

INTEGRATION OF TRAFFIC MANAGEMENT AND AIR QUALITY CONTROL (iTRAQ)

Stefan Gustafsson, Norbert Hübner
European Space Agency

Benjamin N. Passow, David Elizondo, Eric Goodyer, Yingjie Yang
De Montfort University

Roland J. Leigh, James P. Lawrence
University of Leicester

Satish Shah, Jolanta Obszynska
Leicester City Council

Sarah C.M. Brown, Andrew Groom
Astrium GEO-Information Services

1. INTRODUCTION

1.1 Background

An efficient road traffic system is of high importance to our society. Many local authorities face a challenging situation with a steady increase in road traffic, leading to congestion and longer travel times. This is despite measures to reduce congestion, e.g. by improving the traffic control, implementing road tax systems, and stimulating use of public transport and other alternatives. As a result of congestion, fuel consumption increases together with emissions. In particular during peak hours, the emissions found in cities often exceed acceptable local, national, and European limits.

Maintaining an acceptable air quality is high on the agenda for communities. Studies suggest that air pollution results in about half a year of reduced life expectancy and cost UK society up to £20 billion per year [8]. Significant benefits could be reached in both human and economic terms if air pollution levels can be reduced.

Although road traffic is a main contributor to air pollution, traffic optimisation and air quality improvement are often regarded separately from each other and usually fall under the responsibility of different units within the authorities. iTRAQ, Integrated Traffic Management and Air Quality Control, is a service that seeks to jointly

optimise the control of road traffic and air quality. It is novel in making use of space assets as well as terrestrial data sources.

1.2 Approach

iTRAQ combines inputs from both existing terrestrial (such as road loops and air quality monitor stations) and space based sensors (earth observation satellites and satellite navigation data). Computational intelligence is employed to find the optimal way of controlling traffic lights for improved traffic flow while minimising pollution levels.

The concept has been implemented and tested in the course of a feasibility study funded by the European Space Agency within its Integrated Applications Promotion (IAP) programme (<http://iap.esa.int>), which is a programme that works across all civil market sectors to encourage integration of space and non-space assets in order to deliver new services that meet every day needs. The overall ambition of the IAP programme is to generate sustainable space based services based on a user driven approach. The feasibility study was carried out by a team of academic, industrial, and local authority partners, namely De Montfort University, University of Leicester, Astrium, and Leicester City Council.

The overall goals of the project were to analyse the technical feasibility as well as the economic and non-economic viability of the iTRAQ service. Furthermore, the project aimed to propose a way forward for demonstrating the services and the associated system in a pre-operational manner and for making the service commercially available. It included a limited Proof of Concept demonstration in the city of Leicester, UK. The feasibility study was successfully concluded and delivered promising results. It is currently being followed up by an extended Proof of Concept testing the system in the city of Northampton, UK.

In the rest of this paper we first give more background information on urban traffic management as well as air quality management. Then the iTRAQ service is presented together with results from the Proof of Concept. Finally we explain how this concept is intended to be brought to the market to be available to local authorities in need for improved traffic and air quality management.

2. URBAN TRAFFIC MANAGEMENT AND CONTROL

A common way of dealing with large urban transport infrastructures is by using Urban Traffic Management and Control (UTMC) systems [3, 6]. A first approach to controlling the traffic in an urban environment involves the analysis of the environment to generate a static model of traffic patterns for specific times such as

the morning (AM) peak and evening (PM) peak. These static models are then used to plan traffic light signalling scenarios [5].

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 camera 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 signalling strategies, informing drivers via variable message signs or using other information channels like the internet or radio. Engineers can resolve or ease situations during peak hours, or in the case of events such as 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 signalling in a large urban network is an extremely difficult task where a small change can have a big impact on the whole network [5].

Standard traffic light signalling configurations are carefully designed using a variety of techniques from modelling, micro-simulation, macro-simulation, and "green wave" offset adaptation [2, 4].

