Isolating Different Factors Affecting Travel Time Reliability in an Observational Before/After Study

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Abstract

It is increasingly recognized that travel time reliability is important to travellers and goods, and hence there is an increasing demand to include reliability in the evaluation and appraisal of transport projects and programs, as a separate factor in its own right. A number of the policy options already in use as congestion mitigation policies have also positive impacts on the travel time reliability. It is therefore important to evaluate impacts of any remedial action separately both for average travel time (congestion) and for variability of that travel time (reliability). The impacts are generally assessed with an observational before/after study. As many things, independent from the system to be assessed, change between the periods *before* and *after* the installation of the system, observational before/after studies take also into account a reference site, where the effect of these changes is identified.
In a previous paper (Bhouri & Aron, 2013), the reliability impacts of a managed lane case consisting in a Dynamic Hard Shoulder Running (HSR) during rush hours on a French urban motorway was presented. The study was conducted by comparing reliability indicators based on data collected in 2002 *before* the implementation of the system and in 2006 *after* this implementation. Jacques Chirac, former president of France, launched in 2003 an important campaign for road safety and against speeding. This modified the travel time distribution, differently according to the lane. As reliability is based on the percentiles (and not only on averages), it was necessary, in order not to confound the effect of this campaign with the HSR effects, to develop the observational before/after study method for taking into account the percentiles. This method and tre results are presented in this paper.
Keywords: assessment; travel time; reliability;percentile;distribution;observational before/after studies; Hard Shoulder Running;congestion.

1. Introduction

The travel time reliability impacts the choice of the departure time- the drivers take room to counterbalance the unreliability in order not to be late -, and the choice of the travel means- some drivers prefer the most reliable, even longer, travel means. The standard deviation of the travel time is not sufficient to catch its reliability; also

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the measure of travel time reliability is made cautiously, in different ways (Lomax, Schrank, Turner & Margiotta, 2003); (Van Lint, Van Zuylen & Hu, 2008) (OECD/ITF, 2010). When a traffic measure is envisaged, the ex-ante assessment of its impacts is generally made in laboratory, thanks to a microscopic traffic simulation. The use of such a tool results in a series of travel times, making it possible to predict the reliability indicators. Ex-post assessment, after the implementation of the measure on one or several "treated" sites, is nevertheless required, because an unpredicted effect may happen. It is generally based on an observational before-after study, in which are compared traffic indicators computed from data observed on the treated sites before and after the implementation of the traffic measure (Bhouri & Aron, 2013). As the implementation takes place in the real world, and not in a laboratory, some parameters of the experience are not managed: the traffic demand changes between the before and after periods; the drivers' behavior too, due to other traffic measures, modification of the traffic rules or of the drivers' attitude towards these rules. Let us sum up as the "Time Effect", the effect of all those changes. Identifying the Time Effect is important in order not to confound the effect of the traffic measure implemented with other effects. This identification is possible when reference sites are available, where the traffic measure is not experienced, but where the "Time Effect" is effective (Hauer, 1997).

In general, observational before-after studies deal with averages, which are linearly broken down in three parts (the part observed before, the change due to the Time Effect, the change due to the traffic measure or "treatment"). However dealing with the whole distribution (and not only average) is necessary for subjects like reliability, which is based on percentiles of the travel time distribution (Aron, Bhouri & Guessous, 2014).

In our example, the objective is the assessment of reliability impacts of a Hard Shoulder Running (HSR) implementation. We dispose of data from the years 2002, before the HSR implementation and 2006, after the HSR implementation. However, at least one factor impacted traffic in the time between these two periods making hard the reliability assessment of the HSR implementation. a road safety campaign has been launched by Jacques Chirac, former President of France. The consequence was a Speed Limit Campaign (SLC) with many automatic radars controlling the speed on the studied motorway section. Therefore, the compliance in the speed limit (90 km/h) was better in 2006 compared to 2002. The overall traffic evolution between 2002 and 2006 was very low and can be neglected. Weather conditions were also the same. Other possible factors of change (changes in cars performance, road surface, etc.) exist and are grouped with the SLC campaign in a so-called "Time" effect, which will be isolated on the reference site and identified, in order to not affect the reliability assessment of the HSR implementation.

