On Concurrent Holistic-Component Dynamics and Traffic Analysis

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1 Introduction

Intelligent Transport Systems (ITS) technologies are now widely used in transport systems operations but the impacts of ITS in transport policy formulation are less obvious. In many cases, it could even be that ITS represents 'solutions in search of a problem', at least from the policy perspective (Taylor and Bonsall, 2001). This is not always the case, nor need it be. The main purpose of this paper is to indicate at least one method by which ITS may be able to assist in future transport policy development, by providing access to cheap data resources about the detailed, dynamic performance of urban transport systems, using existing infrastructure and without the need for special intervention for data monitoring, to assist in network analysis.

The concept of the 'hierarchy of traffic models' and the differences in the level of resolution available when using different models is widely known (Taylor, 1991, Taylor, Scrafton and Oxlad, 2004); generally in transport analysis we consider three levels, macroscopic, mesoscopic and microscopic. At the macroscopic level, we focus on the strategic machinations of transportation, at the mesoscopic level we are interested in 'link-level' analysis and at the microscopic level we focus our attention on the individual components of the network. However this restricts our view; the need to focus our attention on one aspect may cloud our view of its global impact, and vice-versa.

In a typical metropolitan area, it is normal to dissect it into smaller geographic regions for the purposes of analysing trip movements and managing traffic volumes, based on land-use and zoning. However, levels of pollution from adjacent zones would rarely if ever be considered during (for instance) traffic signal design for a given intersection

Concurrent Holistic-Component Dynamics (CHCD) aims to rectify this by taking into account that a system is more than the sum of its parts, but that at the same time that there are times where the effect of an individual component in a specific area out-weighs its impact globally and each of these can occur at the same time.

Overlaying requirements, the physical interaction between transportation bodies, zoning regulations, the complex interaction between humans and human endeavour/activities, and environmental issues all contribute to the transportation system as a whole, whereas individual vehicles, industries and activities are all components, temporal in nature, that have the ability to traverse the boundaries we impose; thus finding the best solution for a given intersection may in reality cause problems in neighbouring intersections and to the system as a whole.

So, in this paper we will explore the tenets of Concurrent Holistic-Component Dynamics, its application within Locality-Scope and how the ability to view transportation networks as a whole and at the component level simultaneously and dynamically will improve system analysis and overall network performance.

1.1 A point of order

Throughout this paper the term 'system' will be used. Typically we view this to be a *computerised system* which has been developed to function on computers for the purpose of calculating some 'thing'. The authors ask that this notion be replaced with the notion that a *system* is a collection of entities that interact with one another through set rules and boundary conditions, for example, the transportation system. Any mention of a computerised system will be prefixed with the term ‘computerised’ or ‘computer’. This is important; the contact author is a software engineer with many years of commercial experience, but in his very humble opinion, he finds that people tend to race towards computerised solutions before truly understanding the problem at hand. Many times in his career he can point to cases where simply using pen and paper or a very basic spreadsheet would have sufficed but where clients wanted sophisticated software packages. The aim, then, is not to discuss *yet another computerised solution in search of a problem*, this is not to take away from those who justifiably develop computerised systems through necessity, rather it is to try and understand transportation and the transportation system as an *organism*, an animate entity that reacts to internal and external pressures and that functions with the sole purpose of serving its human creators. This suggests a similar approach to the concept of the urban transport system as a *dynamic self organising system*, a paradigm advocated by Rooney (1998) for the planning of sustainable transport and land use systems.

2 Background and History to Locality-Scope

2.1 Introduction

In 2003, Vogiatzis et al (2003) discussed a new type of Urban Traffic Control (UTC) system whereby all vehicles would be connected to the ‘system’ from which the computerised system would be able to best ‘load balance’ the network for greatest efficiency. One of the first stumbling blocks towards the development of such a system was that the amount of information that would be required to be stored, managed, analysed and ultimately actioned would be significant and may well cause decisions to be made that after subsequent events have occurred ultimately render the ‘calculated’ decision useless.

Vogiatzis and Ikeda began the development of the notion of ‘Locality-Scope’, focusing on the implementation of the IMAGINATION concept system. Within the context of transportation, however, some expansion and modification of the high-level notions created by Ikeda and Vogiatzis and their colleagues need to be made. This paper, then, addresses this by broadening ‘Locality-Scope’ and it acts as a continuum to all the previous work. Ikeda and his colleagues have also specifically extended computer science/practical application aspect of the paradigm by then going on and developing 3LOM (Three Layer Object Model for Transportation System Integration) (Ikeda, Vogiatzis, Wibisono, Mojarrabi and Woolley, 2004b) as the practical manifestation of ‘Locality-Scope’ whilst Vogiatzis and his colleagues have concentrated on developing the theoretical basis for ‘Locality-Scope’ (Vogiatzis, 2005, Vogiatzis, Ikeda and Wibisono, 2004, Vogiatzis, Fehlmann, Kelly, Mitchell, Chaudry, Shuttleworth and Malallah, 2006) which complements Ikeda’s direction and development of the concept system IMAGINATION.

