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Reliability Benefits of Active Traffic Management
A Managed Lanes Case in a French Urban Motorway

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ABSTRACT

Traffic management aims to ensure a high quality of service for a maximum of users, by decreasing congestion and increasing safety. However, uncertainty regarding travel time (TT) decreases the quality of service and causes users to modify their plans regardless of the average TT. Indicators describing TT reliability are being developed and should be used in the future both for the optimization and for the assessment of active traffic management operation. This paper describes a managed lane experiment on a motorway weaving section in France - Hard Shoulder Running (HSR) operation- at rush hours. The paper describes the data measurement and the missing data replacement process. It focuses, however, on TT reliability indicators and on their use for reliability assessment on the basis of an observational before/after study. It provides some discussion on the advantages and drawbacks of reliability indicators under different traffic conditions. The before/after study reports not only the effect of the HSR operation but also of a speed limit campaign which affected the free flow travel time. The study particularly shows the difference between using buffer times or using buffer indexes. The paper also discusses the difficulty of interpreting the skew of TT distribution for travel reliability.

1. INTRODUCTION

Managed lanes operations refer to multiple strategies for increasing road capacity or adapting its configuration, in order to favor one transportation mode (bus, taxis, high occupancy vehicles), or to reduce recurrent congestion. In this latter case, typically the increased road capacity is obtained through a redefinition of the transverse profile within the roadway limits. Several technical alternatives are possible, such as the reduction of lane width and the temporary or permanent use of the hard shoulder as a running lane.

In France, dynamic reversible lanes (according to the commuter traffic direction) have been introduced since the 1960s (Quai de Seine in Paris, Saint-Cloud Tunnel in Paris and for the Winter Olympic Games in Grenoble, in 1968). A static Hard Shoulder Running (HSR) operation has been implemented on a motorway weaving section (A3-A86 motorway) with a slight negative impact on safety due to higher speeds even at peak hours. Later, a dynamic HSR operation was implemented on A4-A86 motorway weaving section, only at rush hours. This HSR operation assessment did not show a negative impact on safety (1) and showed an improvement of traffic conditions with regards to classical traffic impact indicators (2,3). However until now, reliability aspects have not been given the attention they deserve.

Reliability is a new issue. Studies show that congestion has an impact not only on average travel time (TT) but also on TT reliability, and there is much evidence that the variability of TT may be more important than its mean value. If a road is constantly congested, users can plan their travel accordingly while unpredictable travel conditions impose great frustration (4,5).

Many researchers have been interested in finding ways to measure and gave a value to TT reliability (6,7) but little has been done on reliability benefits of management operations (8,9). Our objective in this paper is: first, to assess the impact of the A4-A86 HSR operation on TT reliability by the use of well-known key performance indicators; and second, to discuss the effectiveness of these indicators. Discussion on the use of reliability indicators according to the traffic conditions and to their evolution from the “before” period to the “after” period the implementation of this HSR operation is very interesting. It should be noted that in the interval between the “before” and “after” periods, a speed limit campaign for greater safety was launched by Jacques Chirac, former president of France. This speed campaign reduced high speeds and was thus effective only at off-peak hours when HSR was not opened. As a consequence, it affected the free-flow value as well as the mean value of TT. This contributed to show the weakness of reliability indicators based on these values as it does not indicate the effects of the congestion, which is the main source of unreliability, but only the free-flow variation consequences.

Impacts of HSR on the TT and on its reliability are identified with an observational before/after study on the weaving section completed by downstream sections. Data was analyzed for the three years (2000, 2001 and 2002) before the implementation of the HSR operation and for one year (2006) after. First of all, speed data were cleaned in order to eliminate outlier values: the empirical 6-minute average speeds are considered as outliers when they are below or above thresholds. In this case, a function of the ratio flow/occupancy was used in order to try to replace outlier speeds. This paper, however, focuses only on the reliability results and the forcefulness of the indicators on the basis of the year 2002 data for the “before” period and the year 2006 data for the “after” period.

This paper is organized as follows: Section 2 is dedicated to the description of the TT reliability approaches and in particular the introduction of the definitions of a number of

reliability indices used. Section 3 gives the descriptions of the French site where the HSR was tested. The assessment data and the methods used to ensure their quality and replace outlier data are described in Section 4. Section 5 provides TT reliability results and a discussion of the reliability indicators, especially related to the width and skew of the TT distribution. Finally, Section 6 gives the conclusion of the paper.