3. AIR QUALITY MANAGEMENT

Atmospheric constituents which have the potential to harm human health are generally referred to as air pollution. In the UK urban environment there are a range of pollutants in the atmosphere with the capacity to cause harm to both humans and the ecosystem, including carbon monoxide, nitrogen oxides, sulphur dioxide, particular matter, volatile organic compounds, ozone, and hydrocarbons.

Within the UK, as in the rest of Europe, air quality directives are cascaded down from the European Union, providing a structured framework of compliance levels for key pollutant species. The UK government and its local authorities operate a number of systems for monitoring and predicting air pollution, including automatic and manual air pollution monitors, emission inventories and a number of computer models including ADMS-Urban, the national model and the UK Integrated Assessment Model (UKIAM). These tools are used to inform policy makers and developers of the impact of various strategies in order to help reduce air pollution and the population's exposure to it.

The UK government currently operates over 300 national air quality monitoring sites to monitor and manage ambient pollutant concentrations [7]. Air pollution in urban environments remains high on the agenda of the government and local authorities, particularly given increasing urban populations and greater congestion on the already overcrowded traffic networks. Recent epidemiological studies suggest that at present air pollution results in an average 7 month reduction in life expectancy and costs UK society up to £20 billion per year [8].

Measures to improve air quality on the local scale are now very much focused on optimisation of traffic network utilisation by promoting cycling and public transport through park and ride services and bus lanes. In addition, strict requirements on vehicle emissions filtered down from the EU and a road tax system focused on vehicle emissions have helped to reduce air pollution from traffic (although to a lesser extent than expected). However the steadily increasing volume of traffic on city roads is believed to be partly compensating for this improvement [8].

Despite the local, national and European objectives to improve air quality the majority (40 out of 43) of the UK's regulation zones are failing to meet the EU standards on at least one of the regulated gases. As such additional and alternative approaches to improving air quality must be adopted, and one such approach is the optimisation of the traffic system with air quality as a driving element (iTRAQ).

4. THE iTRAQ SERVICE CONCEPT AND ARCHITECTURE

iTRAQ is designed to meet local authorities' needs in the areas of traffic and air quality management. While investigating the needs with local authorities, it was found that there was also a requirement to set traffic lights such that response times for emergency responders are improved, for example when fire and police vehicles need to pass quickly from one place to another. Among the key requirements addressed by the service are:

- Delivery of real-time information on traffic flow, delay, and congestion throughout the urban network.
- Delivery of real-time information on pollution levels throughout the urban network.
- Delivery of forecast information on traffic conditions and pollution levels.
- Delivery of optimised real-time traffic light settings on strategic routes, such that the travel time is improved while congestion target limits are maintained and air quality targets are met.

The information is delivered as a data stream to the present traffic management centre. Since traffic light timing is normally altered only by experienced traffic engineers, the solution would first provide advice to these engineers. However, it is also foreseen for iTRAQ to automatically control the traffic light timing in the future.

As illustrated in Fig. 1, iTRAQ makes use of a number of inputs. It takes data from existing sensors, for example

- Inductive loops already present in some roads to detect passing vehicles.
- Air quality road-side monitors, measuring various pollutants.
- Local meteorological data such as temperature, cloud coverage, air pressure, wind speed and direction, and precipitation.

In addition, more advanced solutions may be used to provide additional input on air quality. For example, CityScan (see e.g. [9] and [10]) is a type of air quality sensor developed by the University of Leicester which can be placed at roof-tops around the city to provide a three dimensional view of the air quality.

