BUS INFORMATION AND SIGNALLING IN GLASGOW
PUSHING THE BOUNDARIES

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1. THE TRANSPORT CONTEXT

For many years now there has been an ongoing and heated debate over what is the best way to deal with our ever-increasing demand for travel. Whilst the debate rages between those who would constrain and those who would provide more, it is almost certain that the solution lies somewhere in the middle. With no single 'magic bullet' for our transport problems in the medium term, those working to address the transport issues need to work in partnership and collaboration to deliver sustainable transport improvements. On this basis we can move forward, implementing appropriate solutions that meet our local and national needs as funding and other opportunities arise.

Recent transport initiatives throughout Scotland and the rest of the UK have demonstrated the breadth of possible areas for improving the transport system. These range from major infrastructure improvements to local service enhancements and from road user charging to deployment of traveller information services. Valuable lessons have been learned from many of the early projects. These are now being used to refine future schemes and steadily improve the quality and effectiveness of the services and other outputs being delivered.

The experience also tells us that if we are to deliver change and improvement to our transport systems and achieve the best value for our investments it is essential that we learn from each other. We need to identify and consolidate on best practice, adopt standards and share our knowledge to ensure that we can progress and invest with confidence.

It is on this basis of sharing and learning that this paper seeks to provide an insight to the provision of Glasgow City Council's Bus Information And Signalling system – BIAS. Highlighting the needs, the vision and the challenges behind delivery of a new generation of system for managing road travel within the urban environment.

2. THE GLASGOW SITE

Glasgow has a population of around 600,000 and is located at the centre of a thriving conurbation with a population of almost 1.2 million. Like any city, it needs to balance its social, economic and environmental objectives so that it can grow, be a prosperous and efficient business centre and still be a pleasant place to live. Transport has a central role in all of these objectives and the City is determined to ensure that its transport networks are operated and developed to support the city and its regeneration. With this mandate and in full support of the national transport agenda the city and its partners are pursuing a wide range of transport initiatives.

One of the key initiatives being pursued by Glasgow is the introduction of Quality Bus Corridors (QBC). Comprising the main arterial routes across the city, QBCs will provide high quality, high frequency and highly reliable bus services that have priority over other vehicular traffic. They will also redistribute some of the priority on routes from the car to other modes including pedestrians, cycles and taxis. This requires a package of co-ordinated actions along the corridors using direct engineering measures, revised traffic regulations, improved traffic control, bus priority and real-time passenger information. It also includes new buses, service frequency and quality improvements and capital investment from the bus operator.

Glasgow is delivering the project along with its main partners, bus operator First and West Dunbartonshire Council. Initially 8 corridors are being delivered, covering a route length of almost 100km with a project value of approximately £30m. This is funded via the project partners and the Scottish Executive's Public Transport Fund programme. The project is under-pinned by an Operator Agreement between Glasgow and First that secures each party's financial contributions, project deliverables and future operational levels of service. The agreement also seeks to measure the benefits from the project and to monitor them during its operational phase to ensure that they continue to be delivered into the future.

3. THE NEED FOR BIAS

An effect of the QBC strategy to favour priority towards other modes is the reduction of road space for the car. At the planning stage it was recognised that a means of managing potential congestion or other traffic problems that might arise was essential. Equally, a means of providing priority for buses at traffic signals and an effective method of mitigating any disruption was also required.

The project also aimed to develop a quality image for the corridors that would attract new public transport users. In addition to service branding and bus shelters, it was considered important to provide travellers with accurate and timely service information. Provision of real time passenger information on buses and at shelters is aimed at engaging with travellers and demonstrating to them that the corridors provide an enhanced service that is dynamically managed and reliable.

These issues pointed to the need for an improved traffic signal control system that could provide adequate monitoring and control facilities to respond to the anticipated traffic management issues on the bus corridors. The system would also have to be flexible enough to support different control regimes across the network as the routes passed along arterial commuting routes, across congested river and motorway cordons and through the classical grid network of the Glasgow city centre. It would also need to accommodate the management of sites adjacent to the corridors and the presence of Glasgow's existing 'fixed-time' Urban Traffic Control (UTC) system. The ability to provide bus priority under any of the control regimes throughout the network of corridors was also essential. In its initial phases, the system would be required to control almost 300 sets of traffic and pedestrian signals and be capable of expanding to accommodate over 800.

