# ASSESSMENT OF TRAFFIC OPERATIONS ON MOTORWAYS: A NUMERICAL MAPPING APPROACH

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## Abstract

This paper presents a tool allowing a reliable assessment of the impacts of traffic operations, based on numerical mapping techniques. The different steps of the method are described. Quantitatives indicators are extracted from the maps of traffic conditions. Examples confirm the potentalities of this new approach. A first one analyses a peak of traffic due to leisure trips on an interurban motorway. A second example deals with the impact of a traffic information system on an urban orbital expressway.

## INTRODUCTION

The penetration of new technologies in the field of traffic management and control modifies in depth the methods and the practices in use in traffic engineering. Developments realised in various sectors such as measurement, data processing and communications open interesting prospects.

On motorways and expressways, these innovations can bring a particularly useful contribution to decision makers and traffic operators in the elaboration of a diagnosis. On these networks, recurrent or non-recurrent congestion represent the major constraint of traffic management. Daily conflicts are emphasized by the constant increase of mobility, the multiplication of seasonal peaks, the importance of the heavy traffic, and the effects of accidents and incidents. The knowledge of these phenomenon and their reduction are some of the essential objectives and actions launched by traffic managers.

The availability of macroscopic data - flow, speed, occupancy - provided by permanent systems, such as loops, cameras or various sensors, allows to consider the elaboration of a precise diagnosis of traffic conditions.

The paper focuses on this aspect. It presents a new tool for a diagnosis on traffic conditions based on numerical mapping techniques. The different steps of the methodoligical approach are described : calibration of a fundamental diagram, determination of critical thresholds, gridding process, mapping iso-occupancy curves, digitizing components. The method is illustrated by two examples concerning an interurban motorway and an orbital expressway. The tests confirm the potentalities of this new approach to set up an observatory of traffic conditions and to quantify the effects of traffic congestion.

## THE TRAFFIC STATES AND THE FUNDAMENTAL DIAGRAM

The macroscopic law of traffic flow on a motorway section can be formulated by means of a function relating two fundamental traffic variables : volume and occupancy rate (May, 1990). The first variable designates the number of vehicles per unit time. The second variable corresponds to the proportion of time during which the carriageway is occupied. In this classical "fundamental diagram", volume is deduced from occupancy rate. The first part of the curve corresponds to the free flow traffic state : volume increases with occupancy up to a threshold called critical occupancy. If the occupancy rate continues to increase above this critical threshold, traffic volume decreases and the traffic state is said to be congested. Therefore, occupancy appears to be the state variable. A traffic state is considered as congested when the occupancy rate is greater than the threshold. This simple criteria allows to discriminate congestion from free-flow traffic.

The taking into account of the two dimensions time and space suggests naturally a recourse to level curves of traffic states. In fact, these curves are the practical tool for the representation of a three dimensional surface - time, space, occupancy - in a two dimensionnal field. Furthermore, this option of graphic displays has the advantage of giving a useful highlighting of :

- recurrent or non recurrent congestion type ;
- the location of congestion sources corresponding to the different types of bottlenecks ;

- congestion times and intensity for a given observation period.

Moreover, it is possible to provide from these curves an overall numerical indicator resuming the congestion effects on the motorway (Allen, May, 1969). Calculated and drawn automatically, these level curves allow the qualitative comparison between days of operation, traffic control modes, measures of operation.... Practical difficulties in getting data necessary for this type of display and complexity of manual layout methods long refrained the development of this approach. Recent efforts in numerical automatic mapping techniques give a new impetus to these procedures (Sutcliffe, 1980).

## THE GRID OF TRAFFIC MEASURES AND THE GRIDDING PROCESS

Numerical mapping covers the techniques allowing to visualise and estimate variations of a continuous function $z = f(x,y)$ defined in a compact field of the two dimensional euclidian space. In order to be represented and calculated, the function must be defined at the nodes of a grid mesh. Each value known at each node of the grid corresponds to the value of a state traffic variable - occupancy - issued at a given time, from a detection station. Thus, for instance, a sensor located on the motorway at the point $x_i$ will give at time $t_j$ the value $z_{ij} = f(x_i,t_j)$.