One novel aspect of iTRAQ is that data directly or indirectly coming from space based services are also used:

- From sensors on-board earth observation satellites information about the background level of pollutions can be derived. For iTRAQ, data from a model called MACC (Monitoring Atmospheric Composition and Climate) were used, which make use of data from OMI (Ozone Monitoring Instrument [11]) and GOME-2 (Global Ozone Monitoring Experiment [12]) sensors mounted on the Earth Observation satellites EOS-AURA (NASA) and METOP (Eumetsat).
- Feeds from positioning data obtained by using GNSS (Global Navigation Satellite System) services help estimating traffic flow and congestion, especially in areas and on roads where no inductive road loops are available. Such data can be made available e.g. from busses or other vehicle fleets equipped with real-time position reporting. Near real-time GNSS data are often also commercially available e.g. from companies that provide positioning or tracking solutions for large vehicle fleets.

All types of inputs are fed to a computational intelligence module made of advanced neural networks and genetic algorithms for finding the optimal traffic and air quality management solution. This works together with a traffic simulator in an iterative

manner that tests various strategies for controlling the traffic lights in simulation to finally provide and recommend enhanced traffic light settings.

Generally it holds that the more and varied the data sources used for iTRAQ, the better the recommendations for traffic light settings provided to the traffic engineers. This approach makes iTRAQ very flexible, since it can easily be adapted to various cities, making use of current infrastructure and taking new sources into account, as they become available.

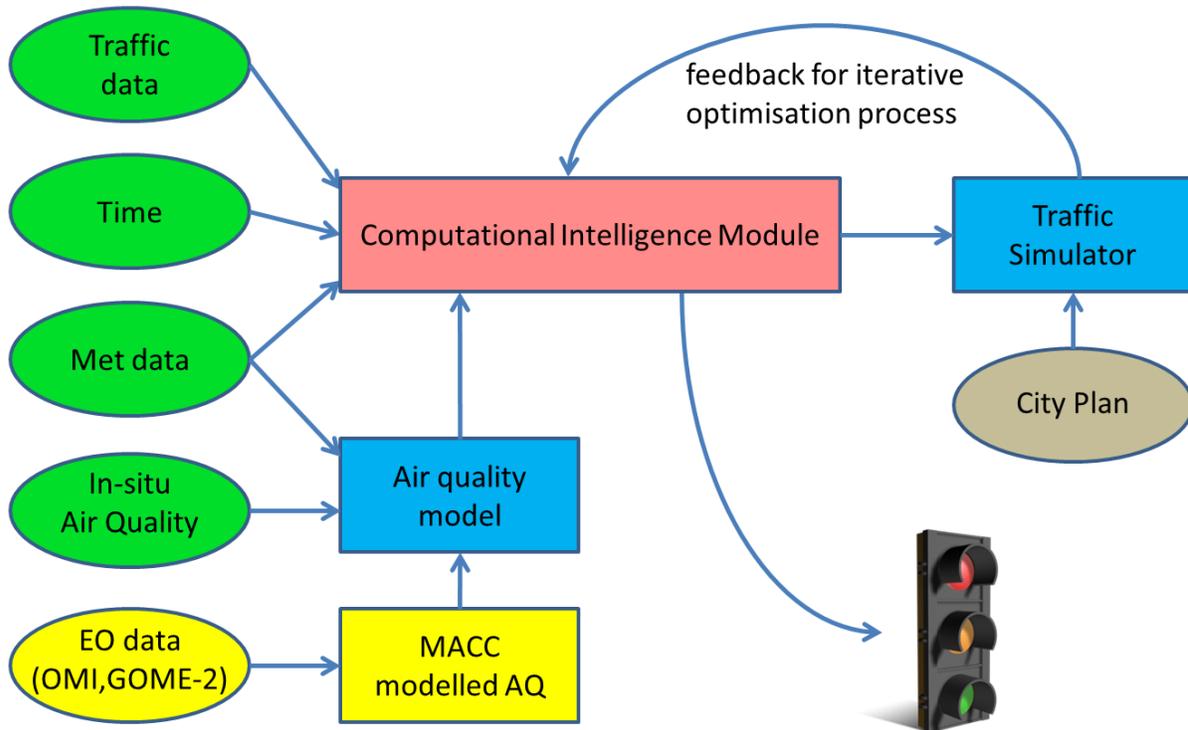


Figure 1: Overview of the modular iTRAQ architecture with data feeds

5. THE PROOF OF CONCEPT

5.1 Setup

In order to validate the concept of iTRAQ, to verify the design of algorithms and interfaces, and to gain experience in integrating iTRAQ in an operational environment, a Proof of Concept demonstration took place. Fig. 2 shows the region of interest for the Proof of Concept, which consists 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 traffic flow, increase

