INTEGRATED MULTI-NODAL TRAFFIC NETWORK SYSTEMS

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Abstract: Heuristically, traffic management is an important study. From the days of the ancients, and well into the future, the need to transport humans and cargo from one destination to another forms the backbone of a commerce driven culture. However, the ability to transport humans and materials also has altruistic benefits to society, one example being the ability to transport the injured from an accident scene.

An integrated multi-nodal traffic network system is a particular direct class of automated system that provides 1) route navigation and obstacle awareness information to traffic network users; 2) coordinated traffic flow management; and 3) traffic movement analysis and reporting. By integrating all three major elements of any traffic network, it is possible to identify traffic hot spots, re-route vehicles from congested sections resulting from incidents, manage law-enforcement issues and plan for future needs.

In this paper, we develop the requirements for a concept system called '***IMagiNaTioN***' (Integrated Multi-Nodal Traffic Network system), and we demonstrate why this is a unique and beneficial system.

Key Words: transportation information management, knowledge management, decision support system, real-time transport modelling, streaming transaction processing

1. INTRODUCTION

In general, traffic control systems are by no means new, and there are many high-quality systems which have a long history of successful implementation, the most notable in the Asia and Pacific being SCATS (Sydney Coordinate Adaptive Traffic System) and SCOOT (Split Cycle Offset Optimising Technique) (Ireland On-line, 2003). The primary purpose of these types of systems is to provide automated safe and efficient traffic signal management predominantly in terms of minimising delay. Such systems are reactive by nature and rely heavily on fixed infrastructure such as detector loops. Furthermore, Traffic Management Centres (TMC) around the world are utilising Decision Support Systems (DSS) and Knowledge Based Expert Systems (KBES) for their Intelligent Transport Systems (ITS) applications (Stack, 1997, Liu et al., 1995). These can operate on a wide variety of inputs ranging from video detection to environmental sensors (e.g. fog, ice, light, pollution). Implementations are primarily concerned with incident detection, safety and providing feedback to motorists via Variable Message Signs (VMS)(Road Traffic Authority (New South Wales), 2002, Wisconsin Department of Transport, 2003). They tend to range in application from the management of bridges and tunnels to entire freeway systems.

Many capable traffic analysis and modelling tools also exist to assist with predictions and analysis of traffic networks. Currently, microsimulation is experiencing widespread popularity with models such as "*Paramics*" (Quadstone Ltd, 2003), AIMSUN2 (Barcelo et al., 1997) and VISSIM (PTV Planung Transport Verkehr AG, 2002) dominating the market. Finally, Global Positioning Systems (GPS) can be interfaced with Geographic Information Systems (GIS) to provide information to traffic network managers and users including route guidance systems and information on travel times. Such systems are already in widespread use in the fleet management context and traffic information is commercially available to road users in many countries (Geosystems Mapping Solutions, 2003, ALDATA Software Management Inc, 2001).

At the highest level, the purpose of *IMAGINATION* is to provide the mechanism by which all these three are able to interact in *real-time* and in *batch-time*.

To elaborate on the issue of users/system customers, we note that any individual and/or organisation such as emergency services or the military are all customers of the proposed system.

This paper is the first in a series that will look at the development of a holistic integrated multi-nodal traffic network system. This paper introduces the framework for the development of such a system, the context in which it exists, and the perceived issues associated with its development. To fulfil its intent, this paper will explore traffic network issues of unit movement, managing unforeseen incidents, data collection/storage/analysis and tactical and strategic management requirements. This will be achieved by showing how *IMAGINATION* builds upon existing technologies in the field, uses and enhances emerging technologies such as streaming transaction databases currently under development at Stanford University, integrates new and traditional technologies to provide hybrid systems that cater for short and long term system needs. Further this paper will propose how all these elements will work together in a concept model for future development.

2. BACKGROUND

2.1 Batch and Real-time processing: overview

In order to assist the reader in understanding the nature of *IMAGINATION*, we begin by examining the above concept. In nature, information is processed both in *real-time* and in *batch-time*. Consider the following example; assume you are travelling alone in your car to work from your new home. Initially, you may choose to travel using only arterial routes to ensure that you at work at the correct time. During that journey, you process the position of other road users in relation to your own position; respond to various external stimuli; manage your current position in relation to the overall route; react to any external stimuli that you may perceive places you in danger; and finally you ensure that you remain within any imposed speed limits/restrictions. This is normally performed in a near automated fashion; in other words, much of the micro-level detail is processed in *real-time* with little to no need to consciously process each action. However, during the journey, you note that particular locations may be perceived as being dangerous, or else, you may note that at specific times of the day, your chosen route is congested. Upon the conclusion of the journey (or perhaps whilst in transit, as an additional process to that of driving), you may decide in future to use an alternate route either because of the perceived danger of the route initially taken, or you may choose to risk the route provided it is at a time of day that makes this acceptable to you. These decisions are made in what we will refer to as *batch-time*.