The aim of this paper is threefold: preliminarily to describe the traffic measure to be studied, the Hard Shoulder Running (HSR) experiment (section 2); second to produce a method for identifying the Time Effect on the whole travel time distribution (thus on percentiles and on the traffic reliability indicators) (section 3); third, to describe the application of the method: the Time Effect is identified (section 4) and finally the effect of the traffic measure on the travel time reliability is identified (section 5).

2. Test Site and Data

The data used in this paper was collected on a weaving section of the A4-A86 French urban motorway. A two-lane urban motorway ring (A86) round Paris and a three-lane West-East urban motorway (A4) meets in the east of Paris and share a four-lane 2.3 km-long section. As the traffic flows of the two motorways are added, traffic is particularly dense at some hours on the weaving section, renowned as the greatest traffic bottleneck in Europe.

A hard shoulder running (HSR) experiment has been launched in July 2005. It gives drivers access – at peak times – to an additional lane on the hard shoulder where traffic is normally prohibited. The size of the traffic lanes has been adjusted. From the standard width of 3.50 m, they have been reduced to 3.2 m. The opening and closure of this lane are activated from the traffic control centre according the value of the occupancy measured upstream of the common trunk section (opening if occupancy is greater than 20% and closure if less than 15%). Note that during its maintenance, HSR was not activated.

Data were collected on a three-km long stretch in the eastbound direction of the motorway (2.3 km on the weaving section and 0.7 km downstream). Collecting data downstream (and also upstream, although not used here) was necessary because a local traffic measure has indirect effects downstream and upstream its location (Bauer, Harwood., Hughes & Richard, 2004). Four inductive loops were used, three on the weaving section and one downstream. Inductive loops provide traffic flow, occupancy and average speed for each lane every six minutes. Data has been analysed for three years (2000, 2001 and 2002) before the implementation of the device and one year (2006) after.

Travel time used for the reliability analysis are mainly calculated from the speed data from the years 2002 for the before period and 2006 for the after period. When the speed data of 2002 are missing or irrelevant, either data from years 2000 or 2001 were used to replace them or the travel time is calculated using the flow and the occupancy.

A comparison between travel times in 2006 and 2002 is possible for all couples of periods where this whole process succeeded both in 2006 and in 2002. The frequency of success is high in absolute value: Cleaning the 87600 six-minute period data by year (2006 and 2002) we kept 53574 pairs of data, even if missing or irrelevant data are not rare: in percentage, the frequency of success is 61% (=53,574/87,600).

Table 1 Breakdown of matched periods in {2002, 2006} where correct data were available for the Eastbound direction

	Category	Number of pairs of data
Open	Day (*)	8110
	Night	137
Close	Day	26692
	Night	18635
Total	Total	53679 /53574

(*) from 7 AM to 8 PM

Except for the HSR open night situation for which few periods are recorded, the amount of data used allows for some confidence in the analysis.

Note that in 2002, as HSR was not installed, the so-called "open" hours are the hours corresponding to the 2006 hours where HSR was effectively opened. This matching prevents to potential bias if unavailable data in 2006 were not distributed as unavailable data in 2002.

3. Separation of the different factors acting on travel time

When evaluating a management strategy in a before after study, we are confronted to other phenomena independent of the studied strategy but acting on the traffic. Indeed, in between the two periods, there are always changes in other factors which are not linked to the management measure such as the variation in traffic volume or its daily distribution, in drivers' behaviour, in infrastructure, in traffic rules, in weather conditions, in the application of new measurements tools, etc. All these impacts are gathered in the « Time Effect », which is generally identified on a reference site. When this site is sufficiently close (in terms of traffic, infrastructure, users ...) to the treated site, the Time Effect is assumed to be the same on both sites.