Similarly, the need to identify buses for priority and provision of real-time information pointed to the need for a bus location and information system. The Automatic Vehicle Location (AVL) system would need to integrate with the bus operator's existing industry standard management systems, provide passenger information and initiate requests for priority as and when appropriate. Additional features that would allow the operator to improve bus monitoring and evaluate his performance were also recognised as mutually beneficial features to support the ethos and collaborative nature of the project. Any system provided would be required to initially manage approx. 460 First Group buses and be expandable to over 1100 buses and several operators.

The needs emanating from the QBC project paralleled the conclusions and recommendations previously identified within Glasgow's Intelligent Transport Strategy review undertaken in 1996. The review acknowledged the different types of traffic networks within the city and the need for a range of integrated tools to manage them. Adaptive control, fixed time UTC and dial-up remote monitoring of signals were all recognised as being required to provide an effective and flexible system. It was also concluded that the individual systems required to be set within a management framework that integrated their operation and optimised their performance. In response to these wide-ranging requirements, Glasgow developed its Bus Information And Signalling system - BIAS

4. THE NEW TRAFFIC CONTROL ENVIRONMENT

Glasgow has been involved in the development and operation of major traffic control systems for over 25 years. This included the early trials of the SCOOT (Split Cycle and Offset Optimisation Technique) UTC in the 1970s and the subsequent Glasgow-wide CITRAC (Centrally Integrated TRAffic Control) UTC in the 1980s. The established goals of these systems were to maximise capacity, minimise delay and use the power of computers to keep the network operating at its optimal level. In preparing the requirements for the BIAS system it was recognised that the goalposts had moved in several important areas. The four most important were identified as:

- Changed objective;
- Changing technology;
- Role of information; and
- Need for integration and convergence.

4.1 Changed Objective

Firstly, It was clear that the underlying objective has changed. Rather than passively service demand, it was now necessary to manage demand and to undertake a more strategic role by actively managing road space and priority within an integrated transport environment.

4.2 Technology

Secondly, the technology used to manage the transport network is changing. Transport Telematics initiatives have over the past 10 years encouraged the merging of transport systems with mainstream information and communications technology. This work is now bearing fruit. The technology supporting transport management is now common with many other business areas and its development is being fuelled with that of the mass market mobile and Internet communications industry. The hardware, software and communications systems required to deliver existing and new solutions are evolving at an increasing pace.

4.3 Role of Information

Thirdly, information has now been recognised to have a major role in how we manage and control our transport networks. In the wider transport environment information is becoming a commodity at the core of an expanding service area aimed at improving how we operate our networks and empowering travellers. The traditional traffic control system approach of locking in information and rendering it inaccessible is no longer tenable. The BIAS system had to be conscious of this in its design.

4.4 Integration and Convergence

Finally, whilst new technology delivers great opportunity to create new diverse solutions and services, it also demands that we follow the rules. Where we wish to have inter-linked systems, shared information, upgradeable hardware and integrated services, the systems must integrate and converge towards the use of common standards. Without common data formats and referencing, agreed communications protocols and the like, we will fail to deliver workable and affordable strategic transport solutions.

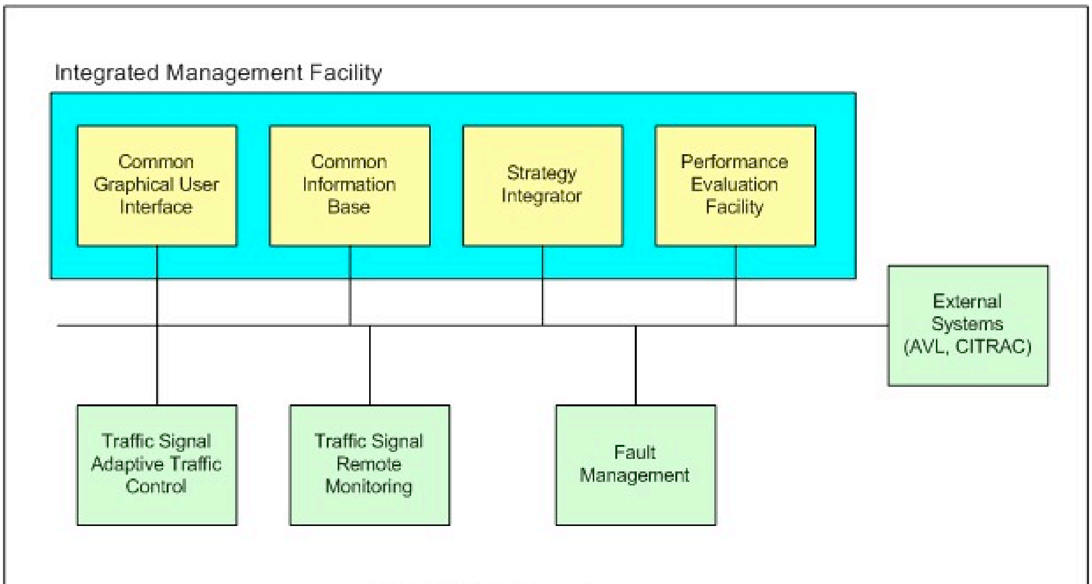
The needs emerging from the QBC initiative and those above have strongly influenced both the design of the system and how it was eventually procured.