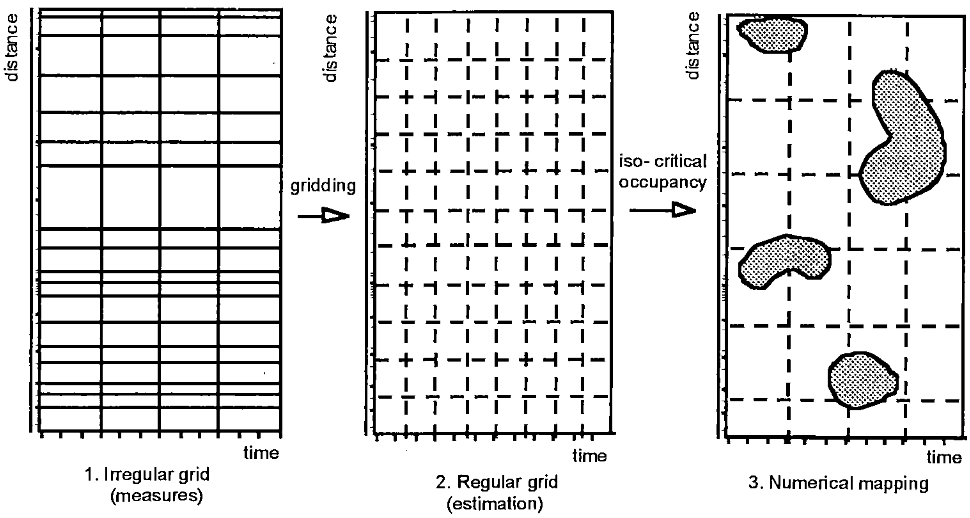


**Figure 1 - Phases of the automatic mapping process**

Different kinds of grids can beconsidered according to the nature of the available data and the geometric design of the motorway. In the time space reference system used in motorway traffic, the grid is generally irregular and rectangular. On the horizontal time axis, the scale corresponds to the integration period of measures issued from the detection stations : 30 s, 1 mn, 6 mn,.... As far as the distance axis is concerned, it allows to locate these stations by the means of their milestonnes along the linear motorway. These stations are not equidistant. This type of grid is the one met with on most equipped motorways and expressways.

Figure 1 resumes the different steps of the process leading to the mapping of traffic conditions. Mapping level curves of traffic states implies first to define a regular grid of values. This phase is the result of an estimation process, usually called "gridding". Any data destined to become a contour map must be gridded. The set of discontinuous data points is transformed into a continuum. The base map area or time-space diagram containing sensors measures is divided into a grid of estimated cells. For each grid cell, a value is assigned, based on the value of one or more neighbouring original data points. Once all of the grid cells have been assigned an estimated z value, then the data can be represented as a contour map. In fact, this new data grid is essential in the whole mapping procedure since it serves as model of the structure. The contour map of traffic states is simply a common means for graphically representing the data within a grid model. The « inverse-distance » gridding algorithm is applied. With this classical technique, the value assigned to a grid cell, $z_{estimate}$ is a weighted average of an arbitrary number of nearby data points. The influence of these neighbouring data points on the grid cell is weighted according to the inverse of its distance (d) from the cell, taken to a certain power. The general formula used for the inverse distance calculation is shown below :

$$z_{estimate} = \frac{\sum_{i=1}^{n} z_i \times d^{-p}}{\sum_{i=1}^{n} d^{-p}} \qquad (1)$$

In this formula, n corresponds to the number of neighbouring data points, p to an integer exponent and $z_i$ to the measurement values (i=1, ...n). The greater the value of n , the less local will be the value computed for the grid cell. Even so, the greater the value of p, the less influence data points will have. Applied to motorway traffic data, this gridding algorithm produces generally a smooth and continuous grid and does not exagerate its extrapolations beyond the given data points.

## CHARACTERISTICS OF THE TRAFFIC PEAKS

Numerical mapping produces various closed components. According to the values of the occupancy rate, the area delimited by each component corresponds in practice to an indicator of traffic congestion. The estimation of this area, very useful in term of assessment of congestion, can be undertaken directly from the graph, as indicated in Figure 2. The map allows thus to exhibit quantitative indicators, characteristics of the traffic states observed.