Sometimes, it is not possible to find a site with characteristics close to the studied site to be used as a comparison one, such as in our case: It is difficult to find a reference site close to the A4-A86 weaving section, known to be the first French jam. We decided to use as the reference site, the A4-A86 weaving section itself during the hours when the auxiliary lane is closed; to identify the Time Effect at these hours; to transfer this Time Effect from the closed to the open hours; to modify the travel time of the before period at these open hours by addition of the Time Effect and finally to assess the effect of HSR open by comparison of the measured travel time for the after period (open hours) as compared with the modified travel time from the before period.

3.1. Methodology

The computation of the impact of any factor on travel time is evaluated in an observational before-after study of the travel times in a four steps method:

(1) To choose a reference site

(2) To assess the Time Effect as a function of the (before) travel time; this will be obtained from the comparisons of travel times on the reference site for the “before” and “after” periods. This function models the variation in travel time between the before and after periods. This function is valid on the reference as well as treated sites.

(3) To build a modified travel time series, adding to the “before” travel time the function defined in step 2.

(4) Finally, to compute the reliability indices for the before, modified and after travel time series. The impact of the traffic measure is obtained by the difference (or the ratio) of the indices from the after and modified travel time series.

3.2. Application

As our objective is the assessment of the HSR impact on travel time reliability, the Time Effect has to be computed not only for the average travel time, but also for selected percentiles. This is possible with the following method, valid for the whole travel time distribution.

3.2.1. Identification of the SLC effect on the reference site and use for the treated site

Let’s sort, on the reference site, for the before period, the travel times in an ascending order, from smallest to largest; let’s do the same for the after period. Years 2002 and 2006 have exactly the same number of 6-minutes periods (closed hours), say N_r (the index r designs the reference site). On these sorted series, it is very easy to compute the percentiles: the α percentile is the travel time at line number $\alpha.N_r$ of the series.

Instead of using the calendar matching between 2002 et 2006, travel times have been (independently) sorted in 2002 and 2006 : whatever i, the i^{th} lowest 2002 travel time corresponds to the 2006 lowest one, even if these two events do not occur at the same hour in the day neither the same day in the year. The hazards are not cancelled, but redistributed. Variations from 2002 to 2006, on the reference site are given by equation (1)

$$TT_{i,\,reference,after} = TT_{i,\,reference,before} + \delta_i \quad i=1 \dots N_r \tag{1}$$

Where, δ represents the changes in travel time. In our context, δ is due to two phenomena:

- A small traffic decrease, which decreases the travel time (only when traffic is dense, i.e. travel time already high); this decrease is balanced by a traffic increase at hours where HSR is open: Indeed more users drive in the rush hours, because the motorway is much less congested than in before. This decrease is thus an indirect consequence of HSR

- The safety management strategy consisting in the Speed Limit Campaign (SLC) which increases the travel time (only when speeds are high, i.e. travel time is low). Eventually, there are other factors (cars, users, road surface) which are grouped with SLC for forming the "Time Effect".

In our case, the series δ_i is decreasing. It is positive for $i < i_0$, and negative after. The initial positive values of δ (until $i=i_0$ where $\delta i_0=0$) are due to the SLC, which limited the high speeds (or the high speed frequency) and therefore increased the travel times for the fluid periods in 2006. The decrease of δ means that this effect is greater for higher speeds and it decreases (towards 0) when speed decreases to the speed limit. Moreover, we will see (Figure 2) that, when δ is positive, the δ decrease is moderate (its derivative related to the travel time is greater than -1) so both travel time series in Eq. (4), are not disordered.

In order to separate the time (SLC) effect from the traffic variation (TV), here due to HSR, let's introduce two *functions* δ^{SLC} and δ^{TV}, specified only at some points (the before travel times observed on the reference site):

$$\delta^{SLC}(TT_{i,reference,before}) = \begin{cases} \delta_i & if \quad i < i_0 \\ 0 \quad if & i_0 < i < N_r \end{cases} ; \tag{2}$$

$$\delta^{TV}(TT_{i,reference,before}) = \begin{cases} 0 & if \quad i < i_0 \\ \delta_i \quad if & i_0 < i < N_r \end{cases} ; \tag{3}$$

Then, δ^{SLC} (.) is defined by continuity for every value of the travel time.