As humans, we build up a map in our minds, a *cognitive map* or *navigation(al) map* (Chown et al., 2001), of the route to take and the obstacles that may be placed in the way. At no time, however, do you only process short streams of information, use some inherit optimising algorithm, and then discard the data, nor do you stop the vehicle every time you need to make a decision, search through vast quantities of information, present the results to yourself and then proceed with the decision making process. In terms of solving transport related problems (in fact any sort of problem) it is necessary to not only be able to make decisions instantaneously (*real-time*), but also be able to analyse existing information to improve future decision making (*batch-time*). As such, it is not possible to only solve queries based on streams of data entering the systems we develop, but it is also imperative to be able to search over the history of an event, a locality, an object or any other conceivable combination of all of these.

2.2 Decision Support/Process Management

Any system developed to manage a traffic network, or that provides *real-time* information to network users, needs to be able to either make decisions or support the decision making process. The method chosen to do this directly affects the efficiency of a system, insofar as, if the system implements a solution based on network inputs that is either made after the 'point of no return' with relation to an incident, or one that is incorrect, then this causes the system to fail, possibly catastrophically. According to Information Builders (2003):

> *Decision Support Systems (DSS) are a specific class of computerized information system that supports business and organizational decision-making activities. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions.*

These systems typically are designed to assist organisations in specific ways, and it is the underlying algorithms that make each one of these unique.

Raicu and Taylor (2002), describe the use of a DSS in the transport of sugar cane. By exploring the various *states* in which the transport vehicles find themselves, they are able to define the parameters and ultimately the equations that govern the movement of the vehicles between sugar cane farms and the various processing plants. Graphically, they use decision process diagrams to articulate each possible scenario relating to the movement of the vehicles within the '*sugar cane transport network*'. By developing this, they laid the basis of the computer application that was then developed to solve the issue of optimising the movement of vehicles within that network.

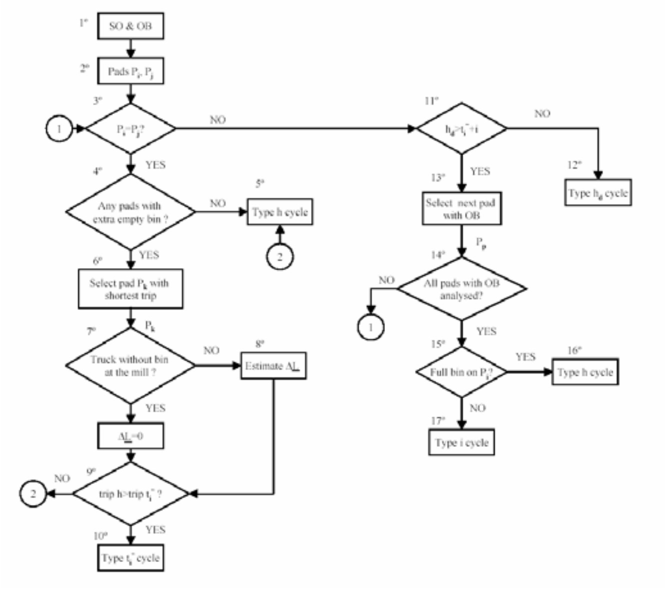


Figure 1 Dispatching Algorithm for the 'stockout and old bin' scenario (Raicu and Taylor, 2002)

Decision support systems remain an integral part of *IMAGINATION*. The type of DSS is left for a later forum, however, the efficiency of the implemented DSS is paramount.

2.3 Data Generation in a R*eal-Time* World

The proposed *IMAGINATION* system is not immune to the necessities of collecting and managing vast quantities of data. Assume for a moment that a proposed traffic network has 100 four-way intersections in a purely-gird formation; the data generated from such a proposed traffic network is used to manage each vehicle within that network, all the traffic management components such as traffic and street lights, the updating of information to each network user and optimise the system holistically. In such a situation, the 'resolution' of data capture becomes an important issue. One could minimise the data collected by only performing the capture process once every hour, however, this would have the implication that traffic would only be able to move between intersections say, once every two hours. One could also go to the other extreme by capturing information once every millisecond. This would certainly provide the system with many data points upon which to calculate the optimum traffic flow/route navigation for the network/user, but to manage that level of data would be extremely difficult.

For example, assume that the minimum data using standard variable types required to operate a typical intersection without considering any vehicles included a signal location (64-bit integer), a signal phase (32-bit integer), and a flag to identify when a vehicle has entered the intersection zone (8-bit integer/character). Each 'record' now contains 13 bytes of data. As we are referring to 100 four-way intersections, we must then collect and send 1.3Kb of data for every event, totalling 2.6Kb. If the resolution has been set to trigger an event every second, then for each minute that passes, we are processing 156Kb, for every hour we are processing 9.36Mb, and for every day we are processing 224.64Mb of data. In a year, we would have processed at the bare minimum approximately 80 GB of data.