in delay, congestion, as well as high pollution levels. Within the region of interest, two junctions along the A6 London Road were selected for the analysis. Fig. 3 shows the bigger of the two junctions (“I” in Fig. 2) optimised in this work together with its traffic light signal stages and default timings for the AM and inter-peak periods.

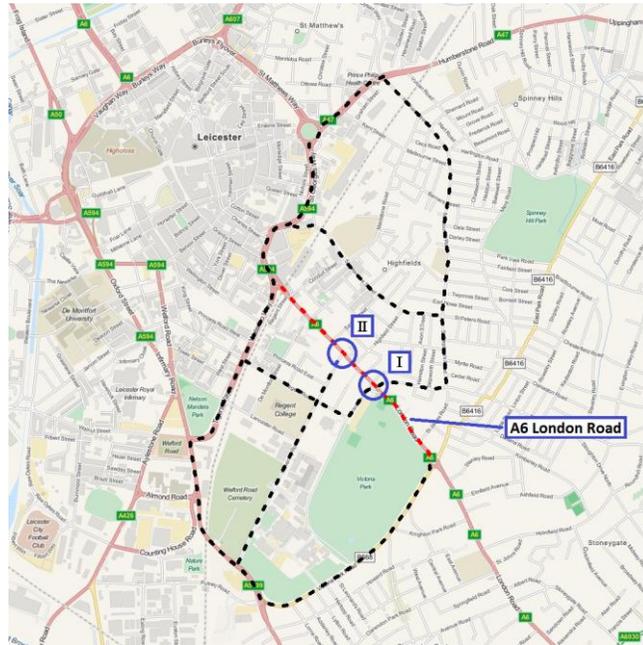


Figure 2: Region of interest in the city of Leicester, United Kingdom

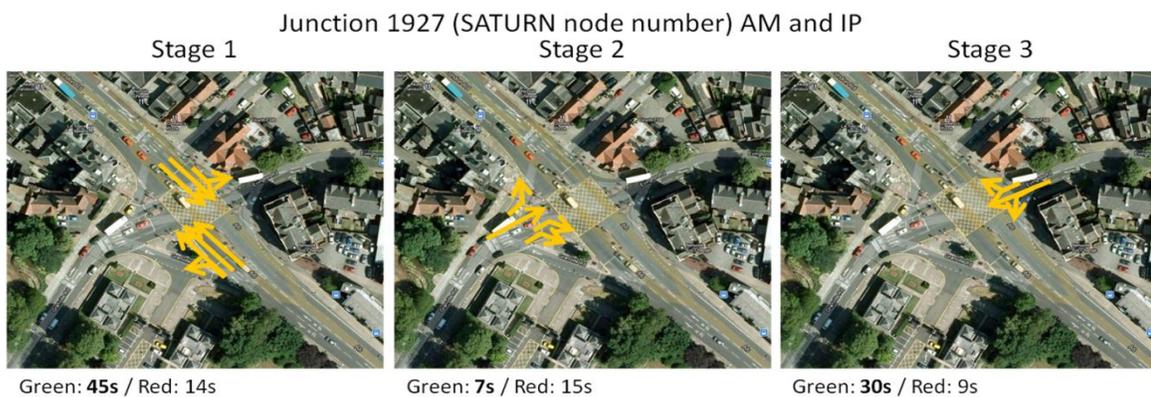


Figure 3: Traffic light signal stages with their default timings for AM (morning) and inter-peak periods, for one junction on the A6 London Road, as optimised in this work. (Background image source: GeoPerspectives)