2. RELIABILITY INDICATORS

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

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 as in (10) and (11):

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

1 - *Statistical range methods*, the main statistical indicators are the *Standard deviation (STD)* and the *coefficient of variation (COV)*. They show the spread of the variability in TT. They can be considered as cost-effective measures to monitor TT variation and reliability, especially when variability is not affected by a limited number of delays and when TT distribution is not greatly skewed. Standard deviation is defined as:

$$STD = \sqrt{\frac{1}{N-1} \sum_N (TT^i - M)^2} \quad (1)$$

while coefficient of variation is written as

$$COV = \frac{STD}{M} \quad (2)$$

where M denotes the mean TT, TT^i the i^{th} TT observation and N the number of TT observations.

Standard deviation is often used in statistical studies because it is easy to compute and because it is linked to a confidence interval assuming a normal distribution. However, the TT distributions are often dissymmetric (due to congestion) and thus far from the Gaussian distribution. So the coefficients linking the width of the confidence intervals to the standard deviation (as the value “1.96 x standard deviations” for the 95% confidence interval) are no longer valid. Therefore, studies have proposed metrics for *skew* λ^{skew} and *width* λ^{var} of the TT distribution (11).

$$\lambda^{skew} = \frac{TT_{90} - TT_{50}}{TT_{50} - TT_{10}} \quad (3)$$

$$\lambda^{var} = \frac{TT_{90} - TT_{10}}{TT_{50}} \quad (4)$$

TT_X is the X^{th} percentile TT.

The wider or more skewed the TT distribution, the less reliable TTs are. In general, the larger λ^{skew} indicates higher probability of extreme TTs (in relation to the median). The large values of λ^{var} in turn, indicate that the width of the TT 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 and proposed another indicator (UL_r) that combines these two and removes the location specificity of the measure (11).

$$UL_r = \begin{cases} \frac{\lambda^{var} \cdot \ln(\lambda^{skew})}{L_r}; & \text{if } \lambda^{skew} > 1 \\ \frac{\lambda^{var}}{L_r}; & \text{otherwise} \end{cases} \quad (5)$$

Where L_r denotes the route length and.

2 - *The buffer methods* focus on “the extra percentage of TT due to TT variability on a trip that a traveler should take into account in order to arrive on time”. These types of indices, especially the *Buffer Index (BI)* appears to relate particularly well to the way in which travelers make their decisions (8). Buffer time (*BT*) is defined as the extra time a user has to add to the average TT so as to arrive on time 95% of the time. It is computed as the difference between the 95th percentile TT (TT_{95}) and the mean TT (M). The BI is then defined as the ratio between the BT and the average TT

$$BI = \frac{TT_{95} - M}{M} \quad (6)$$

Planning Time (PT) is another concept often used. It gives the total time needed to plan for an on-time arrival 95% of the time as compared to free-flow TT. The *Planning Time Index (PTI)* is computed as the ratio between the PT and the free-flow TT ($TT_{\text{free-flow}}$)

$$PTI = \frac{TT_{95}}{TT_{\text{free-flow}}} \quad (7)$$

For example, if $PTI = 1.60$ and $TT_{\text{free-flow}} = 15$ minutes, a traveler should plan for 24 minutes in total to ensure on-time arrival 19 times of 20.

3- *Tardy trip measures* indicate unreliability impacts using the amount of late trips. If travelers only use the average trip time for their travel plans, they will not arrive exactly on time, but can arrive either early or late to their destinations. A *Misery Index (MI)* calculates the relative distance between the mean of the 20% of drivers having the highest TT and the mean TT of all travelers. It is defined as

$$MI = \frac{M_{|TT^i > TT_{80}} - M}{M} \quad (8)$$

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

4 – *Probabilistic measures (Pr)* calculate the probability that TTs occur within a specified interval of time. Probabilistic measures are parameterized in the sense that they use a threshold TT, or a predefined time window, around some specific travel time threshold to differentiate between reliable and unreliable TTs.

Probabilistic measures are useful to present policy goals, such as the Dutch target for reliability, according to which “at least 95% of all TT should not deviate more than 10 minutes from the median TT” : $\Pr (TT^i \leq \beta + TT_{50}) \geq 0.95$, $\beta = 10$ minutes for routes longer than 50 km.

$$\Pr (TT_i) \leq (1 + \beta).TT_{50} \quad (9)$$

In our case, we used the proportional formula given by equation 9. $\beta = 0.2$ is used, which means that we compute the probability that TTs do not deviate by more than 20% from the median TT.