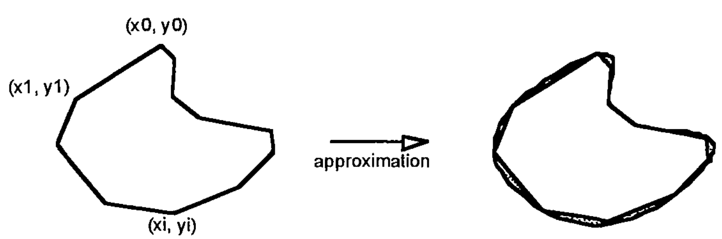


**Figure 2 - Estimation of the area defined by traffic peaks**

We designate by { $(x_i, y_i)$ i = 0, n} the coordinates of the points obtained after digitizing the different closed contours (C), beginning with $(x_0, y_0)$ and ending by the same point $(x_n, y_n)$. In this case, it is possible to establish the following relationship:

$$\text{Area}(C) = \frac{1}{2}\left|\sum_{i=0}^{n} (x_i y_{i+1} - x_{i+1} y_i)\right| \quad (2)$$

This approximation is as much accurate as the step of digitizing is small. Therefore, for each contour of congestion, the beginning, the end, the maximum length of the corresponding peak are determined by simple projection on the axes on the map (Cohen, 1993).

## ESTIMATION OF A DELAY DUE TO A TRAFFIC PEAK

The congestion index defined above can be approximately related to the delay caused the corresponding traffic peak. Indeed, it can be shown that the area A, calculated previously, is related to this delay D by the following formula:

$$D = (k_b - k_f)\,A \quad (3)$$

in the system unit D in veh x h, $k_b$ average density in the bottleneck in veh/km, $k_f$ average free-flow density in veh/km and A congestion index in h x km. In this formula, the two densities correspond to the same value of flow.

The determination of these densities is based on the availability of the occupancy variable, noted t, and on the classical relationship between concentration and occupancy (Cohen, 1993). Furthermore, for a given volume of flow, the difference $(k_b - k_f)$ can be derived from the knowledge of the fundamental diagram q(t).

## ASSESSMENT OF A TRAFFIC PEAK DUE TO LEISURE TRIPS

### An interurban site

Built in 1970, the A7 interurban motorway has a total length of about 250 km. Currently with 2 x 3 lanes, it is the backbone of the axis Lille-Lyon-Marseille. The traffic recorded in 1994 confirms the importance of this axis with the highest volumes of the interurban motorways in France : more than 56 000 vehicles per day including 18 to 20% of lorries. A7 is the preferential itinerary for long distances leisure trips. In summer, traffic peaks exceed indeed 140000 vehicles per day and can even reach 165 000. During the decade 1980-90, the annual arithmetic growth of traffic has reached 5.8%.

Every section of the motorway is equipped with various devices allowing the permanent measurement of volume and occupancy. There used to be one measurement station (loop sensors) every 4.2 km. These stations are irregularly spaced.

Data analysed here were recorded during a traffic peak corresponding to Easter 1995 : Monday 17 April between 0 and 12 pm, in the South-North direction. Figure 3 gives an example of the calibration of the relationship between volume and occupancy on a 3 lanes section of the A7 motorway.

The critical occupancy rate derived is around 20 %. Two situations or regimes are then considered :

- free-flow traffic, defined by an occupancy rate inferior to 20 % ;
- congestion, characterised by an occupancy rate above 20%.

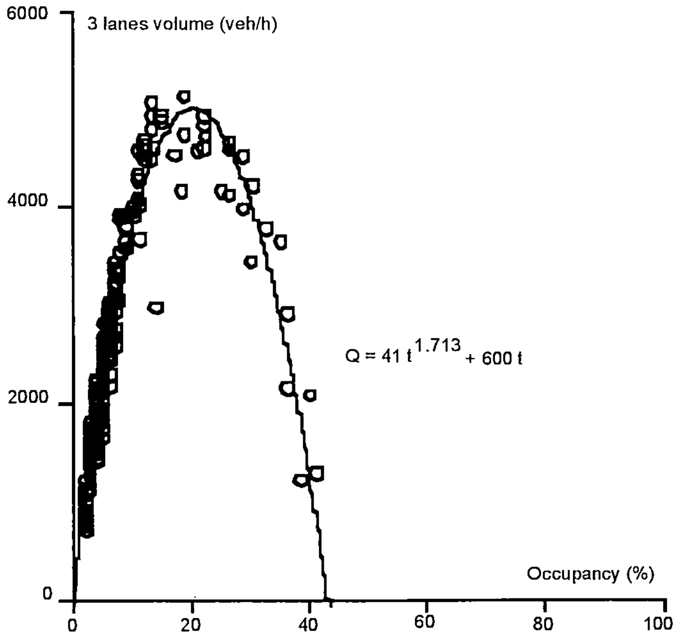


**Figure 3 - Calibration of the fundamental diagram on the A7 motorway**

## Mapping of a peak generated by long distance trips

The limit of 20% is used for contouring and drawing iso-occupancy curves. The inverse-distance algorithm is applied with n=2 and p=2. A virtual grid is created. On the vertical distance axis, the cell spacing is chosen equal to 2 km. Each estimated cell value is a weighted average of 2 measures, given by the 2 nearest detection stations. In order to avoid to obtain complex contours, the level lines are smoothed before being drafted. This process simplifies the analysis and the interpretation of the map.