δ^{TV}(.) corresponds to the impact on travel time of the traffic decrease between the before and after periods, it is equal to the negative values of δ_i (for $i_0<i<N_r$).The new travel time of reference is therefore:

$$TT_{i,reference,\ after} = TT_{i,reference,before} + \delta_i^{TV} + \delta_i^{SLC} \quad ; \quad i=1,\dots,N_c \Leftrightarrow \quad TT_{i,,reference,after} = \begin{cases} TT_{i,reference,before} + \delta_i^{SLC} & i < i_0 \\ TT_{i,reference,before} + \delta_i^{TV} & i_0 < i < N_r \end{cases} \tag{4}$$

We consider that the traffic decrease is completely due to HSR, which allows to some users to drive during rush hour as they become less congested. It would have been useful (but not done here) to check the effects of the traffic decrease on the travel time with a dynamic traffic simulation.

On the treated site, the SLC effect is considered as the same (at the same speed level) as the one identified on the reference site; the travel time "after" is then decomposed in the "before" one, the SLC and HSR effects.

$$TT_{i,treated,\ after} = TT_{i,treated,before} + \delta^{SLC}\left(TT_{i,treated,before}\right) + HSR_i; \quad i=1,\dots,N_t \quad \text{(}N_t\text{ is the number of periods for the treated site)} \tag{5}$$

This defines the HSRi series, which correspond to the HSR effect. Incorporating only the SLC effect to the "before" travel time produces "modified" travel time series:

$$TT_{i,reference,\ modified} = TT_{i,reference,before} + \delta_i^{SLC}; \quad i=1,\dots,N_r \tag{6}$$

$$TT_{i,treated,\ modified} = TT_{i,treated,before} + \delta^{SLC}\ TT_{i,treated,before} \quad ; \quad i=1,\dots,N_t \tag{7}$$

These modified travel time series are generally still sorted, because even if the SLC effect is decreasing when the travel time increases, this decrease is be greater than the increase in travel time.

Note that every line of index i, of equations (4) to (7) is also a percentile equation: TTi,. is the percentile corresponding to the range α, if i= $\alpha.N_r$ (reference site) or i= $\alpha.N_t$ (treated site).

Let $p^{\alpha}_{TT,Site,Period}$ be the α percentile of the travel time series for Site $\in$ {reference ; treated}, for Period $\in$ {before; modified; after}. The decreasing of the δ series implies:

$$(4) \Rightarrow p^{\alpha}_{TT,reference,after} = p^{\alpha}_{TT,treated,before} + p^{1-\alpha}_{\delta^{TV}} = p^{\alpha}_{TT,reference,before} + p^{1-\alpha}_{\delta^{SLC}} + p^{1-\alpha}_{\delta^{TV}} \tag{8}$$

where $p^{1-\alpha}_{\delta^{SLC}}$ and $p^{1-\alpha}_{\delta^{TV}}$ are the (1-α) percentiles of the decreasing series δ_i^{TV} *and* δ_i^{SLC} - In the case where the δ^{TV} series is not decreasing, the term $p^{1-\alpha}_{\delta_T}$ is replaced by δ_i^{TV} with i=α.N_r

$$(5) \Rightarrow p^{\alpha}_{TT,treated,after} = p^{\alpha}_{TT,modified,before} + HSR_i = p^{\alpha}_{TT,treated,before} + \delta^{SLC}\left(p^{\alpha}_{TT,treated,before}\right) + HSR_i \text{ with i}= \alpha \cdot \text{Nt} \quad (9)$$

Let $M^{\alpha}_{TT,Site,Period}$ be the average of the travel times higher than the percentile α (when α =0, this average corresponds to the ordinary average, α is omitted). Let N_s be the number of periods observed on the site. $M_{TT\ site,\ period,\alpha}$ is obtained from equations (4) to (7), by the summation of all lines *i*, or only of lines where *i* is greater than α.N_s, divided by the number of lines.