5. THE GLASGOW SOLUTION

5.1 BIAS UTC - Vision

The BIAS system was issued as a set of functional requirements. They outlined the core objectives that the system aimed to address and the main functional components necessary to deliver them. For the UTC system these components were identified as:

- Adaptive Traffic Control and Traffic Signal Remote Monitoring;
- Fault Management;
- Integrated Management Facility comprising:-
    - Common Graphical User Interface;
    - Common Information Base
    - Strategy Integrator
    - Performance Evaluation Facility.



BIAS UTC Schematic

5.1.1 Traffic Control

The adaptive traffic control and traffic signal remote monitoring components are the conventional traffic control systems used for UTC, providing dynamic and fixed time control facilities respectively. The adaptive traffic control system predominant within the UK is SCOOT. It is now almost 30 years old and although it has undergone some development it has not been updated line with new technology. Despite this, SCOOT was most likely to be the adaptive component of BIAS and would have a significant part to play in providing priority to buses on the routes. It was therefore important that the integrated system attempted to overcome many of the legacy issues that SCOOT presented in terms of user interface, data accessibility and communications. The system also had to accommodate the existing 20 year old Glasgow fixed-time UTC system that still operates at over 500 sites within the city.

5.1.2 Fault Management

The fault management component was aimed at being a single application that could record and manage faults from any of the other component systems. The facility was required to maintain an inventory of all equipment within the complete system and be capable of recording instances of faults, their types, duration, maintenance contractor performance and the history of all equipment sites. Deployment of the system, with appropriate access limits, to the maintenance contractors would improve operational efficiency in the response to equipment failures.

5.1.3 Integrated Management Facility

The most novel and strategic component of the BIAS UTC system is the Integrated Management Facility. This component would provide the user with universal access to the system facilities and provide the 'glue' that integrates all of the other components together. It would provide a window to monitor the road network and give access to essential information within the system. It would also identify problems and manage responses and provide a tool to monitor and evaluate the performance of key activities of the system. In the background, it would also act as the gateway for interfacing between all internal and external systems including the proposed AVL system.

Through this group of components the aim was to deliver a single workstation that could provide an overview of the status of the network and the condition of its associated equipment. The workstation would also provide a single point of entry to the range of sub-systems and tools that are required to manage operation of the road system on a daily basis.

Typically, through display of icons on the graphical interface maps, the user would identify problems and zoom from a network overview down to individual junction level. At any time the user could directly access the native traffic control systems that sit in the background to undertake direct engineering interventions. Equally, equipment faults reported would be selected and directly transferred to the fault management sub-system for onward transmission to maintenance contractors. The user could also declare incidents or events such as roadworks and locate them on the map interface. They could then be viewed and associated with congestion and any specific traffic interventions.

5.2 The Technical Challenges

This was the vision for the system but before committing the requirements to tender it was important to review how achievable and affordable it was. It was recognised that many of the features requested were novel and were pushing the boundaries of the current traffic control industry. The key risk areas identified were those of:

- standards upon which the design was to be based;
- degree of integration; and
- communications technology.

5.2.1 Standards

Traditional standards for UTC systems have focused upon discrete systems and did not address the issues associated with their interconnection or integration. Consequently, each manufacturer or new system has generally been bespoke and could not guarantee to connect to any other. This issue is now being addressed in the UK through the Urban Traffic Management and Control (UTMC) standards [1,2] initiative. This is aiming to develop standards for the interfaces between system elements and the formats of the data that pass between them. This process should produce an 'open' architecture for UTC systems that allows different manufacturer's equipment to be connected together and the marketplace to be more open and competitive.