Figure 4 represents the results of this mapping process for Monday 17 April 1995, in the south-north direction. High density zones are easily located. A direct and simple analysis of the map reveals the following elements.

The first peaks appear around 14h30, the traffic remaining perfectly free-flow until then on the totality of the A7 motorway. The last disturbance ends around 9 pm. Traffic congestion affects mainly two sectors :

- the sector of Vienne on A7 North, with a well localised peak of about 10 km, in the evening between 7 and 9 pm ;
- the section Orange - Valence South, with various peaks near Orange, Bollène, Montélimar or Loriol. Several are particularly important and create queues reaching sometimes 35 km.

## An observatory of traffic peaks

Peaks detected during the analysis can be characterized by multiple parameters : beginning, end, area (or hours x kilometres of congestion), intensity and maximal length. The determination of these indicators is directly derived from the coordinates of the contours on the map. This process allows an exhaustive census of traffic peaks. Table 1 presents an extract from this census for Easter 1995. Thus for example the peak n° 5 on Figure 4, between Loriol and Montélimar North can be easily identified from the coordinates of the corresponding contour.

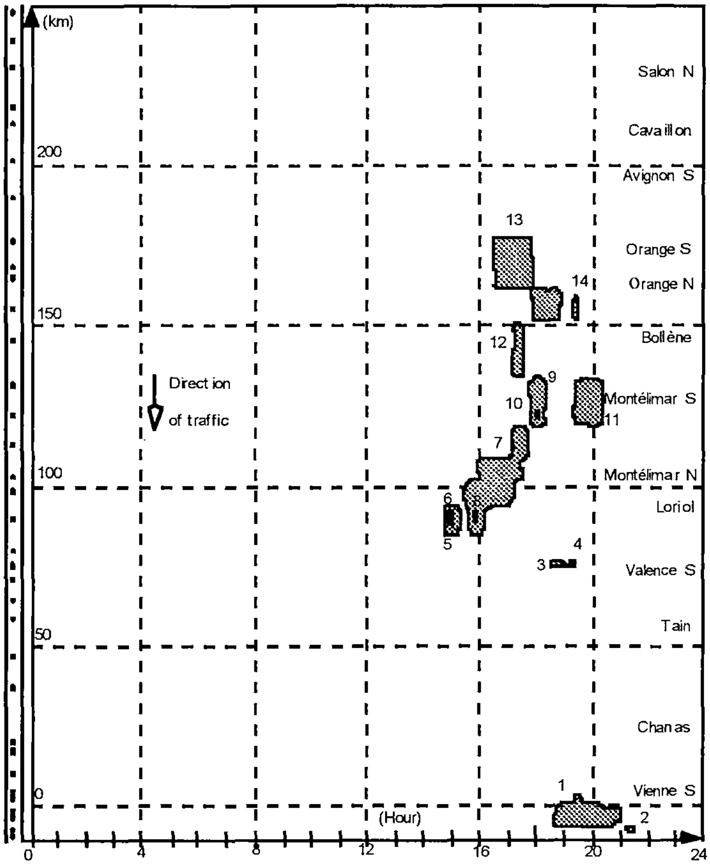


**Figure 4 - Numerical mapping of traffic conditions on the A7 motorway**

**Table 1 - Characteristics of the peaks observed (extract)**

| Peak number | Beginning | End | Duration (mn) | Length (km) | Area (hxkm) | Intensity |
|---|---|---|---|---|---|---|
| 5 | 2h42 pm | 3h20 pm | 38 | 9.9 | 5.6 | average |
| 6 | 2h52 pm | 3h08 pm | 16 | 5.3 | 1.1 | strong |
| 7 | 3h32 pm | 5h40 pm | 128 | 34.8 | 34.1 | average |
| 8 | 3h46 pm | 3h54 pm | 8 | 3.1 | 0.2 | strong |

The different peaks observed Monday of Easter 1995 on the A7, in the South-North direction, represent a total of 120 h* km of congested traffic.