Equations (4) and (6) imply:

$$M^{\alpha}_{TT,reference,after} = M^{\alpha}_{TT,reference,modified} + M^{\alpha}_{\delta^{TV}} = M^{\alpha}_{TT,reference,before} + M^{\alpha}_{\delta^{slc}} + M^{\alpha}_{\delta^{TV}} \quad (10)$$

Where :

$$M^{\alpha}_{TT,Site,Period} = \frac{1}{(1-\alpha)N_s}\sum_{i=\alpha N_s+1}^{N_s} TT_{i,Site,Period};\ M^{\alpha}_{\delta^{SLC}} = \frac{1}{(1-\alpha)N_r}\sum_{i=\alpha N_r+1}^{N_r}\delta_i^{SLC};\ M^{\alpha}_{\delta^{TV}} = \frac{1}{(1-\alpha)N_r}\sum_{i=\alpha N_r+1}^{N_r}\delta_i^{tv}$$

Equations (7) imply:

$$M^{\alpha}_{TT,treated,after} = M^{\alpha}_{TT,treated,modified} + M^{\alpha}_{HSR} = M^{\alpha}_{TT,treated,before} + M^{\alpha}\left(\delta^{slc}\ TT_{treated,before}\right) + M^{\alpha}_{HSR} \quad (11)$$

Where $M^{\alpha}\left(\delta^{slc}\ TT_{treated,before}\right) = \frac{1}{(1-\alpha)N_t}\sum_{i=\alpha N_t+1}^{N_t}\delta^{SLC}\left(TT_{i,treated,before}\right)$ and $M^{\alpha}_{HSR} = \frac{1}{1-\alpha\ N_c}\sum_{i=\alpha N_c+1}^{N_c} HSR_i$

Eq. (5) implies $M^{\alpha}_{TT,treated,after} = M^{\alpha}_{TT,treated,before} + M^{\alpha}[\delta^{SLC}(TT_{treated,before})] + \frac{1}{(1-\alpha)N_t}\sum_{i=\alpha N_t+1}^{N_t} HSR_i$ (12)

3.2.2. Computation of reliability indices for the after, before, and modified series

The reliability indices are firstly and secondly computed for the before and the after periods; then, thanks to Eq. (8-11) for the modified series. Instead of directly comparing the indices for the after and before series, we compare the indices for the modified and the before series on the treatment site; their difference or their ratio give the SLC effect (or, more generally, the Time Effect). Then the difference or the ratio between the indices for the after and the modified series (treatment site) gives the treatment effect.

3.2.3. Breakdown of some Reliability Indices

It is generally possible to breakdown the reliability index (period after) in three components, respectively linked to the reliability index before, the Time Effect (here SLC), the treatment effect (here HSR).

Eq.(8) with α =95% provides such a decomposition for the Planning Time (PT) which is the 95^{th} percentile.

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 the difference between the 95th percentile travel time and the mean travel time; its breakdown is obtained by the subtraction of Eq. (12) from Eq. (8) (with α =95%).

Three other reliability indices are ratios between a numerator and the average travel time: the Buffer Index (BI); where the numerator is BT; the Planning Time Index, where the numerator is PT, and the Misery Index, where the numerator is the difference between the average of those travel times which are greater than the 80th percentile, and the average travel time.

The three components of the after average travel time of equation 12 (for α =0) intervene in the breaking down. Let us note $S_{treated,\ before}$, $S_{treated,SLC}$, $S_{treated,\ HSR}$ the parts of each component in the average after travel time :

$$S_{treated,\ before} = \frac{M_{TT,treated,\ before}}{M_{TT,treated,\ after}};\ S_{treated,\ SLC} = \frac{M\left[\delta^{SLC}\ \ TT_{treated,before}\right]}{M_{TT,treated,\ after}};\ S_{treated,\ HSR} = \frac{M_{HSR,}}{M_{TT,treated,\ after}}$$

The sum of these three parts is equal to 1. These parts are used as weights in the breakdowns of the three indicators - only the breakdown of the Misery Index is presented here, the breakdowns of the two other indicators are even simpler.

In the general case, the misery index is $MI_{Site,Period} = \frac{M^{\alpha}{}_{TT,Site,Period}}{M_{TT,Site,Period}} - 1$ for α=80%.