This initiative is now gaining momentum, but whilst BIAS was being specified it was in its infancy. Although adoption of the standards and their principles was desirable, their adoption as a mandatory requirement within the BIAS contract would have presented a major risk for tenderers and introduced unaffordable development costs for Glasgow. To overcome this problem and not fully abandon the opportunities that UTMC presented, it was decided to set the basic system provision as being non-UTMC. However, tenderers were given the option to provide or upgrade elements of the system to the UTMC standard during the period of the 3-year contract. This contained the risk but allowed tenderers to be innovative and competitive based upon how they saw their UTMC business developing in the future.

5.2.2 Integration

The second risk area related to the level of integration required within BIAS. The project demanded not only linking a wide range of sub-systems but also bringing their internal information and control functions to a common operator workstation and interface. The BIAS team recognised the demands of this requirement but it was fundamental to the integrated approach that BIAS required to achieve if it was going to be able to operate Glasgow's networks and deliver the benefits. The alternative approach of separate systems on separate workstations or uncoordinated applications on a single workstation would be untenable. Although there was no clear model of how tenderers might deliver this component, it was considered that some of the concepts of common information bases and information routing techniques emerging from the UTMC programme trials could resolve the problems. It was therefore decided to proceed with the requirement and push the tenderers to innovate.

5.2.2 Communications Technology

The final and potentially highest risk area was that of communications. With over 300 sites to be controlled initially and a further 500 in the future, the solution and cost for communicating with equipment at the roadside was a major concern. Traditionally communications for UTC systems have been based upon low bandwidth analogue technology that is available at a reasonable cost. Unfortunately, this technology is nearing the end of its commercial life and it is not ideal for connecting today's high-speed computer systems. Indeed, during the BIAS tender preparation period the UK supplier of the analogue circuits gave notice of their intention to cease supplying them. This was subsequently rescinded after universal complaint from the UK local authorities but their future long-term availability is still questionable.

The alternative mainstream digital communications services available provide substantially greater bandwidth than UTC systems require at an unaffordable price. Nevertheless, for the BIAS project it was essential to adopt a communications solution that would meet our immediate needs but also be suitable, available and affordable for the future. As the contractor would be the technical designer, he was judged to be in the best position to identify the technical degrees of freedom. It was therefore decided to allow tenderers to propose analogue, digital or a hybrid communications solution providing that the average operating costs of their solution was no greater than the existing analogue services. Tenderers could use whichever innovative methods were compatible with their system design and as the capital and revenue costs would be included within the tender evaluation process, it would encourage them to seek a minimum cost arrangement.

Each of these risk areas posed a considerable challenge to the BIAS project team. The issues surrounding the risks were interrelated and constantly shifting. Equally, the technologies and their associated market forces were moving forward at a pace, which meant that the quality of any decision was time dependent. In each case, Glasgow managed the risk by moving key parts of the decision to the tenderer who was in a better position to control it.