Based on the above values, and assuming a more complex record structure for all the elements of a real traffic network, it is easy to see that 1) much more than 80 GB of data will be collected and hence 2) these systems need to not only store, but also process and manipulate into information vast sums of data. It is possible, and it would be expected, that techniques such as data packing and the development of specialised database variable types would need to be used (along with the techniques to manage and process) in order to minimise the process/data load on any machine managing the network.

2.3.1 Database Management Systems (DBMS)

By identifying relationships between data, and using those relationships to group data, relational databases provide the mechanism to be able to answer the question, "*How many passenger vehicles travelled through four-way intersections last month?*" However, these sorts of questions do not require any urgency to answer, in fact, whether the system takes 3 nanoseconds or 3 hours to answer that type of question has no impact at all on the ability of traffic to continue to use the intersection in question.

According to Babcock (2002), traditional databases are not designed to manage data queries where *real-time* streams of data are being generated by a system, such as a traffic network or a computer network. Babcock refers to these *real-time* queries as *continuous* queries, and we will continue this tradition.

Ultimately, the time frame within which a traditional DBMS operates is bounded by hours, days, weeks and months, that is, reports generated are used for decisions that are normally made over comparatively long periods of time when compared with true *real-time* environments. However, if one imagines data packets rocketing through data networks, or vehicles moving in traffic networks, the time within which events occur is wholly unpredictable. As such, in the time it takes a traditional DBMS to produce a report, countless events that render the report useless may have occurred. At which point, a DBMS can really only provide a snapshot of the system at the time of the report generation.

Another shortcoming of traditional DBMS is that they do not model the real world in any meaningful way. This is because traditional DBMS are designed to manage transactional data, such as *sales order processing* or *invoice processing*. This means that to model the real world, tables need to be joined which is "*computationally expensive*" (Slater, 1997).

2.3.2 Streaming Transaction Databases (SDMS)

Currently the Stanford University Database Group is developing STREAM (STanford stREam datA Manager). The purpose of this system is to provide a framework, database implementation and query language that will allow network managers the ability to query data streams as they enter the database.

According to Babcock, *data streams* differ from the conventional stored relational model in the following ways:

- *The data elements in the stream arrive online;*
- *The system has no control over the order in which data elements arrive to be processed, either within a data stream or across data streams;*
- *Data streams are potentially unbounded in size;*
- *Once an element from a data stream has been processed it is discarded or archived – it cannot be retrieved easily unless it is explicitly stored in memory, which is small relative to the size of the data streams.*

In such a system, it is imperative that any reporting that needs to occur needs to be performed *on-the-fly*, and there is a need for predicative querying to provide the ability to look into the future.

In order to return any meaningful information from such a system, Babcock describes the use of *one-time queries*, used to evaluate queries with a snapshot of the data at a point in time, and *continuous queries*, which are evaluated over time, and the associated query language to do this. Babu (2001a) continues by suggesting that conventional/stored data sets are appropriate when significant portions of the data are queried again and again, and updates are rare/infrequent, whereas a data stream is appropriate when the data is changing constantly.

We will investigate the issue of streaming transaction databases further later in this paper.

2.4 *Real-time* and *Batch-time* processing: in depth

Until now, we have used the terms *real-time* and *batch-time* with little to no explanation of what we mean.

By *batch-time processing*, we are referring to processing that can happen at any time, and without any negative impact on the functionality of the critical sub-systems, such as the driver awareness components and the traffic management components. Examples of data that can be processed in *batch-time* would include traffic simulation data, or route preference trend reports.

Real-time processing is a little more difficult. We further segregate *real-time* into two common engineering terms being *hard real-time* and *soft real-time*. Examples of *hard real-time* processing include the activation time for ABS braking systems, and the launch time for military weapons delivery systems such as on-board Air-to-Air missiles, and train telemetry and control systems. In *hard real-time* processing, the time at which a process begins and/or ends is mission critical, and must ***strictly*** occur within time tolerances. On the other hand, examples of *soft real-time* processing include initiation sequences on traffic signals, stop sequences on a DVD player and microwave oven clocks. In *soft real-time* events, the time in which a process begins and/or ends in **not** mission critical, and can occur loosely (although by no means without bounds) within time tolerances.

3 ARCHITECTURE DRIVEN DESIGN

"Why do you need to use Data Stream Management Systems (DSMS)?"

The value of a DSMS is that it provides a mechanism to track changes in the network topology and traffic distribution online so enabling congestion cause detection, adaptive intra/inter-domain (city, sic.) routing policies, resource allocation mechanisms for guaranteed application (system, sic.) quality service, admission-control and traffic-policing (Babu et al., 2001a).