Using Eq. (12), it comes

$$MI_{treated,\ after} = \frac{M^{\alpha}_{TT,treated,\ after}}{M_{TT,treated,\ after}} - 1 = \frac{M^{\alpha}_{TT,treated,\ before}}{M_{TT,treated,\ after}} + \frac{M^{\alpha}[\delta^{SLC}(TT_{,treated,before,})]}{M_{TT,treated,\ after}} + \frac{M^{\alpha}_{HSR,}}{M_{TT,treated,\ after}} - 1 \quad (13)$$

The breakdown of the Misery Index (treated site, period after) in three components is given below:

$$MI = \left(\frac{M^{\alpha}_{TT,treated,\ before}}{M_{TT,treated,\ before}} - 1\right) S_{treated,\ before} + \left(\frac{M^{\alpha}[\delta^{SLC}(TT_{treated,before})]}{M[\delta^{SLC}(TT_{treated,before})]} - 1\right) S_{treated,\ SLC} + \left(\frac{M^{\alpha}_{HSR}}{M_{HSR}} - 1\right) S_{treated,\ HSR}$$

The misery index is a kind of average (weighted by the parts $S_{treated,...}$) of:

- The Misery Index for the before period
- A kind of Misery Index of the series $\delta^{SLC}(TT_{i,treated,before})$. This series being decreasing, the term $M^{\alpha}[\delta^{SLX}(TT_{treated,before})]/\ M[\delta^{SLX}(TT_{treated,before})]\ -1$ is the Misery Index of this series, defined at level (1- α), then multiplied by (1-1/α). However the numerator $M^{\alpha}[\delta^{SLX}(TT_{treated,before})]$ is very low, because SLC is related to low travel time, and has a poor influence on travel times over than the 80th percentile
- The HSR effect; it is computable even if the series HSR_i is not monotonous. In the case when HSR_i is increasing (the more travel time before, the more HSR effect), this third term is also linked to the misery index of HSR_i series at level 1- α.

Note two indirect effects: SLC and HSR have indirect effects on the weighting of the "before" Misery Index.

$S_{treated,\ SLC}$ being positive, this decreases the weight $S_{treated,\ Before}$ of the first term (the before Misery Index), thus decreases the after Misery Index. It is the contrary for HSR, since $S_{treated,HSR}$ is negative.

4. Numerical results

For reliability studies, it is better to analyse travel times by lane because the use of average travel times over the lanes leads to a decrease in information on the travel time distribution. That's why in this paper, travel time is calculated for each lane. Furthermore, in order to catch all the travel time variations, travel time is calculated for each measurement station. The 3-km stretch of motorway is divided into 4 sections, each one is covered by one sensor station. We have therefore 4 sections and 4 lanes when HSR is closed and 5 lanes when HSR is open.

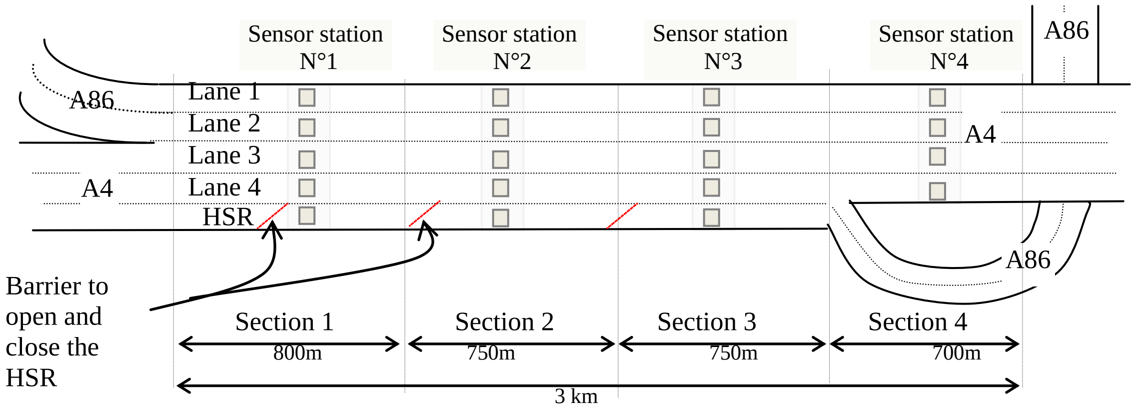

Figure 1: Configuration of the motorway site

As there is a large disparity of the amount of traffic using the different lanes, in order to have comparable results, the travel time of each lane is balanced by the lane's flow

δ, related to the before travel time, is presented on Figure 2 by section and lane. The figures are limited to travel times below 50 seconds (by kilometer), which is equivalent to speeds over 72 km/h. This corresponds to the 77th percentile of the travel time. For lower speed, δ is certainly negative and SLC has no effect.

