OASIS, A New Integrated Control Strategy for a Large Scale Network: Application to "Ile de France" Motorway Network

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1 Introduction and Background

Severe traffic congestion is the daily lot of drivers using the motorway network, especially in and around major cities and built-up areas. On intercity motorways, this is due to heavy traffic during holiday weekends when many people leave the cities at the same time, or to accidents or exceptional weather conditions. In the cities themselves, congestion is a recurrent problem. The control measures which are produced in a coordinated way to improve traffic performance in traffic corridors include signal control, ramp metering and route guidance (Gazis & al., 1963, Papageorgiou, 1997). With respect to the ramp metering techniques, one successful approach, for example, is the ALINEA strategy (Haj Salem & al., 1995) that prevents locally the density on the carriage way to exceed the critical value. Nevertheless, due to the synergetic effect of all metered on-ramps (they interact on each other at different time scale), it is manifest that a global and unique strategy could be more efficient that a local strategy applied to each on- ramp. Due to the lack of a general theoretical background, the non-linear nature of the traffic process, and the constraints imposed by the control measures, the extraction of the decision rules is a highly complicated and time consuming task. The optimization techniques based on the optimal control theory allow dealing straightforwardly with important non-linear features. Moreover, this approach seems promising because the control decisions are based on the minimization of an arbitrary control criterion rather than regulating towards a certain state of the process and because it considers explicitly the control constraints. The common traffic control objective incorporated in this framework is the minimization of all delays in the network by using a coordinated control strategy including ramp metering and motorway to motorway control. The numerical solution of a formulated large-scale non linear optimal control problem is effectuated by application of a non-linear optimization techniques based on the optimal control theory which is able to deal straightforwardly with non-linear features (Papageorgiou & al., 1995). Named OASIS "Optimal Advanced System for Integrated Strategy", this strategy is applied, in simulation, to a large part of the Ile de France motorway network.

The scope of this paper is the presentation of the off-line simulation results of the traffic impact of isolated and coordinated strategies applied to a large-scale motorway network. The isolated traffic responsive strategy is ALINEA whereas the new coordinated strategy is OASIS. To evaluate this approach, the macroscopic modeling tool *METACOR* (Elloumi & al. 1994) is used for simulating traffic flow phenomena in a large scale motorway network.

2 Mathematical Problem Formulation

Consider a traffic process described by the state equation:

$$x(k+1) = f\,[x(k),\ u(k), d(k)] \qquad (1)$$

Where $x(k) \in R^n$, $u(k) \in R^m$, $d(k) \in R^n$ denote the state, control and disturbance vectors respectively. In our study, the state macroscopic variables (the vector x(k)) includes the densities and speeds in corresponding segments of the motorway network links:

$$x = [\ \rho i \ \ vi\ ]^T \qquad (2)$$

Let us consider the equation (1) without *d(k)* which are supposed known.

$$x(k+1) = f\,[x(k),\ u(k), k], \qquad k=0,...,H \qquad (3)$$

With an initial state: $x(0) = x_0$

In the METACOR model, f is a twice continuous differentiable vector function. The equations relatives to the computation of flows and speeds can be found in (Elloumi & al. 1994).

A global control strategy aiming at system optimum minimizes a specific global cost function (Papageorgiou & al., 1995 and 1997). This function can be the total travel time spent in the network during a defined time horizon. One can also use any function that characterized whatever we want to minimize or to maximize (reduction of pollution, reduction of the risk of accident, etc.) or a combination of these different cost functions. For our example, we choose to improve the transport efficiency, by using a cost criterion J that includes the total travel time (a) and waiting time at origins (b):

