The role of Computational Intelligence in Integrated Traffic and Air Quality Management – Feasibility Results

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Extended Abstract

Authorities world-wide have to deal with an increase in demand on existing urban transport infrastructures while sustaining high standards of air quality. The management of urban transport systems and their associated air pollution are a key challenge to the development of cities of the future. Innovative solutions are required in order to overcome these challenges.

A common way of dealing with large urban transport infrastructures is by using Urban Traffic Management and Control (UTMC) systems [1][2]. The UK Department for Transport led Urban Traffic Management and Control initiative recognizes the following common UTMC components: strategic network management, comprehensive performance monitoring, traveler information, congestion monitoring, streamlined fault management, and consolidated asset management [3].

A first approach to controlling the traffic in an urban environment involves the analysis of the environment to generate a static model for specific times such as the morning (AM) peak and evening (PM) peak. These static models are then used to plan traffic light signaling scenarios [4]. None of these components is directly incorporating air quality near real time measurements or statistics into the decision making and control systems. The UTMC collects information about the current situation in the urban environment, such as traffic flow and delay via inductive street loops, car park information, and CCTV feeds from throughout the city. This information is made available to traffic engineers monitoring and managing the network. They can then influence the network by implementing alternative traffic light signaling strategies, informing drivers via variable message signs or on-line or radio information services. Engineers can resolve or ease situations during peak hours, or in the event of car accidents, full car parks, large fires, congestion, special events, etc. Although in theory the collected information enables the traffic engineers to react to a variety of situations, most often, only a few standard traffic light configurations are used for any region in the urban environment. This is because traffic light signaling in a large urban network is an extremely challenging task where a small change can have a big impact on the whole network [4]. Standard traffic light signaling configurations are carefully designed using a variety of techniques from modelling, micro-simulation, macro-simulation, and ``green wave" offset adaptation [5][6]. These static models are then manually revised over time from experience of the traffic engineer. Systems such as SCOOT further adapt some aspects of the traffic light signaling [7].

However, almost all such systems lack the direct inclusion of near real time air quality measurements as part of their control or decision making support. Traditionally, air quality and traffic management issues have been considered mostly in isolation, only cooperating to solve specific well defined problems. While some new systems exist that support traffic engineers to make decisions to improve both traffic and air quality, this is typically high level only. One reason for this is the large number of objectives an engineer needs to consider when implementing a potential solution. Such objectives include finding a robust near optimal travel time, flow, delay and stops throughout the network now and in the near future as well as the minimization of various pollutants. In a large network this quickly becomes a problem with thousands of related objectives.

The ultimate goal of urban traffic and air quality management is the automatic, adaptive, dynamic and optimal traffic control, delivering optimal robust traffic and air quality related objectives. Computational Intelligence (CI), also known as soft computing, is related to Artificial Intelligence and is a collection of "intelligent" methods including fuzzy logic, artificial neural networks and evolutionary computing. CI techniques have revolutionized a number of fields including control engineering [8], medical diagnostics [9, 10], decision making [11], modelling [12] and many others.

In traffic and air quality management, CI can deliver a number of enhancements to the current state of the art. The iTRAQ - Integrated Traffic Management and Air Quality system is a near-real-time system to optimise the use of the road network balanced with the need to sustain high standards of air quality. iTRAQ uses a number of inputs that enable it to sense the current situation in near-real-time and provide accurate forecasts using a computational intelligence module. Traffic flow, queues, and congestion are gathered using traditional ground-based sensors through the UTMC. Air quality information is obtained from in situ monitors, a City-wide Gaussian dispersion model (Airviro), a European-scale ensemble model (MACC), and direct measurements from low-earth orbit satellites (OMI and GOME-2). In addition, the system also reads and uses meteorological measurements such as precipitation, wind speed and direction, air pressure, cloud coverage and temperature.

The iTRAQ system has been designed around a CI module made of a series of advanced neural networks and genetic algorithms for finding the optimal traffic and air quality solution for Leicester City. Many of the data feeds in the iTRAQ system are designed to provide information to the CI or to transfer results from the CI to a series of analysis algorithms to assess the performance of the system. The iTRAQ architecture has evolved throughout the iTRAQ feasibility study. The resulting architecture is shown in Fig. 1 and described here in more detail.