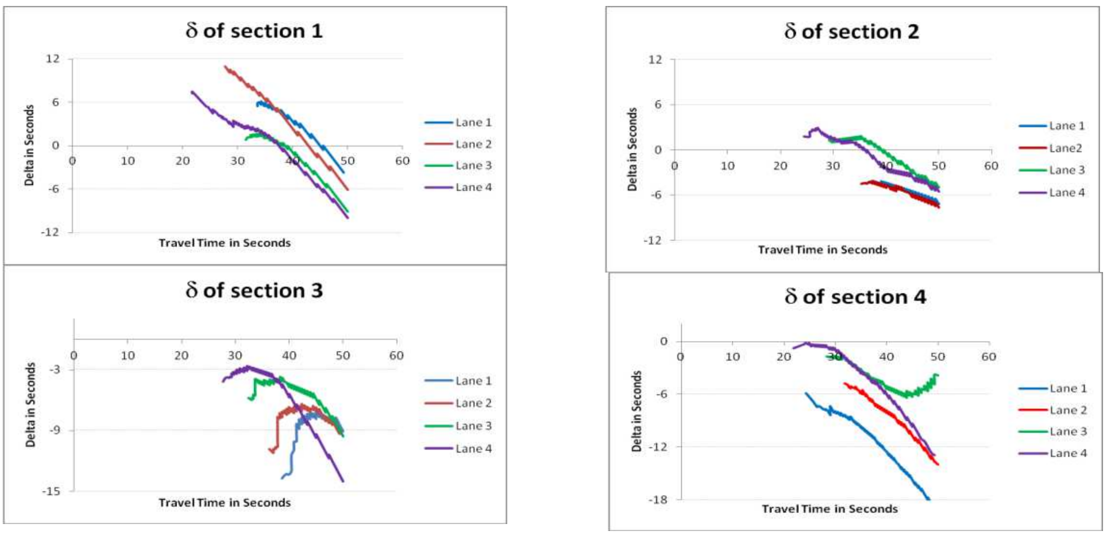

Figure 2: The Delta values for the 4 lanes and 4 sections of the 3-km motorway

The positive part of δ is important only for section 1, it is smaller for section 2 and completely negative for sections 3 and 4. This is probably due to the fact that drivers arrive on the stretch of motorway with the high speed they had before arriving on this weaving section, they reduce afterward their speed. Perhaps the danger is less felt at the end (section 3) of the weaving section, or after this end (section 4).

As expected, for sections 1 to 3 the minimum travel times (by kilometer) observed are the highest on lane 1 (the slow lane, where there are trucks and inserting movements) and the lowest on lane 4; it is no more the case after the, in section 4, due to transient movements.

On section 1, δ is linear related to the travel time: the line (thus the SLC effect by travel time level) is the same for lanes 1 & 2 on one hand and for lanes 3& 4 on the other hand. On lane 1 & 2, at the speed limit (90 km/h, or 40 second/kilometer), the SLC effect is still positive (near 5 seconds); this was not unexpected, because an average speed of 90 km/h correspond partly to vehicles driving above 90 km/h. On lane 3 & 4, at this speed level, the SLC effect is null for lane 3 and 4 - on lane 4, δ is positive for travel times less than 37.5 seconds (96 km/h); this concerns only 2% vehicles. This means that SLC brought a higher compliance to the speed limit on lane 1&2 than on lane 3 & 4.

On section 2, the travel times were below 40 seconds for lane 1&2, SLC had an effect only for lanes 3&4.