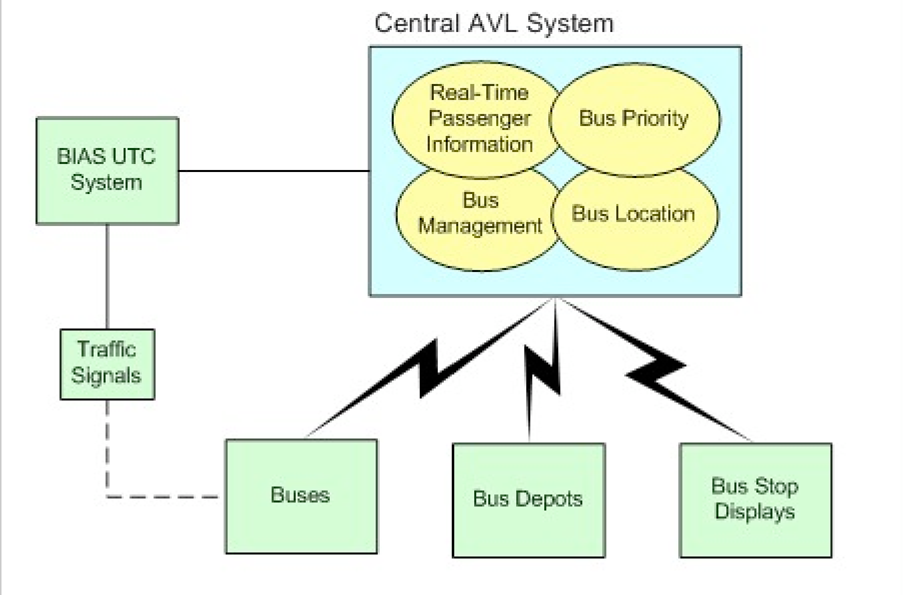
6. BIAS AVL

Although quite common elsewhere in Europe, the introduction of bus location and real-time passenger information systems is relatively new to the UK. The core principles behind AVL systems are relatively simple. Track buses in real-time, identify when they wish priority at signals (and provide it), measure their performance against their schedules and advise passengers when they are due to arrive. However, the reality is not as simple and many will testify to the frustration of getting such systems to operate successfully. AVL systems consume large quantities of ever changing bus schedule data and ultimately depend upon the consistent operation of a host of roving devices (buses), operating in a relatively harsh environment at the end of a fragile communications chain. Failure of any element results in the delivery of incorrect information, loss of service and most likely, disaffected customers.

This can be a high-risk venture for any enterprise. A robust system that works reliably and can be readily supported, as part of the bus operator's normal operation is essential to success.

As with the UTC system, the BIAS AVL system was outlined to tenderers in terms of the main functional components. For the AVL system they were identified as:

- Bus Management and Location
- Bus Communications;
- Bus Priority and Integration;
- Real-Time Passenger Information.



BIAS AVL Schematic

6.1 Bus Management and Location

The functional requirements for the AVL system were prepared in close collaboration with bus operator First, the main QBC project partner. First brought their considerable experience from other UK projects and detailed knowledge of the features that would make the system a success for them. Both parties recognised the importance of the core bus management and location component providing robust and accurate tracking of buses. The preferred option for this was GPS technology, which was acceptably mature for this type of application. Building upon this, it was essential that the system interfaced with the bus operator's main operational systems and methods of working. This would ensure efficient transfer of the operator's bus schedule information and simplify the ongoing, routine support of the system's critical information databases; an activity that if poorly implemented, often leads to eventual failure of such systems. A key component of this was the feature that each on-bus AVL unit was required to hold the schedules for every First bus route within Glasgow. This means that operationally buses can be easily transferred between routes throughout the day without reloading new schedules and data sets. The provision of automatic up and downloading of data to buses upon their return to depots ensures that this process presents the minimum operational burden to the bus operator. The inclusion of a range of support tools for the operator to analyse their service performance was also seen as important to secure their long-term commitment to the system and maximise the overall information available for QBC performance monitoring and evaluation of benefits.

6.2 Bus Communications

The basic requirements were to provide reliable voice and data communications to buses in the most cost efficient manner in terms of capital and revenue costs. There are generally two main options for bus communications; private mobile radio (PMR) systems that are licensed analogue systems installed by the user and digital general packet radio services (GPRS) that are the data equivalent of the mobile phone. The former involves capital investment with relatively low service costs whilst the latter is a leased service payable monthly depending on the quantity of data transmitted. At the time of BIAS AVL specification, PMR was the most proven technology but it is limited to the user's radio system coverage and capacity. GPRS was relatively new with the promise of wide national coverage but there were, and still are, uncertainties in its performance and actual revenue cost in an operational urban environment.

Again, being faced with the dilemma of old and new technology options and numerous combinations dependent upon the specific architecture of the tenderers' various AVL systems, the specification placed the design responsibility upon the tenderers. They were required to submit full communications solutions to support their systems and where they were capable, present both analogue and digital communications options. This approach would allow a clear technical and financial evaluation of the different systems offered with full transparency of the impacts that their architecture would have on operating costs.

6.3 Bus Priority and Integration

Whilst preparing the specification it became clear that the concept of bus priority with AVL systems was widely recognised and much aspired to but not greatly demonstrated. The success of the feature depends on accurate and timely requests by the bus arriving at the traffic signal controller in time for it to alter the existing signal operations in favour of the arriving bus. At a junction that is not under UTC control any disruption caused by this intervention delays other opposing traffic as well as other buses. Where the signals are under central UTC control, such as SCOOT, it should be possible to manage the recovery process and minimise the overall disruptive effect. Within the BIAS project the intention was to adopt an adaptive system such as SCOOT therefore the ability for the bus to notify the signals was a basic requirement. It was further required that buses should be 'intelligent' enough to only request priority if they were behind schedule. The should also be configurable to modify the request depending on additional parameters such as whether the bus was full or empty or running to or from the city centre.