The iTRAQ system uses a variety of data feeds together with a CI module, air quality model and traffic simulator, to arrive at an optimised strategy for simultaneous traffic and air quality management. This is achieved by taking all current related measurements, filtering [13] and feeding them to Artificial Neural Networks which in turn have been trained as time series predictors.

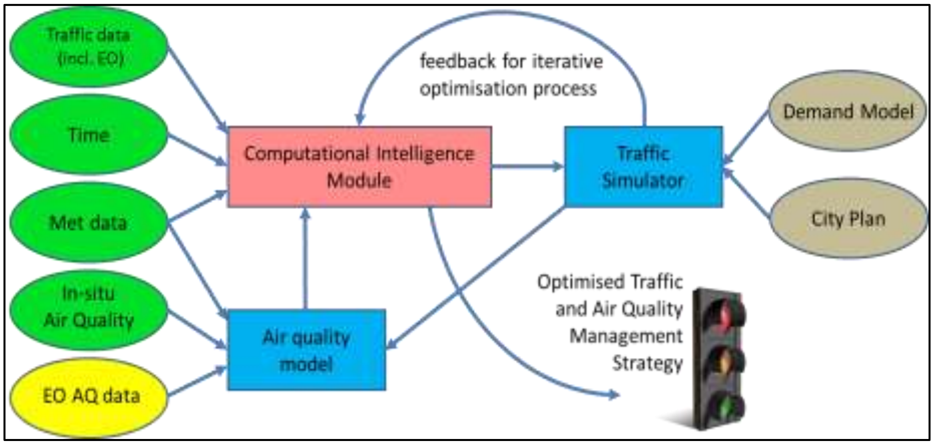


Figure 1 – Overview of the iTRAQ system

Each Artificial Neural Network predicts the flow and delay on each link based on related parameters including previous flow and delay, neighboring links' flow and delay and meteorological readings. Additionally, separate Artificial Neural Networks have been trained to predict pollutant levels for the same links. This information is then being used by an Evolutionary Computation technique to iteratively and efficiently search through the large search space that consists of all possible traffic light signal timings, searching for the solution that best satisfies all given objectives.

The proposed system has been tested in a region of interest consisting of 20 roads around the A6 London Road in the city of Leicester, UK. The A6 is a major arterial road for the city that regularly experiences large amounts of traffic, reduction of flow, increase in delay, and congestion. This particular road has been subject to previous research in traffic as well as air quality optimization [14] [15]. This paper gives an overview of this novel system and presents some initial test results that confirm the feasibility of this integrated system, reducing the traffic delay, increasing the flow and optimizing the local air quality levels.

The system was tested in near-real-time proposing optimized strategies to Leicester City Council for over two weeks. The following constraints were deemed acceptable for the purpose of testing the feasibility of the overall iTRAQ system.

- The system was operational from Monday to Friday from 07:00 to 18:00 each day for two weeks.
- The system suggested optimized traffic and air quality strategies within one hour.
- The traffic signaling strategies of two junctions were optimized, suggesting cycle times, individual stage times, and offsets for both junctions.
- The system has been tested on junctions of a major arterial road.

During this feasibility study, no strategies were directly tested on the junctions but in simulation only. Nevertheless, actual near-real-time data feeds were used to test the operational system as if it would be fully integrated and operational, providing optimized traffic signaling strategies to the traffic engineers in near-real-time. The iTRAQ system has been tested and the quality of the forecasts as well as the proposed optimized strategies have been evaluated.