## ASSESSMENT OF A TRAFFIC INFORMATION SYSTEM

Since May 1994, the Paris City Authorities are providing a new type of information on the Variable Message Signs (VMS) present for several years on the Paris orbital expressway (« Boulevard Périphérique »). Instead of the customary information about queue lengths, motorists are now given a travel time forecast between various motorway interchanges. The numerical mapping approach is utilized to assess the effect of this change in the semantics of the messages on traffic conditions (Cohen, 1996).

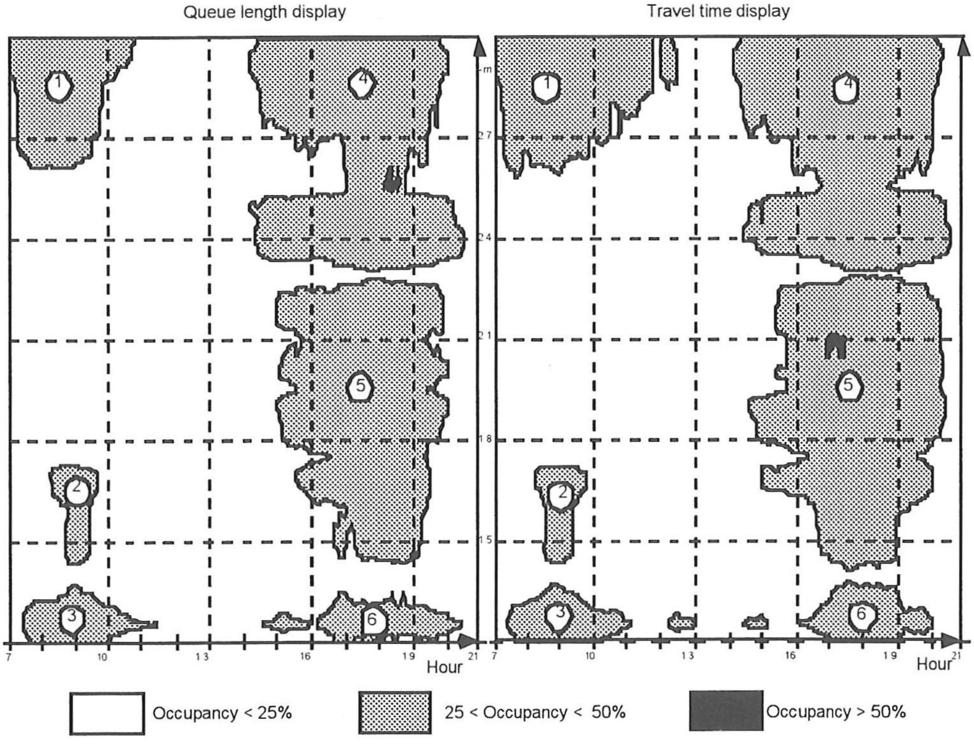


**Figure 5 - Mapping of traffic conditions for different types of message**

Figure 5 compares the operation of the inner carriageway on the northern part of the expressway with alternate use of the two information display strategies. A congestion contour is plotted at an occupancy rate of 25%, which is the saturation threshold of the infrastructure. The qualitative comparison of the maps allows the first conclusions.

Traffic conditions seem to have generally undergone little change. The main traffic peaks occur at the same places and times, irrespective of the type of information which is displayed. The duration of congestion and the lengths of the affected sections both remain fairly stable. However, detailed analysis shows that some high traffic density zones on the boulevard périphérique were slightly extended when « journey time » displays were used. Thus, for example, the morning peak between Pantin and Bagnolet (number 1 on the maps) finished later with « travel time » displays than with « queue » displays.

## PERSPECTS FOR TRAFFIC MANAGEMENT

The methodological approach detailed here for assessment is illustrated by two concrete examples. The first concerns an in-depth analysis of long distance leisure trips on an interurban motorway, the second deals with a traffic information system on an orbital expressway. These two cases, though contrasted, confirm the relevancy of the numerical mapping techniques for the assessment of traffic disturbances and for the automatic determination of their main characteristics (Cohen, 1987, 1989). The process can be easily implemented through information provided by permanent collection data systems.

This approach can be employed by decision makers and traffic managers :

- for the analysis, the representation and the comparison of traffic peaks : daily peaks, seasonal trips linked to leisure mobility, incidents and accidents ;
- for the evaluation of several specific traffic operations and traffic control measures ;
- for the elaboration of statistics concerning the evolution of phenomenon of congestion on urban or interurban motorway networks.

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