Risk Rate Estimation for Motorway Management

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ABSTRACT

Mobility and flexibility are decisive elements in our modern industrial society. Every day, more and more people and goods have to be transported rapidly, at a lower cost and above all, safely. Thanks to continuous economic growth, the volume of traffic increases daily; the result is a gradual saturation of road and motorway networks. Whatever the case, the fundamental requirement remains the same: the increase in traffic (TRANS95) must not take place at the expense of safety. The developments carried out - first and foremost to improve the passive security of vehicles - have led to a clear drop in the number of serious accidents. The improvement in the standard of vehicles has just about reached its maturity. Various administrative and regulatory measures implemented by the authorities to make users more responsible have contributed to the rise in the level of security, but they too have reached their limit. The improvement must therefore now come solely from the infrastructures and their associated equipment.

In view of this fact, safety improvements are attained by means of the implementation of active methods: these are primarily "intelligent" systems (GUIOL94) dealing with traffic management, whose purpose is to help pilot the flow of vehicles according to the situation and as understood on the basis of information processed as the object is to avoid as many *secondary accidents* as possible (accidents which are the consequence of a first accident).To complement these assistance systems, we would like to set up non-contact measuring systems allowing us to obtain a preventative vision of an accident-provoking situation, depending to the conditions at that given time. We want to be able to obtain these results at any point throughout the network, simply by using a geometric description of traffic conditions (flow, speed, taking into account any incidents as they happen) and meteorological conditions.

The purpose of our survey consists of setting up an appropriate algorithmic system capable of supplying various data and syntheses as they occur, to operators in charge of managing the motorway to help them make decisions that are required in the course of their work.

At the start, we used traditional methods of data processing in order to obtain a clear comprehension of the phenomena under review. Then, based on surveys already carried out, we moved into a phase of modelling data and processes. We established the various relations between traffic data and those concerning the geometric description of the road . These characteristics allowed us to define the parameters which influence these phenomena and hence better understand traffic problems.

Key-words : Motorway management, risk estimation.

1. INTRODUCTION

To make the most of the existing networks and to design new infrastructures, it is important that the capacity of the various structures designed to keep traffic moving should be taken into account. Indeed, capacity is an important element in the choice of investments and operative measures. Much research has been undertaken on this theme (CETUR88), (BAYE94), in particular in the United States. The famous *"Highway Capacity Manual"* (HCM) (HCM85), published in 1965 and updated in 1985 is often used as a reference even now. At INRETS(Institut National de Recherche sur les Transports et leur sécurité France), Simon Cohen wrote the first documents synthesising traffic theories and their applications (COHEN90). He is also responsible for many surveys concerning motorway capacity (COHEN 80,82, 83). The results of various surveys undertaken in France (LESORT91), (LASSARE94) show the effects of factors such as the number of lanes, the reasons for travel, the duration of the period of reference, weather conditions or speed regulations. Various methods for evaluation exist, such as the analysis of maximum flow, the adjustment of flow/occupation index curves, the inter-vehicle interval or the bi-modal distribution of flow. However, these various methods use traffic data and the influence of the site is important. The result is that only occasional measurements are carried out and it is difficult to generalise both with regard to the geometric plan of the site and to traffic conditions. Moreover, it is impossible to continuously cover the whole length of the motorway.

We shall therefore try - using the traffic data normally used by operators, taken from occasional measuring sites - to define a method which characterises a risk taking, into account the geometric aspect of the road segment examined. This can then be generalised to other parameters such as lane description and traffic conditions. We shall also try to evaluate the residual capacity[1] of a lane after an occasional incident such as the neutralisation of a lane due to an accident.

Using data which characterise the traffic, gauged using various pieces of equipment that already exist on the motorway network, we shall demonstrate certain links (or relationships) between these quantitative data and various quantitative or qualitative data describing the infrastructure. To do this, we shall use data analysis techniques and research to show a correspondence between characters.

To begin with, we shall implement the various correlations which may exist between values such as speed, flow, lane occupation index and the percentage of Heavy Goods Vehicles. These values are solely quantitative and are provided by measuring stations (RADT) situated on ESCOTA's motorway network. Then we shall take into account the qualitative data such as weather conditions and the type of day (weekday, bank holiday...). The aim of these tasks is to define the importance of various parameters in relation to each other in order to rank them and decide which ones can be left aside or simplified. Once this has been defined, it is possible to carry out a second measuring campaign, in which the choice of infor-mation gathered and measuring sites is made according to definitions established during the previous phase.