What makes the use of a DSMS so interesting with relation to IMAGINATION is that the Stanford STREAM team is investigating the same sort of problem, however when they speak of traffic networks, they are referring to electrons in a wire. Traditional DBMS expect data to be held in some persistent form (Babu et al., 2001b), however DSMS do not necessarily. When one views the application of *IMAGINATION* one notes that there is relative consistency with relation to the type of data being collected. That is for many of the objects within the system, such as the sensors, signals, etc; the data structures will remain somewhat constant. Then again, for data streams from vehicle-borne systems, there are a myriad of sub-systems that stream data to the network user. Examples of these include sending messages between network users, providing them with instructions on what tasks they need to perform whilst in traffic, or re-routing information etc. Furthermore, even though there is perceived consistency with relation to some object data types, the nature of the data collected in the field means that there is potentially a rapid acquisition of data being sent without a set order (other than it being somewhat event driven) with potentially unbounded streams of data intertwined with the bounded streams. As such, a hybrid concept of the DSMS becomes attractive insofar as the various sub-systems will need to manage *different types* of data, and they will need to transfer knowledge between physical databases depending on the task at hand.

The method of managing the format of the data structures within the system is also important. In such a system, modelling how objects function in the real world is more important than modelling processes. An object-oriented approach provides the mechanism by which this can be achieved as it places the onus on the system to be able to decipher the difference between: 1) bounded and unbounded messages; 2) multiple messages entering the system and 3) actual data streams compared to stream noise.

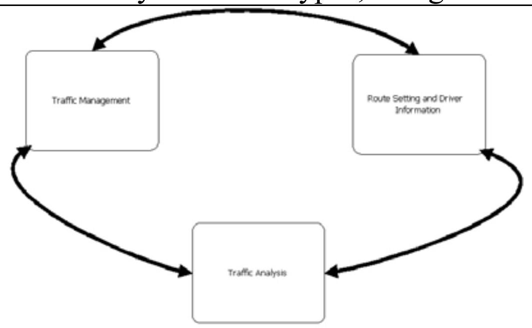
This architecture goes further than just identifying the data needs associated with the database, it is important to note that each component of the system has a pivotal role to play. Each signal, each user, each sensor, and so on, all provide the system with the "bread and butter" to make the system function, moreover, these components, like all physical systems, fail after certain time frames. This associated failure rate and the impact that it has on the network provide challenges for this system. However, by being able to manage all the data coming in from the field, the system has the capacity to automatically predict the failure rates of types of components based on 1) component location; 2) environment conditions and 3) historical performance. This allows the system to develop self-generated maintenance programmes that ensure optimum system/network performance.

The process of optimisation within *IMAGINATION* is related to the following non-exhaustive list of critical tasks: 1) Safe management of traffic flow; 2) optimisation to desirable objectives (eg minimising noise during the night), 3) contingency management during emergencies and disasters; 4) providing feedback to road users; 5) data collection and processing; 6) data processing and information transfer between systems and field components; 7) system and field component management/maintenance (including client systems in network user vehicles); 8) incident solution identification; 9) archived data/system backup failure data restoration; 10) future capacity planning and 11) network additions/modification simulations, just to name a few.

4 IMAGINATION SYSTEM REQUIREMENTS

4.1 Overview

IMAGINATION is required to service the needs of at least three primary users: 1) network managers; 2) traffic analysts; and 3) traffic network users. Each one of these users can be one of two mutually exclusive types, being human or electronic.



The primary *Imagination* functionality

Figure 2 Imagination Information Relationship and Functionality

In order to achieve this, *IMAGINATION* needs to: 1) collect data from as many nodes within the traffic network as is available at any one time; 2) manage the data and provide meaningful information to all levels of user and to all types of users; 3) automate decisions for non-mission critical tasks, and to provide solution spaces during times of critical incidents; 4) distinguish between decisions that need to be made in mission-critical timeframes, and those that can wait; and finally, 5) provide the mechanism by which such a system has the ability to learn from historical behaviour in order to make future automated/human-assisted traffic-flow/route-setting/network capacity planning decisions.

The importance of using the enhanced DSMS becomes apparent in this section, for in order to perform all the above tasks, the system has to be able to collect, process, manage and inform all in *real-time* to network users, and in *batch-time* to network planners and developers.

4.2 Data Acquisition and Distribution

Without data, this system cannot function, and as such, one of the primary sub-systems is the data collection system.

IMAGINATION takes as inputs: 1) Traffic signal data; 2) Road based sensors; 3)Vehicle identification devices; 4) GPS; 5) Probe vehicle information; 6) e-Supporter terminal input; 7) Home user terminal input; 8) In transit terminal input; 9) Real time traffic modelling input; 10) Self-generated reports; 11) and more.