The system was tested in near-real-time proposing optimised 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 17:00 each day.
- The system suggested optimised traffic and air quality strategies within one hour.
- The traffic signalling strategies of two junctions were optimised, suggesting cycle times, individual stage times, and offsets for both junctions.
- Input data sources were street loops, MACC, and meteorology forecasts based on in-situ sensors.
- No traffic light 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 optimised traffic signalling strategies to the traffic engineers in near-real-time.

5.2 Results

The quality of the forecasts as well as the proposed optimised strategies were evaluated. Forecasts of traffic and air quality are directly vital parts of the iTRAQ system, as well as important outputs for the users. The quality of the outputs is relative to the quality of the inputs and the amount of training data.

Fig. 4 shows the traffic flow forecasts made during one week (Monday to Sunday) and actual measurements as taken during the forecasted time periods. The forecast was always for one hour ahead. As can be seen, the forecasts match the overall shape of the actual readings, even on weekend days.

Fig. 5 shows the mean per cent error and standard deviation of the traffic flow condition forecasts on different road links in the region of interest and during the near-real-time operational test run. Eighteen forecasters have an average error between 4% and 10% and a median error between 3% and 7%, while the other two have significantly larger errors. These two forecasters exhibited adequate outputs, similar to previous outputs and that of other forecasters. At the same time, the actual readings they are measured against, the street induction loop data, suddenly changed dramatically out of proportion. As a result, the error, measured as the

difference between forecasted and actual, increased accordingly. On closer inspection of the corresponding near-real-time data feeds it became apparent that these induction loops experienced some sort of fault, providing flow data that were outside the road links flow capacity limits. Interestingly, the overall iTRAQ performance for the periods where the system received this suspicious data showed no significant change in the quality of the outputs, confirming the robustness of the iTRAQ system architecture.

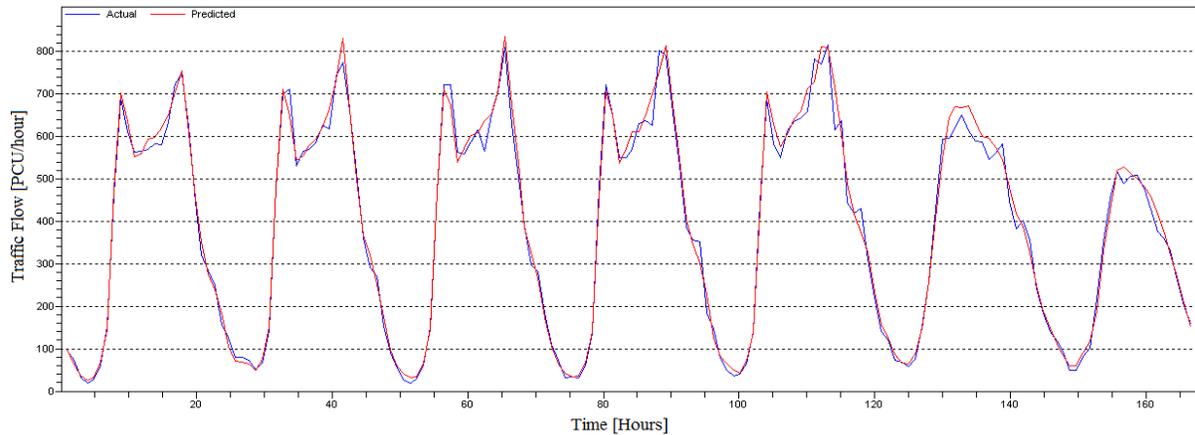


Figure 4: Graph of traffic flow condition forecasts (for one hour ahead) for one week (Monday to Sunday) together with actual measured readings from the forecasted time period. Forecaster based on large training data set. Forecast and data are from the A6 London Road. Average error: 18.9 Passenger Car Units (PCU)/hour.