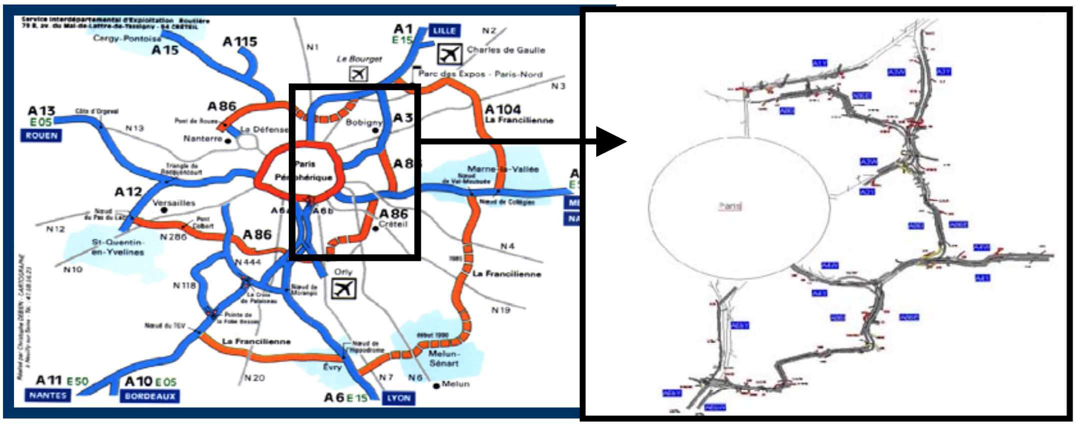
$$J = \sum_{k=0}^{H} \left[\underbrace{T \sum_{l=1}^{L} \sum_{s=1}^{S} \rho_{l,s}(k).\,\Delta_{l}.\,\lambda_{l}}_{(a)} + \underbrace{T \sum_{o=1}^{O} w_{o}(k)}_{(b)} \right]$$

Where H, L, S, O denotes respectively the horizon, the number of links, the number of segments in each link, and the number of origins respectively. The terms Δl, λl and *wo* denote the length of the link *l,* the number of lanes, and the number of vehicles in the queue at the origins *o* respectively.

The control variables are characterized by a set of control trajectory $u(k)$, $k=0,\ldots,H$, such that $u(k) \geq Umin$ *and* $u(k) \leq Umax \leq 1$. Let us denote $ql(k)$ the outflow at time k of the link l. We denote $u(k)\,ql(k)$ the controlled outflow for the link l. In the case where $\{u(k)=1\}$, the outflow $ql(k)$ is not controlled, elsewhere we have $u(k) \times ql(k) < ql(k)$. Although expressing a dynamic physical procedure, the above formulated problem is, from a mathematical point of view, a static optimization problem due to the discrete-time nature of the involved process. The algorithm uses to minimize this cost function J can be any non-linear optimization algorithm such the basic steepest gradient descent or a quasi-Newton method (BFGS). In our example, the RPROP algorithm (Riedmiller & al., 1993) is used and known to be a fast and simple algorithm.

The developed optimization algorithm has been implemented in the kernel of the simulation tool METACOR. In order to close the control loop, the hierarchical control scheme was applied. In particular, the rolling horizon technique was implemented in OASIS.

3 Test Site Description



Geometry: The considered network in this study is in the East part of the Ile de France motorway network. The test site covers around 250 km long and includes nine main motorways: A1Y, A3W, A3Y, A4W, A4Y, A86I, A86E, A6bY and A6W. The whole considered network comprises 70 on-ramps. In this study, among the 70 on-ramps, only 50 will controlled. These 5à on-ramps include 20 motorway intersections where the motorway-to-motorway control (MTMC) has been applied.

Traffic Condition: The considered test site is the most critical traffic area of the overall Ile de France motorway network. The recurrent congestion is extended over several hours of the day. The congestion phenomena are observed regularly during the rush hour in particular on the A86I, A86E and A4W motorway axis.

4 Off-line simulation studies

In order to judge the relevance of the control settings in a realistic traffic environment, the macroscopic simulation tool METACOR is used. METACOR is based on a macroscopic, dynamic modeling philosophy. Traffic flow is considered as a fluid with specific characteristics. Motorway traffic flow is described by a second-order flow model. Urban traffic flow is described by a first-order flow model with particular attention being paid to the junction phenomena. Sub-flows of vehicles with common destination are explicitly taken into account, and propagated along the network links. At motorway bifurcation and road junctions the sub-flows are splitted according to the splitting rates provided.