Bus priority was the obvious area of integration between the BIAS AVL and UTC systems. However, with the concept of the Integrated Management Facility within the UTC system there is potential for greater levels of integration between the systems. To improve administration and management of AVL system faults they should be passed directly to the UTC fault management facility for recording and automatically passing to the maintenance contractor. Similarly, alerts and alarms generated by the AVL system should be passed to the common user interface for recording and action by the control centre staff. This principle can be extended where other key parameters from the AVL system should be recorded within the common information database. This could then be used to assist in identifying common problem areas within the network, evaluating performance in delivering bus priority requests and the development of key performance indicators. Opening up access to relevant data across the system, whilst respecting the commercial sensitivity of the bus operator's core data, will present new opportunities for operational enhancements and improved business intelligence.

6.4 Real-Time Passenger Information.

Although it is almost impossible to calculate the monetary benefits accrued from providing real-time passenger information it is widely accepted that it has a key role to play in improving the travel experience for public transport users. They represent the idea of quality, good service, assurance, etc. - but only if they are accurate and reliable. The QBC aim was to promote the quality aspect of the services and to demonstrate that the routes on the corridors were superior. It was therefore proposed to provide real-time passenger information displays within bus shelters at the most popular bus stops along the route. Initially only 100 could be deployed on the basis of cost but if successful further deployment would be considered. The signs would present 3-lines of information and be driven directly from the central system over the radio system. They would countdown in real-time for the next 3 approaching buses with the third line being optionally available to present service related messages to bus users. The signs had to meet the usual general performance requirements to meet legibility, environmental and security specifications. However, other key considerations for the signs were their robustness in terms of withstanding the harsh physical interference encountered at some stops and their aesthetics in terms of providing an attractive presentation to the public within Glasgow's style of bus shelters. Other types of passenger information signs are required for on-bus and for shopping centres, etc. with the system having the capability to drive web based information displays should they be required in the future.

7. DELIVERING THE VISION

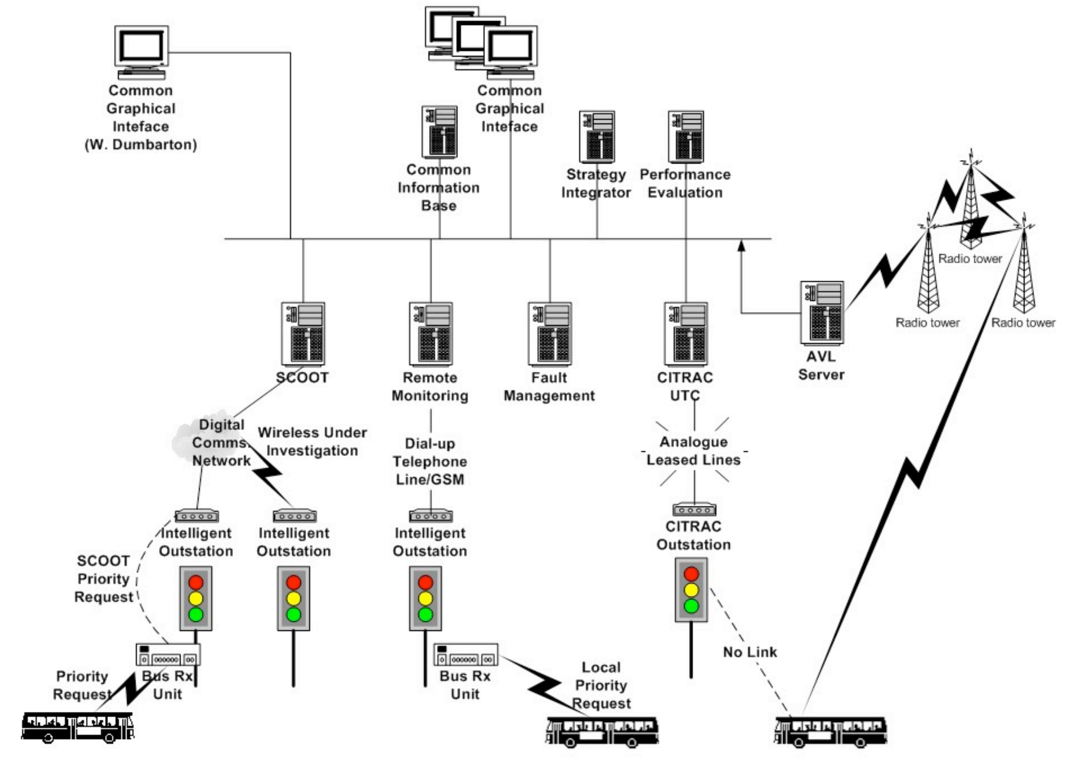
Traditionally, UTC and AVL systems exist in separate market sectors. To address this and the innovations called for within the project, it was tendered as lots where contractors could bid for the UTC lot, the AVL lot or both combined as an integrated solution. This was considered the best approach as it allowed contractors to play to their strengths but also permitted systems integrators to compete, develop alliances and bring innovation to challenge the conventional players.