As can be noted, these inputs are both internal to the system **and** external, as it is the combination of these that is the power behind the system. In addition, it is possible with modern mobile (cellular) phone technology to integrate GPS, duress, personal security applications and so on into a vehicle (Masri, 2003). This allows current model vehicles to be integrated into *IMAGINATION* immediately. Further, with the advent of Web Services,

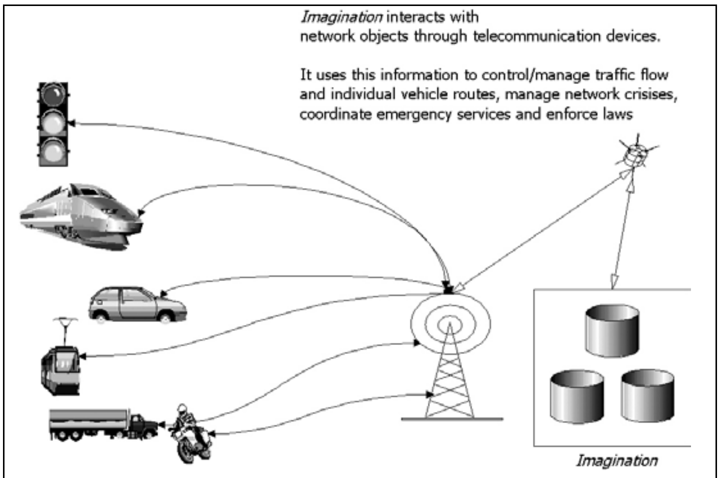


Figure 3 Data Acquisition and Information Management

mobile phones could also be used to provide *real-time* driver information directly to the *IMAGINATION* client system inside vehicles.

4.3 Information Processing

Due to the nature of *IMAGINATION*, the way in which the information is processed is critical.

There are two distinct types of information processing that the system must perform: 1) *continuous*; and 2) *static*. In addition, the system must be able to distinguish between bounded and unbounded messages coming in at the same time from various sources, and it must be able to identify the appropriate level of priority that needs to be assigned to each such data stream entering the system

As an example, consider the issue of the following events occurring within the traffic network during peak time, but not necessarily at the same point: 1) a railway boom gate fails; 2) a vehicle crash, and 3) a network user running late for work because they left home late. Although if you were the individual running late, you may consider the ability to *influence* traffic to assist you would be a 'nice thing', the reality is that the railway boom gate failing and the vehicle crash are far higher priorities. Normally, one would consider the issue of getting emergency services personnel to the vehicle trauma as a far higher priority than that of the boom gate causing traffic congestion, but if the boom gate is on the target route of the emergency services personnel, then the priority changes. This decision, and then the subsequent 're-routing' needs to be done almost instantaneously to ensure that there is real benefit to the road accident victim(s). This requires a combination of *continuous* and *static* processing to be performed and *static* processing can be used to provide the optimum solution sets to the problem of what to do in any given situation if the situation is known to the system. If this has not been the case, then again by using DSS techniques, and being able to search through live and historical data, traffic managers will be able to make decisions based on similar previous incidents, and then have the new solution stored for future reference.

4.3.1 Continuous Processing

The continuous nature of events within a traffic network lends itself quite naturally to using a *DSMS*. The ability to process *continuous queries* in *real-time*, means that a *DSMS* will provide the framework within which traffic network users and the traffic management components of the system can have traffic information communicated to them. By being able to view and process the data from all the input channels available in *real-time*, should an event trigger an action, such as a traffic network incident, it can respond depending on the incident in *hard* or *soft real-time*. The data collected, however, is not discarded immediately; high importance is placed on managing historical data, as that provides *IMAGINATION* with the ability to predict unit network behaviour into the longer term.

4.3.2 Static Processing

Static processing provides two fundamental information paths, one being the standard type reports that are of interest to traffic managers and analysts, and the other being data stored and processed in relation to solutions associated with whole of network incidents. These two information paths are by no means mutually exclusive; they both feed into each other to provide solution sets in times of crisis.

4.3.3 Non-Linear Data Acquisition/Distribution and System Stability

So far, we have accepted that we are dealing with two types of data acquisition and distribution resulting from whole-of-network events, being bounded and unbounded, and more also, we accept that data is entering and being redistributed within the system on a continuous basis, but until now, we have skirted around the issue of event non-linearity. As an example, when traffic builds up on a road segment due to a slow moving vehicle, traffic signal phases appear to change from the perspective of a driver of a faster vehicle, without any consideration that traffic is being slowed as a result of this slow vehicle. This is not the case however, as traffic control systems can detect that vehicles have not passed a sensor and dynamically adapt their phasings accordingly.

This not withstanding, the problem becomes that as a result of the slower vehicle, the potential is that traffic all down the road segment will be affected until the slower vehicle chooses to either stop to one side, or choose a different path from that of the majority of fast vehicle drivers. Naturally, this can have an impact on the whole network, especially during peak times. This then suggests that traffic flow is non-linear in nature, and can, based on network conditions, regress to a chaotic state, that is, traffic congestion.