The first step is the model calibration and validation. Constant parameters included in METACOR model equations reflect particular characteristics of a given traffic system depending upon street geometry, vehicle characteristics, drivers behavior etc. Constant parameters should hence be specified so as to fit a representative set of real data with maximum accuracy. The estimation of the unknown parameters for the METACOR model is nontrivial task since system equations are highly non-linear in both the parameters and the state variables. The most common approach for the identification of non-linear systems is the least squares output error method which minimizes the discrepancy between the model and the real process with respect to some quadratic output error functional. The procedure is based on the "complex" method of M.J. Box,1956. This method is a sequential search technique which has proven effective in solving problems with non-linear objective functions subject to non-linear inequality constraints. No derivation is required. The procedure should tend to find the global minimum due to the fact that the initial set of points are randomly scattered throughout the feasible region. According to the considered large scale test site, the calibration and validation process was confronted to several problems. In particular, the wrong and false real data collection was the critical one. In order to achieve this step in comprehensive way, the considered test site was splitted in 9 axes. The calibration and validation process was applied to each one.

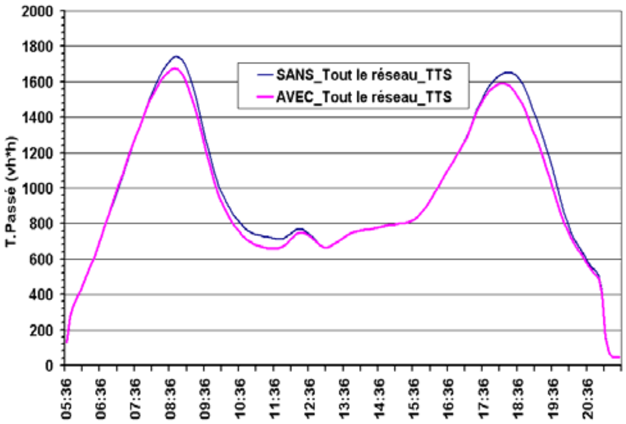
The second step is model validation on the overall considered test site. The mathematical model is applied to traffic data different from ones used for parameter estimation. In particular, accuracy of the model should be investigated under several traffic conditions ranging from fluid flow to severe congestion at different times of the day. Despite the large scale of the considered motorway network, the obtained results indicate that METACOR reconstitute the congestion in space and time with an acceptable accuracy.

The last step is the control strategies evaluation. Several simulation runs with realistic demands (based on real data) has been performed aiming at evaluating the traffic impact of isolated and coordinated ramp metering strategy named ALINEA and OASIS respectively.

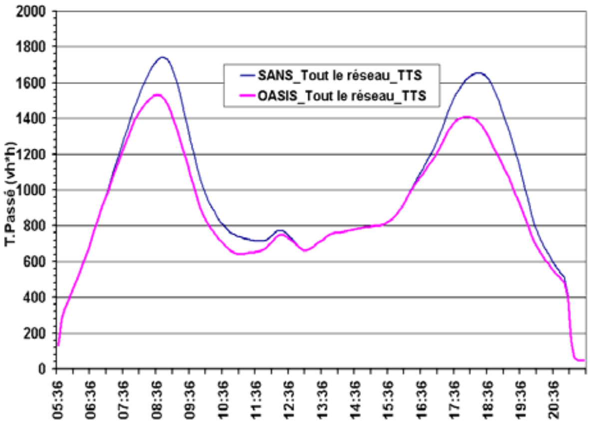
For all investigated scenarios, the simulation starts and finishes under free flow conditions; i.e the corresponding demand is always served. Under these conditions, the index TTD takes same values for all scenarios, hence the comparison may be based on the TTS index only.
The following scenarios are tested:

- No control (reference)
- ALINEA (isolated strategy)
- OASIS (Coordinated strategy)

With respect to the traffic impact, compared to the non control case, the isolated control strategy improves the total spent in system by around 3 %. In case of the integrated strategy, the improvement of the TTS index is multiply by a factor 3. More details can be found in Haj Salem H.,(2002).



ALINEA vs No Control



OASIS vs No Control

5 Conclusions and Next Steps

The application on a large scale network including 50 ramp-metering controls and 20 motorway-to-motorway control is promising in terms of traffic performances and computational effort. This algorithm is the first step for the on-line use of the coordinated control algorithm in a real world application. As final objective, the association of a robust and fast model for forecasting the demands at associated origins to the coordinated and integrated control algorithm will yield a powerful and efficient tool for a large scale motorway traffic control.

In frame of the work plan of the European Project “EURAMP” (2004-2006), the implementation of OASIS is planed on a limited part of A6 motorway including 6 consecutive on-ramps. After the real life evaluation process in term of traffic impact and implementation devices and software development, the generalization of the ramp metering technique on the Ile de France motorway network will be decided.

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