After a full and comprehensive evaluation the two separate lots offered the best value solution. The UTC lot was awarded to Peek Traffic with specialist sub-contractor Mott MacDonald. The AVL lot was awarded to Serco Integrated Transport, a system integrator bringing together Action Information Management's (AIM) AVL system, Bridge Radio Systems and Densitron for real-time information displays. Based upon the tendered rates, the expected outturn costs for the project is £9m with the UTC and AVL components estimated at £5m and £4m respectively.

Despite the scale of the project and the level of innovation demanded the designs submitted by the winning tenderers for both the UTC and AVL met the upper bound of the project's aspirations.

7.1 BIAS UTC System

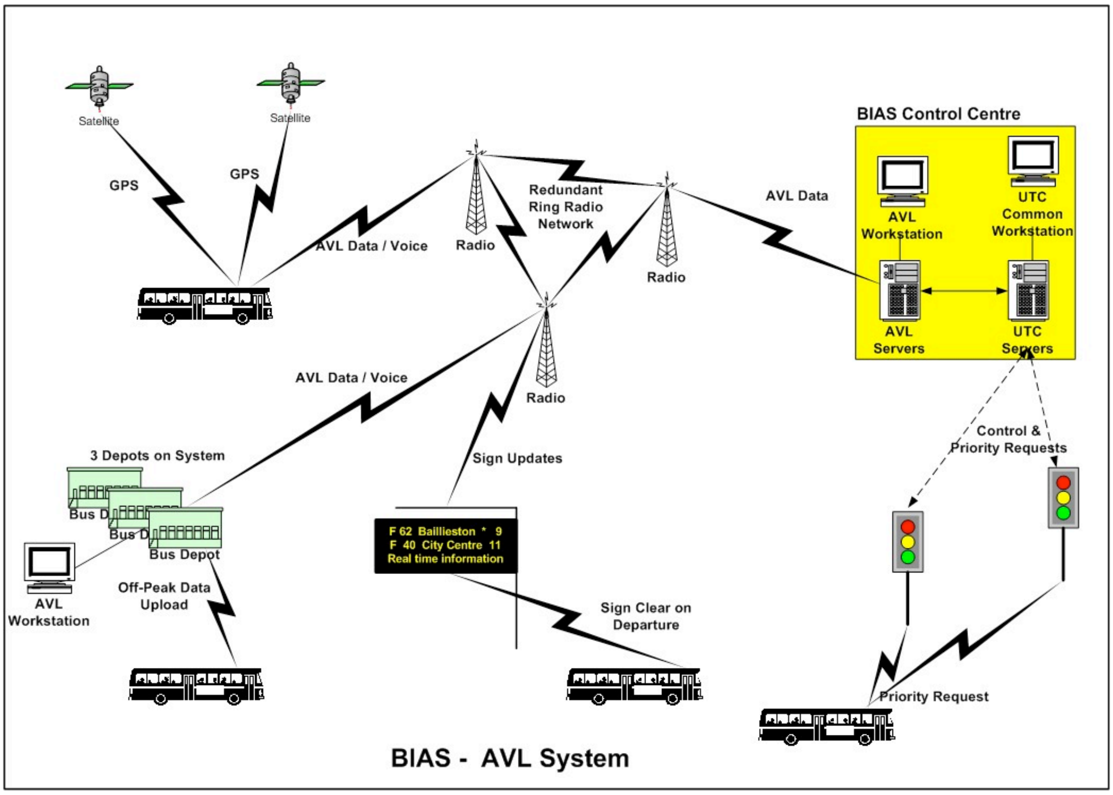
Within the UTC component, Peek brought together their traditional expertise in the traffic control industry and the traffic control systems engineering and development skills of Mott MacDonald. The partnership demonstrated that they had engaged with the overall vision of the BIAS project and included within their design many of the outputs emerging from the UTMC demonstration projects. In particular, Peek provided a new generation of roadside equipment operating over digital communications and an overall system solution that would be compliant with the new UTMC standards. This ensures that the system is as open as possible and can be readily adapted and enhanced in the future as Glasgow's transport strategies develop. In acknowledging the significance of the communications issues for UTC at this critical time of change the proposal also offered to undertake a joint exercise after award to investigate alternative communications solutions that might present better value options for the project.