This example is very similar to the catch-cry of CHAOS theory, being:

> *The flapping of a single butterfly's wing today produces a tiny change in the state of the atmosphere. Over a period of time, what the atmosphere does is diverges from what it would have done. So, in a month's time, a tornado that would have devastated the Indonesian coast doesn't happen. Or maybe one that wasn't going to happen does.(Rae, 2003, Stewart, 1989)*

What we note here is that the movement of traffic can be viewed as a chaotic system (although we defer a comprehensive investigation of traffic and CHAOS theory to a future forum), where small input changes can become catastrophic output changes. This then has the potential to affect the system's stability, and more so, its ability to always maintain a non-congested (non-chaotic) state.

However, by accepting this, and by implementing an appropriate research programme that investigates that non-linear nature of traffic and attempts to find solutions to the problem, then this can be incorporated into the system intelligence modules.

4.3.4 Issues envisaged with information processing

There are a number of challenges envisaged for the development of *IMAGINATION* with relation to information processing, and they include but are not limited to: 1) latency times between an event occurring in the network and the data being transmitted back to the system; 2) the time it takes to process the incoming data; 3) the effect of such a vast amount of data being stored on processing time; 4) the effectiveness of the DSS for the retrieval of information/data for current and future event actioning; 5) the loss of mission-critical operation due to system (hardware and/or software) failure; 6) determining the 'critical-mass' for the number of field input channels to make the system sufficiently useful; 7) the effect of dropping below the critical-mass level of field inputs on the system effectiveness; and so on.

In the current geo-political climate, security will play an important role in the development of the system. It needs to be protected from hackers, and other malicious persons, and those who will attempt to use the system to identify where the police are located, for example.

Each one of these challenges needs to be met by a comprehensive research programme that can then provide the mechanism by which the next phase of development can begin.

4.3.5 Process loading

The system needs to have the process loads monitored and managed as the system begins to grow. The issue of process loading is envisaged to be solved using server farms.

4.3.6 Operating Systems

Although the topic of a future series of papers, the choice of operating system or suite of operating systems is critical. It is commonly known that all operating systems have the advantages and disadvantages, hence the choice of operating system(s) will be determined by: 1) operational suitability; 2) ease of system management; 3) cost-effectiveness.

5 THE DESIGN OF THE TRANSPORT CONTROL SYSTEM

This section systematically moves through each of the primary sub-systems.

IMAGINATION itself has the potential to also assist in Public Policy development. It does this by providing authorities with the ability analyse data managed within the system, provide evidence in support of policy initiatives and long term trend predictions or 'what-if' scenarios. As the system is continually being updated, it allows authorities the ability to see the impact of their initiatives from the time of implementation, and then to modify any such initiatives quickly and efficiently.

The system manages each object in accordance with its type, if it is a road, it will manage information about when it was constructed, when it was last maintained, and which section was maintained, with what material it is constructed of, so on and so forth. This is repeated with each object in the system until it is possible to build a virtual electronic replica of the network within the system itself. The system itself views the network as our brain would view our body, and to that end, a traffic network is analogous to the human body as traffic networks are quite literally organisms in their own right.

When a system itself manages incidents, it is no different to the way the body sends white cells to defend against germ attack, yet here, we have no 'germs' but we do have blockages/congestion that have a similar affect. This is where *IMAGINATION* becomes truly different from anything else currently available. Its design is deeply rooted in that of nature, and looks to take its inspiration in the way it functions directly from there.

This requires the system to manage more than just the vehicles on the road. It needs to know where government buildings/shopping centres-precincts/schools-universities/etc are located. Furthermore, the system needs to know the type of pedestrian/bicycle/car/truck/train/bus/etc traffic is generated at these locations, and the status of each one of these objects. The more the system 'learns' about the objects within itself, the better able the system is at managing the network efficiently.

5.1 Data Collection System

This sub-system is straightforward in functionality. Its primary purpose is to collect data from road-embedded sensors, traffic signals, vehicle borne GPS and identification sensors, video cameras, satellite systems, human data entry and more. It enters the data into the appropriate databases for use either immediately or into the future. This sub-system is the *eyes and ears* of the *IMAGINATION*.

5.2 Data Storage System

This sub-system manages all the data collected from the Data Collection System. Due to the expected volume of data that would be collected from a system of this magnitude, a new type of database management system that combines all the positive features of Object-oriented database management systems (OODBMS) and streaming transaction database management systems (STDBMS) will be developed. This new conglomerate database management system would utilise new computer system management algorithms that optimise the efficiency of the system.

Furthermore, the Data Storage System manages the quality of the Transport Control System I/O.

5.3 Central Intelligence System

This is the *heart and mind* of the *IMAGINATION*. It utilises a number of Artificial Intelligence techniques to manage information querying and solution management, to define and manage all data in the *IMAGINATION*, and to provide the mechanisms by which that data is transformed into useful information. With both pre-defined business rules, and dynamically constructed business rules arising out of *IMAGINATION* operations, this sub-system provides data processing and analysis services to the system.

5.4 Traffic Control System

The Traffic Control System is responsible for implementing traffic management services to the network users. Examples of this include managing road traffic signal services and coordinating with rail control systems. Information derived from the *Central Intelligence System* would drive traffic signal sequences allowing for the efficient movement of traffic through transportation corridors.

