The current practise in incorporating reliability into cost-benefit analysis suggests then that the money value of time savings benefits is split into pure journey time improvement and improvement in the standard deviation of travel time (ΔSTD). The above equation then becomes

$$TSB = (\Delta TT * VOT) + (\Delta STD * RR * VOT) \tag{12}$$

where RR is given value 0.8 for passenger transport by car based on available case studies valuing reliability in relation to average travel time. Using the equation above and our results in Table 1 we can calculate the total monetary value of time savings benefit on the A6W when using ramp metering as

$$TSB = [(25.4 - 22.3) * VOT] + [(11.8 - 7.7) * 0.8 * VOT] = (3.1 * VOT) + (4.1 * 0.8 * VOT) = (3.1 * VOT) + (3.3 * VOT) \quad (13)$$

Although our calculation is crude, it illustrates how incorporating reliability into project assessment may change the overall results of any project assessment. According to our results, the largest monetary benefits when applying ramp metering on the A6W motorway does not come from the improvement in reducing congestion (the monetary value of pure journey time equals 3.1 times VOT) but rather from improved reliability, where the monetary value of improvement in reliability of travel time equals 3.3 times VOT.

For the assessment of different strategies to improve highway operations results are important. Ignoring reliability from the project appraisal would lead us to underestimate benefits of ramp metering by half in this case. Hence, traditional assessment on the benefits of ramp metering would underestimate greatly the impact of intervention. Incorporating reliability into cost-benefit assessment more than doubles the time savings benefits.

4.2.3. Summary of Findings

Although the above analysis is based on a specific motorway stretch near Paris, France, there are some general lessons to be learnt. First, different existing reliability measures will result with inconsistency in results. This is likely to cause confusion amongst the policy makers if enough attention is not given to the property of each measure. Implications of different measures on policy are, however, beyond the scope of our paper.

Secondly, travel time variability accounts for an important part of the user experience. Buffer time or Buffer Index seem quite useful in measuring user experience and more importantly in communicating these results both for decision makers and users of the network.

Thirdly, failing to unbundle time saving benefits from improvement in average travel time and improvement in the variability in travel time is likely to lead to sub-optimal policy solutions. Our case study clearly shows that benefits derived from congestion management are likely to be higher than traditionally estimated (in our case from the A6W motorway benefits are more than doubled). When policy makers are choosing between different policy options, failing to account for these benefits might lead to a situation where less optimal solutions are adopted before more cost-effective ones.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Reliability of travel time is increasingly becoming an important part of transport policies around the world. At the same time, monitoring, measuring and assessing reliability benefits have not been sufficiently taken into account in the national transport policies.

Recalling the key challenges that policy makers face when trying to ensure optimal strategies for improving reliability, we can draw conclusions on policy implications of our results.

First, monitoring variability of travel time in addition to average travel time is obviously important. In the case of A6W motorway near Paris, the buffer needed for the trip equals the average travel time during the morning peak. For the user of the network this means that one needs to double the actual travel time in order to ensure on-time arrival. Looking at the average travel time alone would obviously leave an important part of the picture hidden. Hence, identifying prevailing reliability levels by monitoring existing variability in travel times plays a major role in understanding how the network performs and, more importantly, how users experience the trip.

Presenting and communicating results in terms of buffer time or planning time seem intuitively understandable. Introducing the planning time concept is very useful both for the user and network manager. It is, after all, the total time spent for the completion of the journey that matters. Reducing the time needed (both the actual travel time and the time needed to ensure on-time arrival) for the trip as a whole is an effective way to present benefits of policy interventions and argue for benefits.

In this paper we argue, through a case study on the French A6W motorway, that reliability can be measured and the related monetary benefits of the policy intervention can be assessed. Incorporating reliability into policy assessment is likely to change priorities of projects and increase benefits, especially in congested situations as shown by the example.

Reliability should be incorporated into planning and assessment of transport policy strategies. As shown with the example, failing to unbundle the impact of the improvement in variability of travel time leads to an underestimation of the benefits derived from the policy. In our case study, traditional assessment would underestimate significantly the benefits.

Although we acknowledge that while a number of promising techniques are emerging to better incorporate reliability into cost-benefit analysis, the more pragmatic approach presented here is likely to be useful when applied at least as additional information to the traditional cost-benefit analysis.

Finally, many reliability policies are already in use as congestion mitigation policies. It seems that strategies for improving travel times are useful also in reducing unreliability. However, we also argue that impacts should be assessed separately for both.

Managing existing capacity better can be a cost-effective tool to improve both average travel time and the variability in travel time. Our results suggest that costs of unreliability indeed rival those of congestion at least at the A6W motorway during the morning peak hours. Reliability should therefore be given the same policy prominence as congestion has been traditionally given.

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