3. THE TEST SITE DESCRIPTION: THE A4-A86 MOTORWAY

In the east of Paris, a three-lane urban motorway (A4) and a two-lane urban motorway (A86) share a four-lane, 2.3 km long, weaving section. As the traffic flows of the two motorways are merged, traffic becomes particularly dense at some hours on the weaving section, known as the greatest traffic bottleneck in Europe. Until summer 2005, 182 000 vehicles using this stretch of road every day used to form enormous bottlenecks, with over 5 hours’ congestion a day and tailbacks regularly averaging 10 km. Traffic would be saturated by 6.30 a.m. and the situation would not revert to normal until 8.30 p.m.

A HSR experiment was launched in July 2005, which gives drivers access – at peak times – to an additional lane on the hard shoulder where traffic is normally prohibited.

The openings and closings of this lane are activated by the traffic control centre according to the value of road occupancy of the common trunk section, measured upstream (opening if road occupancy is greater than 20% and returning to closing if less than 15%).

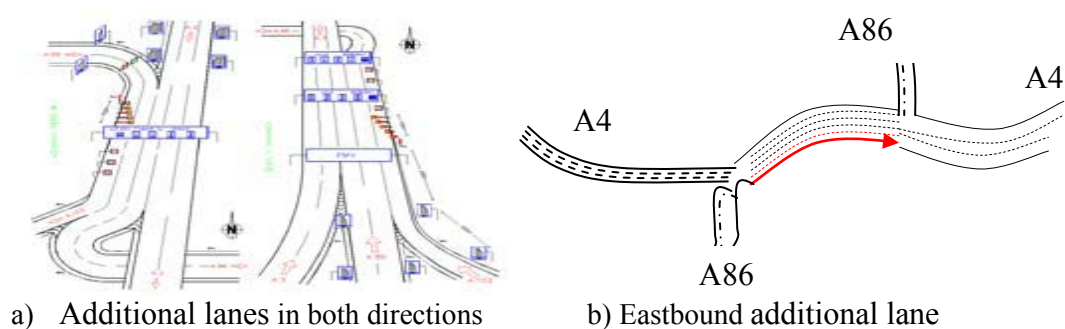


FIGURE 1 The weaving section A4- A86.

Daily statistics on the duration of hard-shoulder running on working days in 2006 show an average of 5 hours’ use into Paris and 4 hours’ use eastward out of the city. On Saturdays, the hard shoulder is open for an average of 4 hours into Paris and 3 hours and 45

minutes in the opposite direction. On Sundays it is open in both directions for 3 hours and 20 minutes.

Moveable safety barriers are installed on the right side of the additional lane. When this lane is closed, closure devices pivot to block the hard shoulder. These devices are installed at several key locations on the section so that drivers can see them whatever their position and are thus dissuaded from using the lane.

The width of the hard-shoulder has been increased to 3m and the width of the other lanes reduced from the standard 3.5m to 3.2m.

Safety has been improved by the installation of automatic incident detection cameras. In the event of an incident or accident when the lane is open, vehicles on the hard shoulder lane can be detected and the hard shoulder is then to be closed. Additional safety measures are provided by speed control radars on the A4 motorway in both traffic directions.

4. DATA DESCRIPTION

Inductive loops provide data regarding traffic flow, occupancy and average speed for each lane every six minutes. Although data were available on a 8-km-long stretch (in each direction), analyzed here are only data on a 3-km long stretch in the eastbound direction (2.3 km on the weaving section and 0.7 km downstream).

Data have been analyzed for three years (2000, 2001 and 2002) before the implementation of the device and one year (2006) after. Four inductive loops in the eastbound direction (three on the weaving section and one downstream) were used for calculating the TTs presented here.

4.1 Travel Time Calculation

The TT for the route is calculated from the four consecutive traffic stations as follows:

- At each traffic station, for each lane, the TT is the ratio of the length of the stretch of road covered by the traffic station, divided by the 6 minute average speed for the lane. However this TT might be disregarded (considered as missing data), if the average speed for the lane does not respect the thresholds (explained in the next section).
- At each traffic station, the average TT over the lanes is the weighted sum of the non-missing TTs of the different lanes. Each lane TT is weighted by the proportion of the traffic flow circulating on this lane (over the total traffic flow for the period). This process requires that the speed on at least one lane is relevant.
- The TT of the route constituted by the four consecutive stretches is the sum of the TTs of the stretches. This requires that the process described in the previous paragraph is successful for the four stretches.