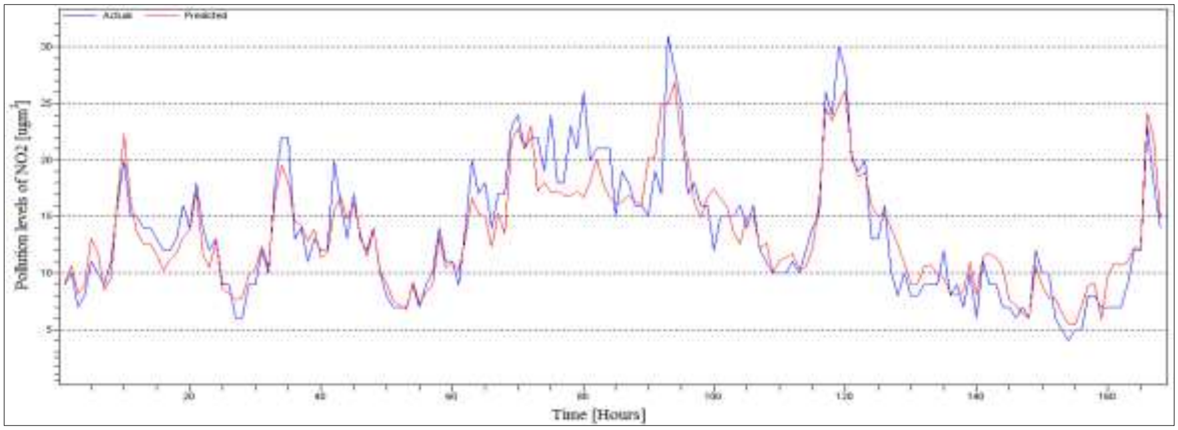
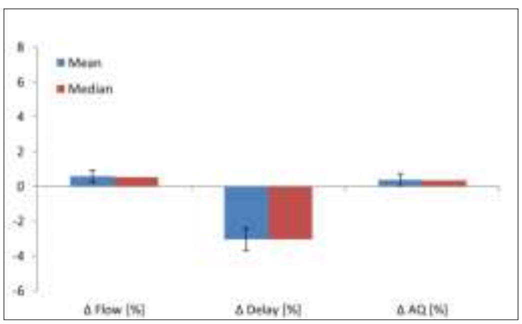
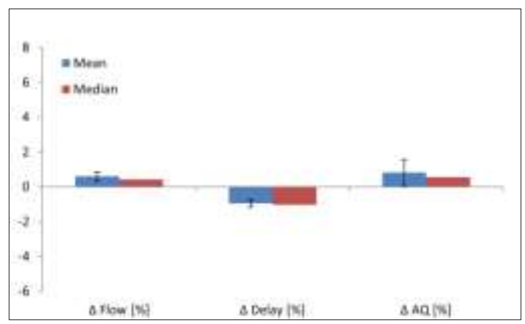


Figure 2 - Graph of Artificial Neural Network based hourly pollution forecast (red = Predicted) together with Airviro readings (blue = Actual). Forecast and data are from the A6 London Road, Leicester, UK from data collected in 2011. Average error: 1.6 ugm^3.

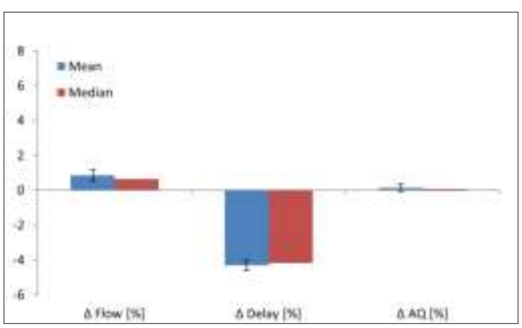
Based on predictions, such as the one shown in Figure 2, the system efficiently searched for solutions that would present near-optimal solutions satisfying the objectives. The four graphs in Figure 3 show the level of enhancements as found through simulation using the iTRAQ system in near real time with real data.



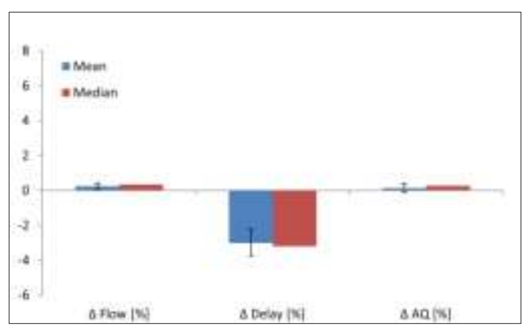
a) Average over all operational hours



b) AM peak - 8 to 9 o'clock



c) Inter-peak – 12 to 13 o'clock



d) PM peak – 16 to 17 o'clock

Figure 3 – System optimizing signal timings for two junctions in Leicester, UK, (a) over all operational hours (7 AM to 6 PM), (b) during AM peak hour (8 to 9 AM), (c) during the day (12 to 1 PM), (d) during PM peak hour (4 to 5 PM) during the demonstration period. Values are given in percent change from prediction.

Traffic engineers were asked to review the iTRAQ system's output. The engineers confirmed the system to consistently work well, producing suitable solutions in each case.

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