To begin with, we want to establish a correlation between the geometric aspect of lanes and traffic capacity. Then information concerning perturbations will be integrated as they occur, along with meteorological data. This will allow us to fix a risk level above which it is no longer possible to keep current traffic moving under adequate safety conditions. We then devise a model allowing us to characterise the thus estimated danger digitally.

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[1] The residual capacity is the number of vehicles that can drive along a given lane further to its maximum capacity being reduced because of an incident.

The results of these different stages are then combined within a decision-support system (DSS) which carries out the synthesis of data and presents it to the operator.

2. REMINDER OF TRAFFIC ENGINEERING

To calculate the risk level on a given segment of motorway, we shall use certain variables produced by measuring and counting devices set up on the motorway network which allow us, in particular, to calculate the true distance between vehicles. First of all, we shall give a brief introduction to the theoretical notion of safety distance, along with a short presentation of traffic variables.

2.1 Safety Distance

Various surveys concerning the safety of vehicles in the same lane have attempted to link the space s to the instant speed v by means of the formula $s = f(v)$. The commonly acknowledged theory is that the total time required to stop a vehicle when it is faced with any danger is the sum of the reaction time and the braking time. The reaction time is the lapse between the moment a driver realises there is a danger and the start of braking. The distance covered during this time lapse is presumed to be proportional to speed v. The braking time is the lapse between the start of braking and when the vehicle comes to a halt. The distance covered during this time lapse is proportional to v^2.

If L is the length of the vehicle, the safety distance, i.e. the minimum distance that must be left by each driver between his vehicle and the one in front of him, is as follows : $s = L + Tv + cv^2$ where T is the driver's reaction time and $c = {}^1/_2 a$, where a equals maximum acceleration. Experiments carried out in France (COHEN 90) allow us to calibrate the following formula : $s_v = 8 + 0.2 * v + 0.003 * v^{2.}$ (1).

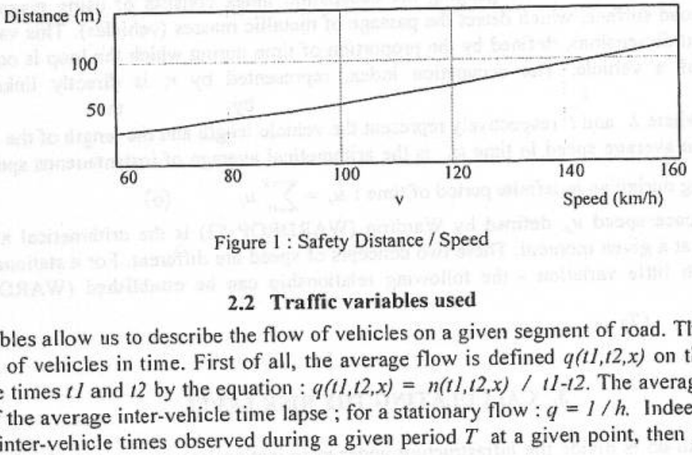

Figure 1 : Safety Distance / Speed

2.2 Traffic variables used

These variables allow us to describe the flow of vehicles on a given segment of road. The flow is the distribution of vehicles in time. First of all, the average flow is defined $q(t1,t2,x)$ on the abscissa x between the times $t1$ and $t2$ by the equation : $q(t1,t2,x) = n(t1,t2,x) \ / \ t1\text{-}t2$. The average flow is the converse of the average inter-vehicle time lapse ; for a stationary flow : $q = 1 / h$. Indeed, if N is the number of inter-vehicle times observed during a given period T at a given point, then : $T = N H_{av}$, with H_{av} being the average time interval. $T = \sum_{i:1}^{N} h_i$ (2)

The flow measured q equals : $q = N/T$ or $q = 1/H_{av}$. If an individual flow q_i is combined with this, at the passage of each vehicle, one obtains: $q_i = \frac{1}{h_i}$ (3)

When calculated using individual flows, the average flow q is equal to the harmonic average of individuals flows $q = \frac{1}{\left[\frac{1}{N}\sum_1^N h_i\right]}$ or $q = \frac{1}{\left[\frac{1}{N}\sum_1^N \frac{1}{q_i}\right]}$ or $q = \frac{1}{h_{moy}}$ (4)

The concentration, or density, describes the distribution of vehicles in space. The average concentration $k(x1,x2,t)$ at a given moment t on a road segment limited by points $x1$ and $x2$ is as follows : $k(x1,x2,t) = n(x1,x2t) / x2 - x1$. If one observes the passage of N vehicles, one can define the individual concentration k_i as being $k_i = 1 / s_i$ where s_i is the space in front of the vehicle (i).