5. Reliability assessments

5.1. Travel Time calculation

Even though, in order to catch all the travel time variability, the “Time Effect” was analyzed independently for each motorway lane and section, communication about reliability cannot be made for each lane. We then calculate the travel time for each section as a function of each lane travel time balanced by the lane traffic flow. The total travel time on the 3-km studied section is the sum of travel times on the four sections (see figure 2). This calculation is made for the year after (2006) on the basis of measured data and for the reference travel time on the basis of the data measured for the year before (2002) corrected by the positive value of Delta (δ^{SLC}):

$$TT_{S_i} = \frac{\sum_{l=1}^{NL} TT_l^i \cdot q_l^i}{\sum_{l=1}^{NL} q_l^i} = \frac{\sum_{l=1}^{NL} \frac{L^i}{v_l^i} \cdot q_l^i}{\sum_{l=1}^{NL} q_l^i}$$

Where S_i is the section i (the sensor station n°i); $TT_l^{\,i}$ is the travel time on the lane l on the section I; L^i is the length of the section; $V_l^{\,i}$ is the speed on the lane l on the section I; and $q_l^{\,i}$ is the flow on lane l of section i and finally NL is the number of lanes on the section.

5.2. Reliability indicators

Table 2 provides some reliability indicators for the reference site (HSR closed), the treatment site (HSR open), and the modified series (integrating the time or SLC effect). One can find these indicators formulas in (Bhouri et al., 2012)

The probabilistic indicator used here is linked to the median; it is $Pr(TT_i) \geq 1.2(TT_{50\%})$

As reliability concerns high travel time (percentile α=80% or higher) and SLC concerns at most the 2% of lowest travel times. So reliability indicators for the "modified" series, integrating the SLC effect, are very close to the "before" reliability indicators.

Reliability results given on table 2 confirms that HSR improves the average travel time (even at hours where it is closed, due to traffic diversion); some reliability indicators (as Planning Time, Buffer Time, standard deviation of the travel time) are much improved. When the average travel time is at the denominator of the indicator, an improvement is harder to obtain because it would correspond to a double gain: a gain in variability greater than the gain in the average. PTI is improved, but not for MI; for the same reason, the probabilistic indicator, where the median takes the place of the average is not improved

Table 2. Values of some reliability indicators

		HSR Open			HSR Closed		
		Treated	Modified	Before	Treated	Modified	Before
Statistical ran	STD	36,1	76,6	76,8	47,2	77,3	77,7
	COV	26%	34%	34%	34%	44%	44%
Mean	Average	136,8	224,2	224,1	139,4	177,1	176,2
	Median	124,2	222,1	222,1	120,6	153,7	152,8
Buffer Time	BT	68,0	95,2	95,3	89,4	121,8	122,6
	PT	204,8	319,4	319,4	228,9	298,9	298,8
Buffer Index	BI	50%	42%	43%	64%	69%	70%
	PTI	183%	243%	244%	215%	255%	260%
Tardy Trip	MI	40%	41%	41%	56%	63%	63%
Probabilistic	Pr(TT > 1.2*TT50)	20%	14%	14%	8%	10%	10%
Skewness	var	54%	61%	61%	79%	91%	93%
	skew	557%	73%	73%	693%	329%	324%

Conclusion

As reliability indicators are based on percentiles and not only average, a method was needed for identifying the Time Effect and the treatment effect in the framework of observational before/after studies. Here the Time Effect results from a speed limit campaign, and the treatment effect of an Hard Shoulder Running experiment on an urban motorway weaving section.

The proposed method requires the availability of the travel time distributions at two periods (before and after the treatment) on two sites (reference and treated). The method is based on the assumption that the "time "effect, identified *by travel time level* on the reference site, applies also (for the same travel time level) on the treated site. A positive consequence of identifying the Time Effect by travel level consists in alleviating the constraint when choosing a reference site: it is no more required that its traffic structure is very close to the one of the treated site. The method and the assumption are particularly trustworthy when the Time Effect is increasing or decreasing in function of the travel time - this was the case in France, where speeds tend to decrease.

This approach confirms, after discarding the Time Effect, the HSR effect on the travel time reliability

The method would apply for reliability in other areas.

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