In the situation where there are one or more crises in local network segments, the Traffic Control system needs to not only manage the movement of traffic in that segment, but it also needs to predict the impact of the alteration within the network as a whole. At all times, *IMAGINATION* works at the micro **and** macro levels.

5.5 Vehicle Navigation System

This micro-level sub-system provides information directly to users of the traffic network. It dynamically suggests alternative routes based on traffic conditions such as known network incidents, and flow capacities. Again these suggestions are driven by information that is derived directly out of the *Central Intelligence System*

GPS technology provides the most natural solution to identifying the location of individual vehicles in the system and the mechanism by which updated information would be translated back to each network user. This information would be transferred to and from network users' available data transmission systems.

5.6 Monitoring System

This sub-system provides a *real-time* virtual representation of what is happening in the real world. This sub-system would be identical to any other currently available traffic management system, differing only in the way the information is presented to the user. It also provides a mechanism by which the users of the system can manually modify the current state of any of the elements in the system that they have control over, i.e. traffic signals, lights, etc.

It provides information to network managers, and subsets to network users as required allowing for manual re-routing.

5.7 Reporting System

This sub-system provides periodic and ad-hoc reports from historical data stored in the Data Storage System. Reports would include, but are not limited to, reports relating to vehicles using the network, network infringement hot spots, and other incidents such as congestion points.

5.8 Emergency Services and Enforcement System (EMS)

This sub-system, in consultation with the Reporting System, monitors in, *real-time*, the effects of natural disasters and the like, and also provides information for law enforcement officials with relation to traffic infringements.

Further to this, it will provide EMS personnel with the ability to detect vehicle crashes. This information can then be used to report on network deficiencies and 'black spots'.

This sub-system is primary geared towards providing emergency services personnel with an operational management tool.

5.9 Fares and Toll System

This sub-system provides a mechanism by which tolls and fares relating to certain corridors within the traffic network can be charged automatically back to drivers. These sorts of systems are currently available.

5.10 Extendable Interface Service

This sub-system provides the mechanism by which additional features can be added to the system without the need to replace the entire system. It also allows for feeds to be placed in and out of the system.

5.11 Use CASE Analysis, Entity-Relationships, DSMS Configuration and the Database Schema

5.11.1 Use CASE Analysis

We have created a list that is by no means exhaustive (nor detailed) of the various users of *IMAGINATION*:

(1) Road Construction/Management Agencies; will use the system for managing the current road, analysing the traffic conditions, planning construction of new road, maintaining the current road, charging levy for expressway/highway usage;
(2) Law Enforcement Agencies; will use the system for controlling traffic flow, treating traffic accidents, detecting speeding vehicles, chasing criminals,
(3) Environment Management Agencies; will use the system for monitoring air pollution, ultraviolet rays, etc
(4) Civilian users (car/bicycle/pedestrians); will use the system for identifying the best route and in-transit navigation, avoiding congestion, calling for assistance in emergencies;
(5) Military Organisations; will use this system for finding the optimal route to locations based on logistic needs, and for management the troop/civilian movements during emergencies;

(6) Commercial Organisations; will use the system for transportation planning with relation to the shipping of goods through the traffic network (such as couriers, freight organisations, etc);
(7) Public Transport Planners; will use the system to develop optimal public transport routes;
(8) Policy Makers: use the system to develop Public Policy that will benefit network users and balance this with the impact of the network on the environment. Further to this, they will use the system to look at future enhancements to the network that can minimise the impact on the environment.
(9) Traffic Managers; will use the system to manage vehicles within the network, to optimise both traffic flow and safety to all network users;
(10) Traffic Analysts; will use the system to analyse traffic trends, to model the impact of future changes to the network and to identify the environmental issues associated with existing and/or new enhancements to the network, just to name a few.

5.11.2 Prototype Entity Relationship Diagram

The prototype Entity-Relationship diagram is below:

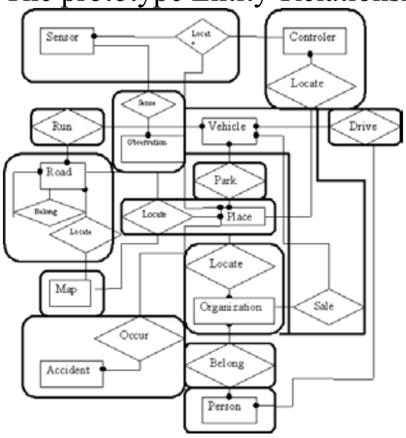
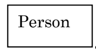
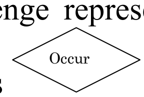


Figure 4 Entity-Relationship Diagram of Database Structure

In the ER diagram, rectangular objects represent entities, and appear similar to 

, and a lozenge represents relationships as thus 

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Lines connect the relationships with 1) many-to-one: ; 2) one-to-many: ; 3) many-to-many: ; 4) one-to-one: ______.