BIAS - UTC System

7.2 BIAS AVL System

The AVL component provided by Serco brought together 3 strong players in their own fields. The AVL system provided by AIM used GPS vehicle location on buses to regularly update the central computer of the bus position and its status. From this, the central system provides a wide range of monitoring information to the bus operator and a robust ‘engine’ to drive real-time information displays to advise passengers when the next bus will arrive. Particular strengths of the AIM system are the manner in which information is presented to the bus operator and its statistical reporting tools on bus schedule adherence and service performance; critical elements to ensure efficient and sustained use by the bus operator. The radio system option adopted was the private mobile radio solution as it provided the best migration path from First’s existing voice radio system. It also has known, fixed operating costs whereas there was revenue cost uncertainties with the alternative GPRS solution that were unacceptable to the bus operator. The system can be adapted to operate using GPRS in the future if desired. Real-time passenger information will be provided within the busiest shelters on the routes and within BIAS equipped buses. Within the initial phases of the project 460 buses are being equipped and 100 shelter displays deployed.



8. PROGRESS TO DATE

The contracts were awarded in the summer of 2003. The AVL system is now substantially installed and will be site tested against one route in March 2005. Rapid deployment of buses and bus stop displays will follow thereafter. The major challenge identified with the system is that of initial configuration with the bus operator's schedule and other operating data. The bus operator's data must initially be 'clean' of errors otherwise the AVL system generates and displays wrong information and statistics.

The basic version of the UTC system providing the common graphical user interface, fault management and the SCOOT traffic control function are now operational. Work is continuing to deliver the more enhanced features of the system on a phased basis until December 2005. In the meantime, work progresses to prepare the 300 traffic control sites which have to be phased with the physical traffic management measures being implemented by others as part of the wider QBC project. The initial copper cable based digital communications method has been proven. A trial of an alternative wireless solution is currently under way which if successful will provide substantial benefits for ease of installation and reduced future operating costs.

9. WHERE NEXT

In providing the BIAS system Glasgow has pushed the traffic technology boundaries in terms of providing the basic integrated tools to manage elements of its transport network. It has moved away from discrete, individual closed systems that work in isolation to an integrated approach that supports operational integration, information sharing and modular expansion. The design is substantially compliant with the emerging UTMC standards and opens the way for integration of a much wider range of functions that the City's traffic managers need to deliver. Operationally, BIAS will allow Glasgow to more effectively identify where the traffic and travel bottlenecks occur and be more proactive in its interventions. It will also support a much greater public transport focus and facilitate investigation and measurement of the network's performance against operational targets. However, the BIAS system is not an end in itself, it is only a tool to address the underlying transport problems that affect our cities and towns. The ultimate solution to these problems lies with other initiatives and collaboration between a wide range of parties including the public.

In this respect, BIAS has adopted a system architecture that can allow it to contribute further. Within BIAS, new applications can be readily added to the system to give control of new functions and provide and disseminate information to other systems. This could include others within Glasgow City Council and external agencies such as the police, transport authorities, adjacent local authorities and the public via web based information pages. Already, Glasgow is considering adding additional applications to integrate the city's carpark guidance system and provide roadside variable message signing for incidents and events.

10. CONCLUSION

The BIAS project set out to push the boundaries of conventional traffic control and deliver a system capable of meeting the needs of today's wider urban transport management agenda. In doing so it has highlighted some of the challenges that have arisen and the new opportunities that are now emerging through BIAS and similar UTMC initiatives. However, as BIAS moves ahead with its technical implementation, the focus must now move to the original and greatest challenge that is to manage the network and deliver benefits. Only a positive contribution in this area will be a true measure of success.

Acknowledgement
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Cartwright, Mark (2004) Meeting the traffic management obligations of UK LAs, **Traffic Engineering and Control, 46** (11) 364-370.

Welsh, Paul (2004) Network management – the transport tool for the 21st centuary, **Traffic Engineering and Control, 46** (11) 371-376.

Notes

1. UTMC Technical Specification TS001. Available from www.utmc.gov.uk
2. UTMC Communications Specification TS002. Available from www.utmc.gov.uk

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