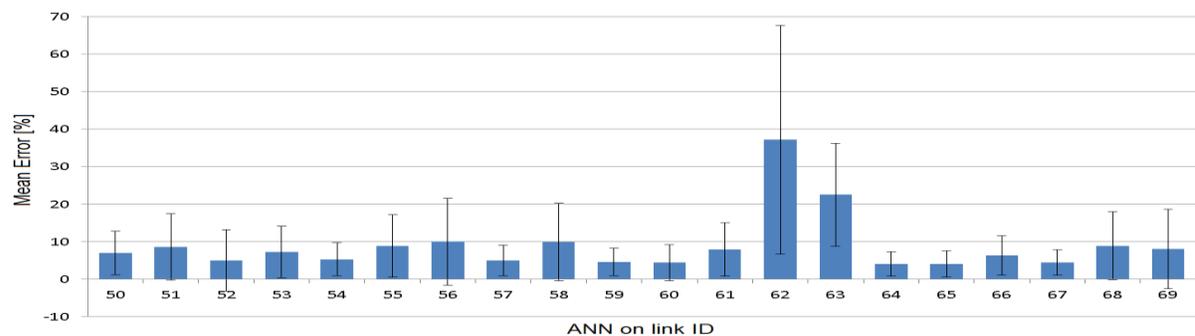


Figure 5: Mean per cent error and standard deviation of traffic flow condition forecasts of 20 road links (IDs 50 to 69) in the region of interest and during the near-real-time operational test run. Note the high error on two links, caused by faulty readings from the induction loops.

The air quality forecasts occasionally gave somewhat larger errors, but still the average mean error was 25% or better for any road link in the area of interest.

The near-real-time iTRAQ system successfully supplied traffic engineers with traffic and air quality forecasts and proposed traffic light signalling strategies that in simulation optimised the traffic and air quality throughout the region of interest concurrently.

Test results showed a clear reduction in the mean traffic delay of over 3%. In addition, the optimised strategies offered an increase in traffic flow for 89% of the time with a mean increase in traffic flow of 0.6%. An increase in flow means that more cars can get through the network in the same amount of time. The reduction of delay together with the increase in traffic flow presents a reduction of average journey time.

Interestingly, the tests also showed a small increase in mean pollution levels. Here two effects need to be understood. On the one hand, a decrease in delay directly decreases the fuel consumption and thus a decrease of pollution levels is expected. At the same time, an increase in flow has the opposite effect, letting more cars through the network and hence increasing fuel consumption and pollution levels. Therefore, there is only a small change in overall pollution levels. Nevertheless, Leicester City Council's traffic engineers confirmed this to be a positive result as an increase in flow effectively reduces the overall peak duration and thus reduces the duration of the pollution peak as well.

Note that the presented results have been achieved using only two neighbouring junctions within the much larger region of interest. Generally, the more junctions are simultaneously optimised the better the improvements are expected to be.

6. VIABILITY AND WAY FORWARD

The iTRAQ feasibility study also looked into the economic and non-economic viability of iTRAQ and how it can be brought to the market. A market analysis was undertaken, showing clear evidence that iTRAQ's core objectives - traffic management and air quality management - are closely linked with major policy issues and directives, which can thus both be addressed by the service. Work still needs to be done to assess to which extent iTRAQ is able to address the full suite of local authority requirements.

In a first instance, iTRAQ is aimed for the UK where a number of medium sized cities face similar traffic and air pollution problems. In the UK, the level of sophistication of traffic management systems in use today is quite diverse. Some authorities already have some components in place to make iTRAQ work efficiently while others would require an in-depth overhaul of their traffic management systems.