A comparison between TTs in 2006 and 2002 is possible for all pairs of periods where this whole process was successful both in 2006 and in 2002. The frequency of success is high in absolute value (53,574 periods) out of the 87,600 periods of the year, even though there were many cases of missing or irrelevant data: in percentage terms, the frequency of success is 61% ($=53,574/87,600$).

4.2 Data Quality and Missing Data

Although data seem generally very good, some are missing, inaccurate or irrelevant. It is crucial to ensure that this does not distort the mean TT or the TT distribution.

Anomalies in traffic data are identified when they are higher or lower than given thresholds – some data are unrealistic, such as an occupancy greater than 100%, a 6-minute average speed greater than 150 km/h, a 6-minute flow (by lane) greater than 400 vehicles. In these cases data for the corresponding period and lane are eliminated and then considered as missing.

Thresholds for discarding very high or very low speed data impact the TT distribution and therefore could have an influence on data accuracy: errors can be made both when discarding or keeping the data. We preferred thresholds that would allow the elimination of large amounts of data as long as these missing data could be recovered. Recovery was processed as follows:

- History-based recovery: For the years 2000, 2001 and 2002, missing data for a given period and lane were substituted, when possible, by data of another year, for the same 6-minute interval at approximately the same date and time (same month, same day of the week, same hour). The data from 2000-year and 2001-year were used to reconstitute the 2002 missing data and the same process was used to reconstitute data for years 2000 and 2001).
- Occupancy-based recovery. In most cases of missing data, flow and occupancy seem correct whereas speed is missing. Therefore, for the “after” period (2006), a speed-recovery method based on a function of the flow/occupancy ratio was introduced. Assuming that all vehicles using the lane have the same length L , the harmonic speed average (\bar{V} , in km/h) on a given lane is inversely proportional to the occupancy (o) as given by equation (10).

$$\frac{1}{\bar{V}} = 100 \times o / [N(L + \lambda)] \quad (10)$$

Where L is the length of the vehicles and λ the length of the sensor (in meters). The occupancy is proportional to the time of presence on the sensor of the set of the N vehicles during the 6-minute measuring period. Generally, road occupancy data are recorded using two digits (no decimal places), which does not always give an accurate picture of a situation. Fortunately, the road occupancy data for the HSR site were recorded using four digits (two more decimal places), thereby providing a more accurate estimation of speeds. For example, for $N=100$ vehicles/6min, an occupancy $o=5\%$ and $(L+\lambda)=5\text{m}$, the speed is 100km/h, it is 84.74 km/h if $o=5.9\%$ and it is 99.8 km/h if $o=5.01\%$.

The speed of a vehicle is generally obtained, within two inductive loops, as the ratio of the distance between the two loops and the difference between the times of passage of the vehicle right at the two loops. Errors occur when one of the two loops defaults. Obvious errors can be corrected using one single loop: the inverse of the speed is estimated from the sum of the values of the time spent by the vehicles on the loop which is supposed to be correct.

Before using this recovery, it was necessary to check whether the occupancy-based speeds were close (or not) to the empirical speeds (see Table 1). The average TT and percentiles 90% and 95% are slightly smaller with the occupancy-based recovery. This means that for very low empirical speeds (less than 5km/h) the occupancy-based formula gives a higher speed value.

Table 1: Comparison between empirical 2006-year TTs , and occupancy-based speeds

	Method	Average	percentile		
			50%	90%	95%
Night_ closed	empirical (**)	118.3	113.2	126.8	139.3
	occupancy	116.0	113.3	124.8	129.6
Night_ open(*)	empirical	125.7	116.6	148.4	185.0
	occupancy	125.2	116.9	150.5	192.0
Day_ closed	empirical	156.0	131.2	221.7	246.5
	occupancy	155.8	130.9	221.7	245.8
Day_ open	empirical	137.9	125.0	182.4	206.1
	occupancy	137.0	124.3	180.8	205.1

TTs are in seconds

() only a few (138) values*

*(**) observations are disregarded when measured average speed is outside the range {5;150}*

km/h

Note also, that it is not easy to estimate the accuracy of the equipment. As traffic measurement equipment is periodically updated, measurement accuracy may change. This fact may mitigate certain results.

4.3 Traffic trend between 2000-2002 and 2006

The level of the traffic volume exerts an influence on the TT and its reliability. When analyzing the TT reliability for two years, the traffic volume trend between these years must be taken into account.