Taking into account that vehicle length $L = \sum_{i=1}^{N} S_i$ the average concentration k on the segment is

$$k = \frac{1}{\left[\frac{1}{N}\sum_1^N \left(\frac{1}{k_i}\right)\right]} \quad \text{or} \quad k = \frac{N}{L} \qquad (5)$$

As for the flow, the average concentration is the harmonic average of individual concentrations. For a stationary traffic flow, the average concentration and the average spacing are the opposite of each other

$k = 1 / s$. The occupation index is a variable often used nowadays in the field of motorway operation. The most common procedure for gauging the occupation index consists of using magnetic loops buried in the road surface, which detect the passage of metallic masses (vehicles). This variable is a volume without dimensions, defined by the proportion of time during which the loop is occupied by the passage of a vehicle. The occupation index, represented by r, is directly linked to the concentration k by the equation $r = (L + l)k$, where L and l respectively represent the vehicle length and the length of the loop. At a given point, the average speed in time u_t, is the arithmetical average of instantaneous speeds u_i of vehicles passing during an indefinite period of time : $u_t = \sum_1^N u_i$ (6)

The average space speed u_s, defined by Wardrop (WARDROP 52) is the arithmetical average of vehicle speeds at a given moment. These two concepts of speed are different. For a stationary traffic flow - i.e. with little variation - the following relationship can be established (WARDROP 52)

$$u_t = u_s \frac{\sigma^2 s}{u_s} \qquad (7)$$

3. CALCULATING THE RISK LEVEL

The first thing to do is divide the infrastructure under examination into segments and sub-segments showing similar conditions with regard to their theoretical capacity characteristics[2]. In the case of modern motorways, this sub-division is not always a prerequisite for calculations, even when fairly

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[2] The theoretical capacity is the maximum number of vehicles that can transit on a given road segment. This value is theoretical and it is calculated using the various parameters of road construction.

long segments are examined. Indeed, this sub-division is only justified by the existence of specific elements which interrupt the uniform course of the road : slip roads, intersections, significant slopes... Other factors besides those described above can be taken into account such as the lengthways and crosswise profiles, the radius of bends etc.

3.1 Description of the method.

Theoretical curves representing the variation in flow according to concentration (see fig 2), show that - depending on the segment's capacity - the flow will reach a limit value above which the vehicle flow will slow down and its concentration increase.

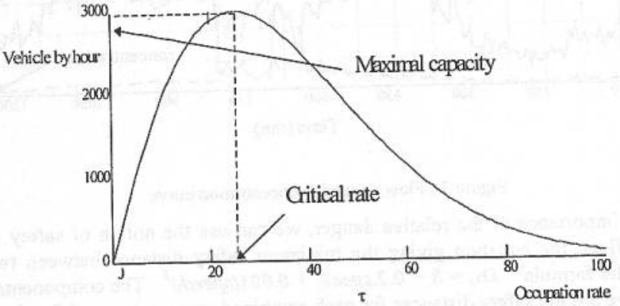

Figure 2 : Flow / concentration curve

The practical curves (based on measures of flow, speed and concentration), show that for a given segment, an increase in flow is not necessarily accompanied by a significant reduction in speed. The result is a virtually linear increase in concentration compared to flow and this creates potential congestion. Indeed, if the flow before the point examined is equal to a value close to that of the critical capacity[3], congestion arises and the result is a traffic jam whose size is greater than if the flow of vehicles had been slowed down at the point examined.