The database keeps dynamically changing information relating to accidents, data obtained by sensors and human activities, as well as static components, such as road network configuration, building/place (park, shopping mall, etc), organisations, vehicles, and persons. The observed data is transmitted from sensors directly or from streaming data pool. Some streaming data packets will be large and updated very frequently and therefore, it is impossible to store all data into a conventional database management system. The streaming database acts as a temporal storage system of streaming data, and filters the data to be stored into the historical database system.

5.11.3 Prototype Schema

The prototype schema is as follows:

Sensor	**Controller**	**Vehicle**	**Road**
Sensor-ID Sensor-Type *Place-ID* Maker Set Date Data Type Interval	*Controller-ID* Controller-Type *Place-ID* Maker Set Date Interval	*Registration-No* Vehicle-Type Maker Product-No Year Engine-Displacement Sales-Office-ID	*Road-ID* Root-Name Const-Date Paving-Type Length *Map-Location* *Upper-Road-ID*
Organization	**Person**	**Map**	**Accident**
Origination-ID Organization-Type Organization-Name Founded Date *Place-ID* Address	*Person-ID* Person-Type Person-Name Birthday Sex Address Role *Affiliation*	*Map-ID* Scale Image File Name Altitude Longitude	*Accident ID* Accident-Type Date & Time *Place-ID*
Run	**Park**	**Drive**	**Belong**
Vehicle-ID *Road-ID* *Date & Time*	*Vehicle-ID* *Place-ID* *Date & Time*	*Person-ID* *Vehicle-ID* *Date & Time*	*Organisation-ID* *Place-ID* *Term* Role
Observation	**Place**		
Sensor-ID *Date & Time* Value	*Place-ID* Place-Type Place-Name Address *Map-Location* Photo-File-Name		

Figure 5 Basic Relations of the prototype schema

5.11.4 DSMS Configuration

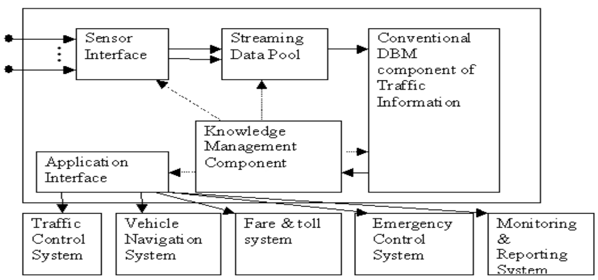

Figure 6 The Configuration of the DSMS

Figure 6 shows the configuration of the DSMS; this diagram shows the way that each component of the DSMS interfaces.

Role of each component:

(1) Sensor Interfaces: collect sensed data from the real world, for example, the arrival of cars at tollgates, video image by cameras, temperature, weather conditions, and traffic incidents reported by polices.

(2) Streaming Data Pool: collects streaming data transmitted by sensors. The streaming data is updated so frequently that traditional/conventional database management systems are not capable of managing it.

(3) Knowledge management component: Manages the 'knowledge' of how to detect the real world conditions, how to treat frequently updated data, how to accumulate streaming data and store them into the conventional DBMS, and how to trigger various controllers.
(4) Application Interfaces; connects various application systems, traffic control, vehicle navigation, information boards, fare and toll system.

6 CONCLUSION

In this paper, we have proposed the framework for a holistic integrated multi-nodal traffic network system, and the context within which it exists. Moreover, we have attempted to provide an overview of the work to be done; however, the elements presented within the overview are by no means exhaustive. We have also discussed that the design of the system lies in the way nature manages individual organisms, and how we intend to translate that core management strategy into a system that can holistically manage each aspect of the network as if it were an organism in its own right.

The benefits of such a system are numerous, but primarily they are: 1) the efficient transfer between major system components such as traffic control, traffic network users, and traffic network planners/analysts; 2) the improved efficiencies in traffic flow management; 3) increased safety for all network users; 4) improved route setting for network users; 5) improved intelligent traffic management and system self-learning through *experience*; 6) reduced traffic law infringement; and 7) enhanced "what-if" scenario planning/modelling, just to name a few, and each of these is as a result of taking a '*back-to-nature*' approach to system development.

6.1 Future work

The development of this system will be through a phased approached. Starting with developing micro-simulation models of small traffic network segments, data from these simulations and real-world sources such as train schedules, vehicle-borne GPS/navigation, and land use activity.

Concurrently, work will also be initiated in relation to the development of an enhanced DSMS that can manage *real-time* and *batch-time* data acquisition and information processing. Technologies such as GPRS enabled mobile phones, blue-tooth, and other wireless systems will also be investigated to identify lag time and data quality/integrity issues with data transmission to remote systems.

ACKNOWLEDGMENTS

Mrs Carolyn M Packard, Information Systems Manager TransAdelaide. For her assistance in ensuring the database management issues were realistic.

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