The examination of vehicles x kilometers traveled per year on the weaving section in both directions showed that traffic decreased by 2% between 2000-2002 and 2006. Traffic increased at night by 7% and decreased during the day by 4%. This corresponds to a change in drivers' behaviors. These traffic variations are not very high, so their impact on TT, although difficult to estimate without using a simulation model, should be rather low.

A modification of TT reliability may have an impact on the traffic level, because some drivers are sensitive to traffic conditions; therefore, some trips are advanced, postponed or rerouted. In the case of an ex-post assessment of a new traffic management system, it is easy to describe what happened (in terms of traffic volume or of its distribution during the day). The breakdown of vehicles x kilometers when HSR is opened/closed shows an open part equal to 19% in the before periods (years 2000-2002) and 20.1% for the after period (year 2006).

Note that in 2000, 2001 and 2002, HSR was not installed; the open periods are the periods corresponding to the 2006 periods where HSR was effectively opened. The correspondence between the periods is made on calendar principles.

The slight increase in 2006 of the part of drivers traveling during rush hours (20,1% in 2006 against 19% in 2000-2002) corresponds to a shift in 2006 of some drivers from off-peak to peak hours (now less congested).

This contributes to a better understanding of the link between driver choice and TT reliability. This should be helpful for building and calibrating a driver behaviour model based on TT reliability – such a model is being required for ex-ante studies.

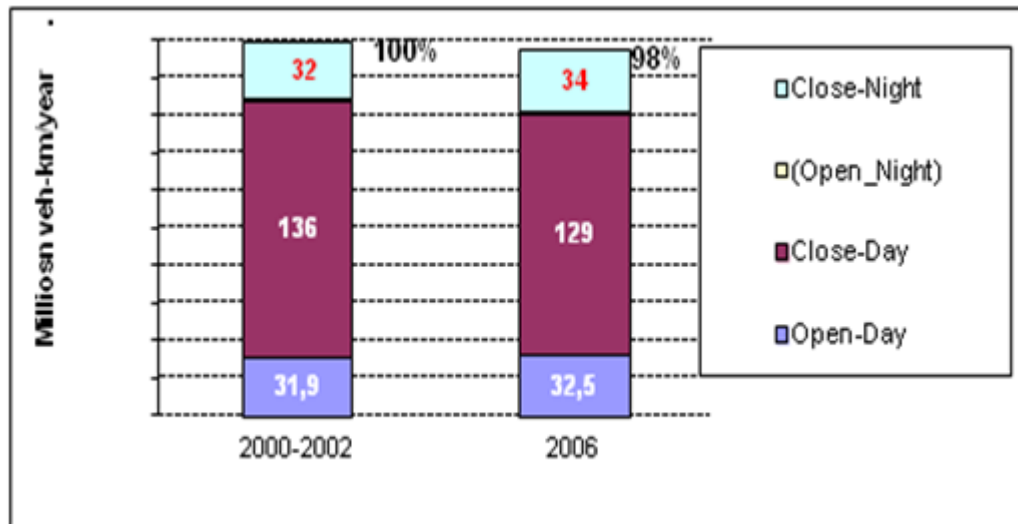


Figure 2 Evolution between 2003 and 2006 of vehicles x kilometers (millions) on the HSR site, by year, according to the period in the day, the HSR status.

Rain involves longer travel times, thus increasing travel time variability and reducing its reliability. Therefore it was necessary to compare rain occurrence between the two periods (2000-2002, 2006) by HSR status (open, closed) in order to account for the impact of rain in the HSR assessment. Two meteorological sources were available: rain gauges and human observation.

- According to the rain gauge records, the proportion of rainy 6-minute periods passed from 4.5% in 2000-2002 to 4.3% in 2006. When integrating human observation, this proportion became 7.3% in 2000-2002 and 7.0% in 2006.
- The proportion of traffic during rain in 2000-2002 is practically equal to the 2006 proportion, and this holds true in all the HSR situations (open, closed).

According to these values, it was not necessary to expressly consider the special case of rain in the reliability studies.

5. RELIABILITY ANALYSIS

Impacts of HSR on the TT and on its reliability are identified with an observational before/after study on the 3 kilometers of weaving section completed by downstream sections. Furthermore, in 2003 Jacques Chirac, former president of France, launched an important campaign for road safety and against speeding. This speed limit campaign reduced the high

speeds. We observed a reduction of the free-flow speed from 104 km/h in the year 2002 to 94 km/h in the year 2006 (12). Analyses are conducted on both the HSR and the speed limit campaign. Fortunately, the speed limit campaign was important only at off-peak period (when HSR was not opened). We can assume that, during peak hours, speeding was very limited in the “before” period, since the average speed was very low and therefore the speed limit campaign did not impact the periods when HSR would be opened.