The conclusion is therefore that the idea of a *"critical"* speed or *"optimum"* speed should be suggested ; this speed, appropriate for each segment and each time during the day, represents the speed above which a significant danger of a rapid increase in traffic concentration - and therefore congestion - arises. The danger obviously comes - as indicated above - from the increase in concentration and hence the reduction in distances between vehicles. This "critical" speed can also be viewed from another angle ; above a certain flow value, if speed increases[4] with the flow, the distance between vehicles drops and braking distances increase. The recognised importance of respecting safety distances clearly underlines, in a practical manner, the notion of danger exposed here. Obviously, to be representative of a segment and comparable to other segments, this notion must be calibrated. E represents the matrix of data corresponding to measurements taken on July 27th 1996 (see fig 3). These date are divided into sub-matrices, each corresponding to a value type as below : Flow, Speed; Lane occupation index; Number of samples *i* (6-minute periods). In order to calculate the concentration :

$$\text{concentration}_i = \frac{E_{i\,0} \cdot 10}{E_{i\,1}} \qquad (8)$$

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[3] The critical capacity can be defined as the maximum number of vehicles which can drive along a given land in a given time without reducing the safety level.

[4] Or remains stationary, which only slows the process down

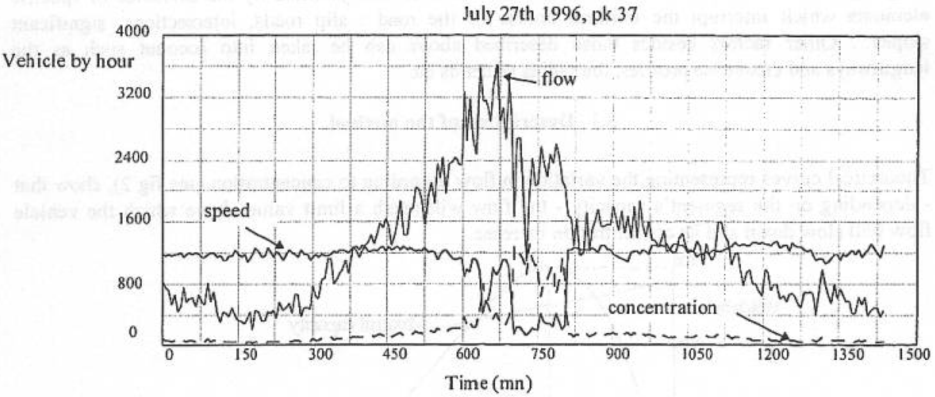

Figure 3 : Flow / speed / concentration curve

To determine the importance of the relative danger, we can use the notion of safety distance. At a given speed and flow, the equation giving the minimum safety distance between two vehicles is approximated by the formula : $Ds_i = 8 + 0.2.speed_i + 0.003(speed_i)^2$ The components of the vector Ds calculated above are the safety distances for each combined measurement of flow/speed. The next stage consists of comparing the (theoretical) evaluated safety distance between vehicles and the actual distance measured between vehicles. These values are obtained by taking the converse of the concentration (in vehicles/km) and then by converting this result into vehicle/metres; we find:

$$k2_i = \frac{1000}{concentration_i} \text{ (vehicles / meter)} \qquad (9)$$

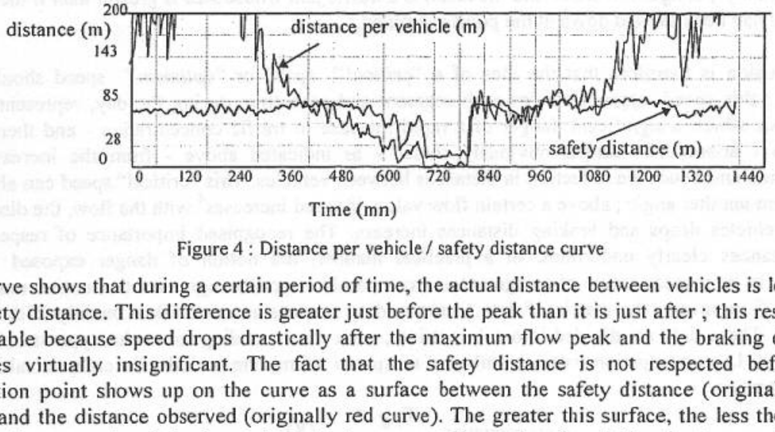

Figure 4 : Distance per vehicle / safety distance curve

The curve shows that during a certain period of time, the actual distance between vehicles is less than the safety distance. This difference is greater just before the peak than it is just after ; this result was foreseeable because speed drops drastically after the maximum flow peak and the braking distance becomes virtually insignificant. The fact that the safety distance is not respected before the congestion point shows up on the curve as a surface between the safety distance (originally blue curve) and the distance observed (originally red curve). The greater this surface, the less the safety distance is respected and the danger logically increases. We can therefore define the danger related to a drop in speed due to a traffic jam as the difference between the integrals of curves showing actual and theoretical safety distances, evaluated at their first point of intersection (generally during the beginning of the flow increase) and the abscissa point corresponding to the flow peak. Since the curve showing actual distances is based on occasional measurements, it is necessary that a calibration of this curve be carried out first, so that the integral of this curve can be calculated. This adjustment must be as precise as possible in the zone concerned by the integral. For example, we could look at the linear adjustment obtained using all the data collected throughout the day, firstly for the safety distance and then for the actual distance separating vehicles:

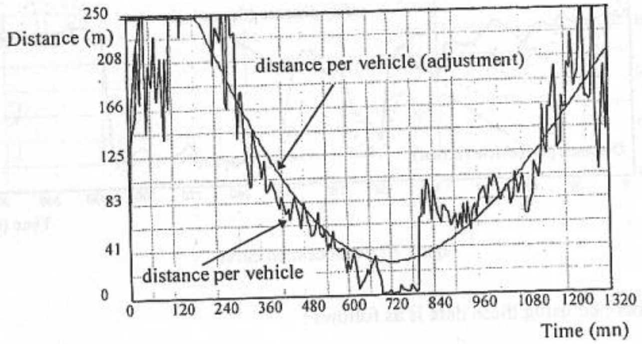

Figure 5 : Distance adjustment

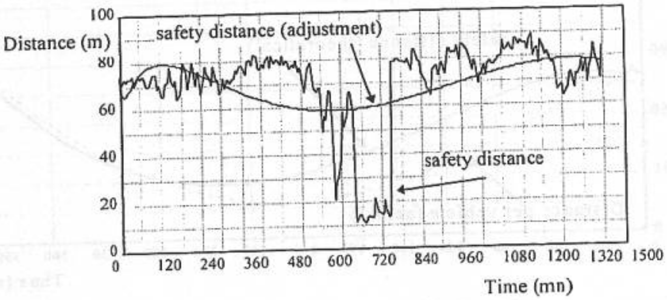

Figure 6 : Safety distance adjustment

The two graphs above show a mixed result of these linear adjustments; the adjustment of the actual distance between vehicles is satisfactory, unlike that showing the safety distance which behaves quite differently from the initial curve, in particular for the most important period, i.e. the period during which the distance between vehicles is less than the safety distance. We must therefore use a different adjustment of the curve showing safety distances, but calculated over a shorter interval, covering the time lapse corresponding to the slowing on traffic speed. We therefore create a sub-matrix consisting in the same parameters as before, but centred around the event in question.

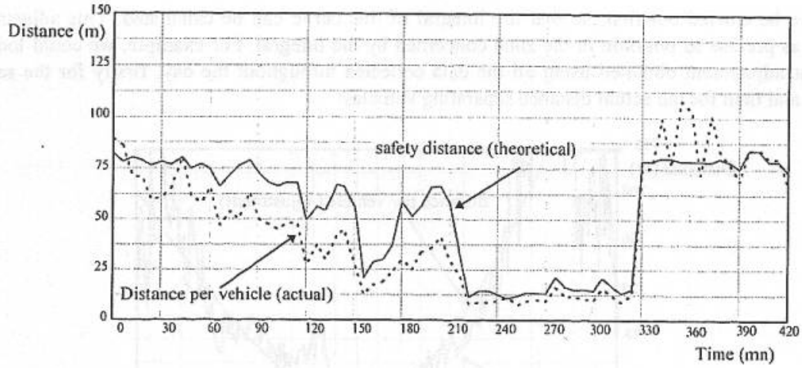

Figure 7 : Event centred curve

The calibration obtained using these data is as follows :