In addition, preferred solutions for delivering the service may also differ from one authority to another. For example, whereas one authority may prefer to buy a fully automated iTRAQ system and operate the solution on its own, another may wish to only receive forecast data and traffic light advice as a service. This means that iTRAQ would have to be customized for each user. By means of a flexible concept, iTRAQ can make use of a variety of input sources to the computational intelligence module, which match the local environment.

To assess the economic viability of offering iTRAQ as a service, different types of iTRAQ implementations were therefore considered, varying in degree of complexity and how the service is operated. These formed the basis for a number of financial projections.

Regarding non-economic viability issues, a point of attention was that within many authorities, traffic and air quality issues are handled by different divisions, which could pose a programmatic barrier to service take-up. Legal and regulatory issues were also studied. In enhanced versions of iTRAQ making use of comprehensive data feeds for example from road pricing systems, especially data security will need due attention.

To gain more experience in integrating iTRAQ and adapting it to another environment, an extension project (iTRAQ-X) is currently being executed to implement and test the iTRAQ system in the city of Northampton. This tests the system on a significantly larger area, influencing a much larger proportion of the traffic lights and also integrating GNSS-based vehicle data feeds. The results from this study should be available towards the end of 2012. Discussions are also on-going for starting a large-scale demonstration of iTRAQ in the frame of an ESA IAP Demonstration Project. This would permit entire regions to be optimised by iTRAQ and could eventually lead to iTRAQ proposed strategies automatically being implemented for a truly adaptive and optimal traffic and air quality management system.

7. SUMMARY

The feasibility study confirmed that iTRAQ is a technical feasible and a viable concept. A limited Proof of Concept delivered promising results and tackled a number of integration challenges. The inherent flexibility makes it suitable to be adopted to various local environments making use of present data sources and limiting the level of customisation needed for authorities.

More information can be obtained from

- The project's dedicated webpage on ESA's IAP web-site, available at: <http://iap.esa.int/projects/transport/itraq>. Information on other IAP-sponsored projects and how to apply for funding can be found on the following website: <http://iap.esa.int>.
- The Final Report of the iTRAQ Feasibility Study, available for downloading from the IAP web-site [1].
- ESA or any of the project partners: Leicester City Council, University of Leicester, De Montfort University, and Astrium UK (please see the project web-page for contact details).

Bibliography

- [1] *iTRAQ: Final Report*, May 2012, available from <http://iap.esa.int>
- [2] Bell, M. G. H., *Transport Planning and Traffic Engineering*. Butterworth-Heinemann, Nov 1996, ch. Signal Control in Networks, pp. 506–516.
- [3] Cheese, J. and Radia, B., “UTMC programme overview: Emerging results, communication standards and the demonstration projects,” in *Tenth International Conference on Road Transport Information and Control*, no. 472, 2000, pp. 143–146.
- [4] Garcia-Nieto, J., Alba, E., and Carolina Olivera, A., Swarm intelligence for traffic light scheduling: Application to real urban areas, *Engineering Applications of Artificial Intelligence*, vol. 25, no. 2, pp. 274–283, 2012.
- [5] Papageorgiou, M., Diakaki, C., Dinopoulou, V., Kotsialos, A., and Wang, Y., Review of road traffic control strategies, *Proceedings of the IEEE*, vol. 91, no. 12, pp. 2043–2067, 2003.
- [6] Radia, B., Integrating the traffic management applications of ITS: An overview of the UTMC programme in the UK, *ITS Journal*, vol. 6, no. 1, pp. 83–90, 2000.
- [7] *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*, Volume 2, Defra, 2007.
- [8] House of Commons Environmental Audit Committee, *Air quality: A follow up report*, ninth report of Session 2010-12, Volume 1, 2011.
- [9] <http://www.leos.le.ac.uk/aq/cityscan.html>
- [10] <http://www.pollutionradar.co.uk>
- [11] <http://aura.gsfc.nasa.gov/instruments/omi.html>
- [12] http://www.eumetsat.int/Home/Main/Satellites/Metop/Instruments/SP_2010053161447506