The reliability analyses in this paper were made for four different situations: day-open / closed and night open/closed.

5.1 Global evaluation

The HSR effect may be split in two components:

- A direct effect on TT reduction and on TT variance reduction,
- An indirect effect on the daily traffic distribution. Indeed, when comparing off-peak and peak hours before and after HSR implementation a shift of some traffic from day off-peak hours (HSR closed) to peak hours (HSR open) was observed. Day traffic increased by 2% at peak hours, and decreased by 5% at off-peak hours. This shift is most likely related to the improvement of traffic conditions when HSR was opened: the supply during peak hours allows the passage of more vehicles. Also a part of the demand might shift from off peak to peak hours; this part corresponds to drivers who were constrained, before the HSR implementation, to drive during off-peak hours in order to avoid very congested peak-hour traffic. This shift implies a reduction of TT and its variance at off-peak hours.

Without this indirect effect, the TT reduction during peak hours as well as the TT increase during off-peak hours would have been greater. However there is no point in trying to distinguish the part of each component in the TT and its variance because the drivers experienced the global result of these two components.

We can see from Figure 3 that average TT increased for all periods except for the day-open periods.

During the day periods, the decrease of TT was due to the positive impact of HSR; the increase, when HSR is closed can be due to two different factors:

- HSR closed periods are generally during off-peak periods; and the speed limit enforcement due to the speed limit campaign led to increased TTs,
- there were some peak hours in 2006 where HSR was unavailable – for instance it was under maintenance in August 2006.

The average TT increase during night periods when HSR was closed can be easily attributed to the speed limit campaign, which induced the average TT increase for the few HSR nightly opened periods. These periods were partly congested, and HSR opening then led to a decreased TT. But this congestion cleared up quickly as the demand is low at night and the speed limit campaign led to an increase in the TT as compared to the “before” period – the final result being an increase of average TT.

5.2 Buffer times and buffer indexes

As one can see on the left-hand side of Figure 3, BT decreased for all periods. PT decreased except for the day periods when HSR was closed, where it was nearly stationary. This difference between the PT and BT evolution for the day-closed periods is due to the

increase in TT average and not in any decrease in TT₉₅; this is less favorable for drivers, but still remains an increase in reliability.

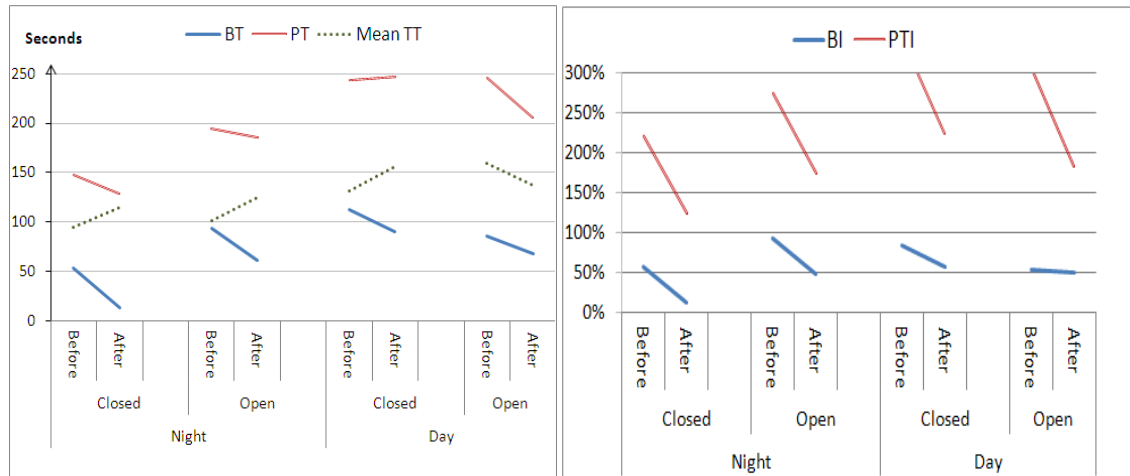


FIGURE 3 Impacts of HSR and the speed limit campaign on Buffer indexes

Remark. The strong decrease of BT in 2006 at night, when HSR was closed, is most likely due to the speed limit enforcement campaign which increased the mean TT, inducing more homogeneous speeds in 2006 than in 2002, therefore an improvement in TT reliability.