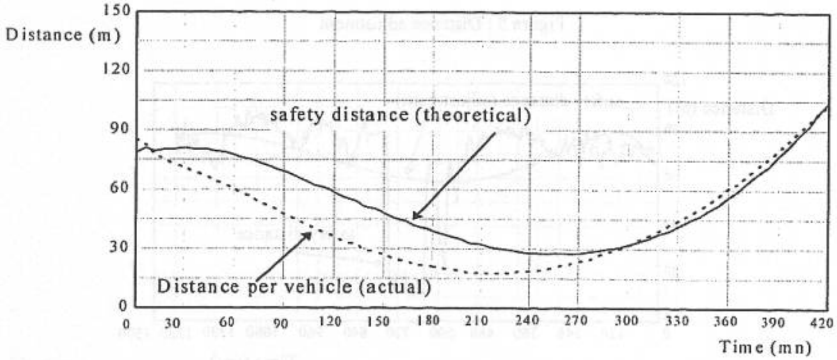

Figure 8 : Event centred adjustment curve

These adjustments are more satisfactory insofar as they are closer to the original data in the most important portion (time lapse). The risk level is straightforward: it is equal to the difference between the integrals of the two equations representing the safety distance and the actual distance.

$$f = \frac{1}{P_2 - P_1}\left[\int_{P_1}^{P_2} Z_1(x) - Z_2(x)\ dx\right] \qquad (10)$$

The risk level, as calculated here, has two meanings :

- First of all, it increases when the integration zone increases. Basically, this means a longer potential congestion period and hence a higher risk.
- It also increases with the difference existing between the safety distance and the actual distance separating vehicles.

These two characteristics of the risk level are due to the fact that integration involves calculating a two-dimensional area and that both of these dimensions influence the result.

4. INTEGRATION INTO THE COMPANY SYSTEM

At the current stage of our work, we are only having the results of our calculations validated by operations staff. Our prototype is not yet at a valid enough stage to be placed directly at the disposal of the operations staff. Moreover, we have concentrated mainly on the modelling and algorithmic aspects of the problem. Ergonomics and the man/machine interface have purposedly been left aside for the moment. However, we have attached great importance to the data concerning communications with the system. Especially as it is intended to be used by operators, the information, its formulation and the various external methods input and output are part of the language and variables used by such operators on a daily basis. Eventually, we want to evolve towards a system capable of detecting - as they happen - the points on the network where the phenomena described above are liable to arise. To do this, we use the data produced by the various counting stations as given below

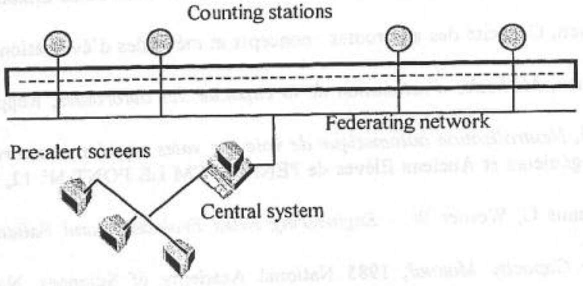

Figure 9 : Experimental system

By analysing the data describing traffic, the system detects conditions liable to favour an increase in the risk level associated with each section of the infrastructure. Beyond a given threshold, the system moves into a pre-alert phase and automatically switches the information onto a specific screen, where it is permanently displayed along with the risk level as it develops. This allows the operator to follow the evolution of traffic conditions and to decide what measures should be taken to prevent, or at least reduce, the consequences of any incidents that may arise.

5. CONCLUSION

The aim of this article is to present a method capable of combining a risk level with a motorway type infrastructure. This function is integrated into a decision-support system intended for use by operators in charge of the operation we are setting up.

In this first phase of work, we have modelled the various traffic data in order to be able to study the connections between them and with other, external parameters such as weather conditions. The next phase, the interactive processing of these data will allow them to be integrated into a decision-support system capable of signalling to the operator the various "accident-provoking" zones in view of the traffic conditions. This will be done actively.

At the current stage in progress, our work forms an approach to problems with the help of simplified models. We have checked the feasibility and the coherence of our processing. To do this, we began by setting up simulations using fictitious data selected with the operations staff. This first series of verifications allowed us to check the consistency of the results obtained with our system. We then set up a series of controls consisting of replaying actual situations. We were thus able to estimate the precision of the system's reaction.

The phase now in progress consists of refining models and processes in order to produce a genuine control panel which can be placed at the disposal of any member of the operations staff.

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