On the right-hand side of Figure 3, we can see that PTI decreased sharply in 2006 for the four situations (day_open/closed and night_open/closed) differently from the PT which remains stable for the day-closed periods and decreases slightly for the night-open periods. The decrease in PTI is due to the rise in the free-flow TT. This rise is only due to the speed limit campaign and isn't influenced by traffic conditions (congestion or fluid). We can therefore conclude that:

When comparing the situations in 2002 and 2006, the evolution of PTI (which decreased) is misleading for users because the PT did not always decrease.

Comparing the evolution of BT and BI, we can see that both have the same evolution between 2002 and 2006. This is because the average TT depends also on the amount of congestion. The average in the denominator of the BI formula, cannot inverse the trend of the numerator, it can only accentuate or reduce the trend.

The BI decrease is less important than the BT decrease for the day-open periods ($BI_{2002} = 54\%$, $BI_{2006} = 50\%$; $BT_{2002} = 86,3$ s and $BT_{2006} = 68,4$ s). This is because in 2002, the average speed corresponded to congested traffic conditions only for the day_open periods where average TT was equal to 160 seconds, meaning a speed of 67.5 km/h.

Reliability can be defined either in time by the BT, the extra time which must be added to the average or in percentage by the BI. In this example these indicators are not equivalent since the average TT varies from one period to another, but both remain valid reliability indicators.

5.3 Tardy trip and probabilistic indicators

Tardy trip measures indicate unreliability impacts using the amount of late trips. A Misery Index (MI) calculates the relative distance between the mean of the 20% highest TT (mean of $TT > TT_{80}$) and the mean TT of all travelers. Figure 4 shows the evolution of the Misery Index. It shows that it decreased significantly for all the periods. The decrease when HSR is closed is due to the increase of mean TT due to the speed limit campaign. This means that TT reliability is noticeably improved but not only due to the HSR effect. However, for the day-open period, mean TT decreases as shown on figure 3. Therefore reliability improvement is only due to the HSR effect.

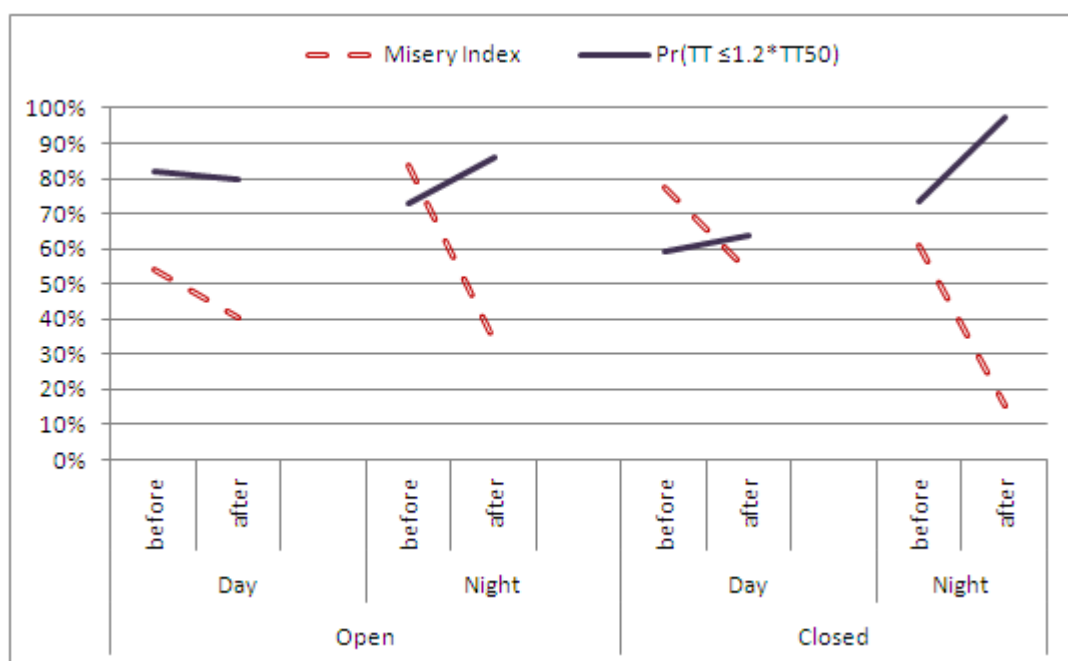


FIGURE 4 Impacts of HSR and speed limit campaign on the Misery Index and the Probabilistic Indicator

The probabilistic indicator gives a different point of view. We can see on Figure 4 that the probability indicator decreases very slightly for the day_open periods (around 2%). It increases for other periods. This slight decrease comes from a decrease of the median; therefore the value (1.2 x median) corresponds to a shorter TT, more frequently exceeded. The number of travelers having high TT values was not any fewer in 2006 than in 2002, but the mean of these high TT was lower in 2006 (MI passed from 54% to 41%).

5.4 Skew and width indicators

Van Lint et al. (11) presented λ^{Skew} (equation 3) and λ^{Var} (equation 4) as a robust measure for skew and width of TT. They argued that:

- During congestion, unreliability of TT is predominantly proportional to λ^{Var} . This is not refuted here: the value $\lambda^{\text{Var}}=0.77$ in 2002 can be considered as large, whereas the value $\lambda^{\text{Var}}=0.54$ in 2006 is much lower, while congestion decreased from 2002 to 2006.

- In transient periods (beginning of congestion and end of congestion), unreliability is predominantly proportional to λ^{Skew} . However we cannot have this interpretation of λ^{Skew} here, since we have calculated λ^{Skew} for all opened HSR periods, which include transient periods, congested and non-congested periods. We say that for this large set of periods, the interpretation of λ^{Skew} is difficult, since the λ^{Skew} numerator and denominator depend on the location of TT_{50} related to the congestion. Different situations may occur. In 2002, in day_open periods, $TT_{50}=155,9$ seconds was in congestion (speed=69,3 km/h), whereas in 2006, $TT_{50}=124,9$ seconds (speed=86,5 km/h) was no longer congested.

In 2002, TT_{50} was high because more than half of the periods were congested. It implied a large λ^{Skew} denominator ($TT_{50}-TT_{10}$)= 67.7s, and a relatively low λ^{Skew} nominator despite of congestion ($TT_{90}-TT_{50}$)=52.4s. Both reasons lead to a relatively low λ^{Skew} value (0.77).



FIGURE 5 Evolution of the width and skewness indexes

6. CONCLUSIONS

Reliability is a new dimension for assessing traffic operations and is as important as the traditional factors such as road capacity, safety, equipment and maintenance costs, etc. This paper presents the TT reliability assessment of a HSR field test from a French motorway and discusses the effectiveness of some key performance indicators.

Field tests provide large amounts of data which are necessary for any assessment. The first concern is the quality of data.

In this field test, TT is estimated from speeds which are measured by inductive loop sensors. The use of six-minute average speeds instead of individual speeds (not available) tends to hide parts of the TT variability, therefore of its reliability, but nevertheless reliability indicators based on six-minute data remain meaningful. Data analysis shows the accuracy of data, although some outlier speeds were identified and considered as missing data. The missing data for the “before” period was replaced on the basis of an historical method. For the “after” period, missing data were replaced with a flow/occupancy method.

In order to distinguish between the HSR effects and other concomitant aspects, traffic analyses were performed with regard to day and night periods and open and closed HSR.

The results show a positive effect of HSR on TT reliability.

In addition to the reliability assessment of the HSR, the paper discusses the ability of different indicators known to accurately report the TT reliability improvement. Results show that lower PT increases driver satisfaction and a smaller BT implies greater reliability, even if the PT does not decrease. Comparisons between PTI from different years may be misleading to travelers. In this field test example, reduction in PTI was due to the increase in free flow travel time and not to a decrease of the PT. Increase in free flow time is due to a greater respect of the motorway speed limit imposed by the speed limit campaign. Further to these classical indicators, the paper discusses the robustness of λ^{Var} and λ^{Skew} indicators to measure respectively the width and the skew of TT distribution. It shows the effectiveness of the width indicator and its robustness to indicate both reliability and congestion. Results from this HSR French experiment show however that the λ^{Skew} indicator is not always suitable for the reliability assessment. Indeed, two factors impact traffic in this experiment: on the one hand the HSR implementation, and on the other hand the speed limit campaign, supported by the automatic speed control systems. The speed limit affects traffic only for non-congested periods and therefore when HSR is closed. As a consequence it affects the denominator of the λ^{Skew} indicator which depends on this non-congested traffic. The use of this part of the TT distribution as a component of the λ^{Skew} definition affects the quality of this indicator: values of λ^{Skew} reveal more a lower TT median value rather than reliable traffic conditions. As λ^{Skew} is not an effective indicator for reliability assessment, the combined indicator of width and skew, the Ulr indicator is also affected, and cannot therefore be considered as an effective indicator.

In the future, the optimization of traffic operations should be developed with respect to, among other criteria, TT reliability in its various forms.

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