Locality-Scope itself can be viewed in several ways however no concrete decision, from a theoretical stand-point, has been reached on what it is exactly.

Vogiatzis et al (2004) defined Locality-Scope from the perspective of a computer science implementation, and they did so in the following way:

> ***Locality*** *is implemented as a transactional system using historical and statistical data as the basis for deciding the optimal phases for a signalised intersection. Furthermore, locality can be either a singular signalised intersection or a grouping of related signalised intersections.*
>
> ***Scope*** *is implemented as a knowledge generation, management and application system that identifies intentions and objectives as being the basis for decision making.*

Although accurate, these definitions are tightly coupled to computer science and the development of a computerised system. Nonetheless, it can be seen that Locality-Scope, at its heart, is a *decision making paradigm*. This is important to note as it aims to bring together mathematical and non-mathematical theories by providing the 'glue' that links them together. It is not meant to be a *unifying theory*; at least this is what the authors expound. Whilst it cannot be unifying as it ultimately it is a theory that leads to decisions; it does not proclaim that by using its formulae one can solve all challenges within transport, but it does have the potential to be used outside of transport. This being the case, there is a need to define these definitions outside of a specific field; transport is multi-disciplinary and as such, we need ways to discuss these ideas generically enough to make them useful, and specific enough to allow them to be scientifically validated.

2.2 Guiding Principals of Locality-Scope

Until now, there has been no formalisation of the guiding principals of Locality-Scope; what is to follow are the general guiding principals of Locality-Scope as the authors believe they should be:

1. Group and individual dynamics, being able to identify and balance the wants, needs and desires of entities and of entity groups is important.
2. The interaction between entities has both a local and global effect; seemingly disparate entities have the ability to affect the functioning of one another.
3. Where practical, it is possible to view entity interactions as being isolated systems. In such cases, we can use this to both speed the process of understanding the mini-system and subsequent decision-making.
4. Entities within a system can only infer the strategies and tactics of other entities through their *behaviour*. The actions of one entity are thus interpreted by other entities based on their understanding of the context in which the first entity exists, their experiences, the inherited experience of other entities as passed to them, and their internal bias.
5. Each entity has a *worldview* of the system itself; this view is mono-directional and information to and from each entity is also mono-directional (that is one entity can not 'look into' the worldview of another entity) [principle is based on the work by Wiggerts (1995a, 1995b)].
6. The time between the beginning of 'significant' events occurring and the entity finally reacting is called *system latency* within the context of Locality-Scope. The term is used generically, however there are distinctions; *entity latency* would more commonly be referred to as *reaction time*, and *group latency* is latency in a group of entities. In the case of group latency, we can treat the group as a *system* in its own right.
7. Each entity maintains knowledge at its global and local level; this forms a holistic and component level of system knowledge/understanding. Access to this information is concurrent and the amount and quality of that information is dynamic.
8. Holistic understanding of the system is more than the sum of the component parts; the combination of certain components leads one to a greater level of understanding based on accepted system norms, historical context and current image of the specific moment at hand.
9. Each entity makes its decisions based on the level within which it exists; when necessary it may refer to other entities regardless of level thus allowing for the free flow and improved quality of information.
10. Any *human-centric* system displays *guided self-organisational* (cybernetic) properties; that is, systems such as transportation systems are not wholly self-organised, they function within a certain set of boundary conditions and general rules for behaviour. The process of managing transportation systems requires the *system* to *understand* that human endeavours are guided and self-organised at the same time and self-improve through feedback.

Note that many of these principles can be directly applied into a computerised system however this is not their reason for being. Rather it is a side-effect of the current level of computational resources that are available today.

2.3 Intelligent Agents/Multi-Agent Systems

The points in the previous sections could, and most probably would, be modelled using Intelligent Agents in a Multi-Agent System (e.g. as discussed by Panwai and Dia (2005). This is a natural assumption as each entity can be modelled as an object within an object-oriented model, and the requisite *intelligence* (rules by which the agent must behave) can be encoded within them. However, again, it is important to note that the purpose of CHCD is not to simply develop a computer program; rather it is to provide a framework that can equally be applied outside of a computer based solution. The intelligence we need to model is humanistic, that is, we need to be able to understand the impact of our decisions as being more than statistical weightings applied to rules of behaviour. Aberrant behaviour is as important as nominal behaviour.

2.4 General Systems Theory and Biomimicry

In many of the Locality-Scope papers that have been presented the notion that both Locality-Scope and the concept system IMAGINATION are 'taken from nature' has been emphasised. General Systems Theory forms the basis of many decision making theories and is also the basis of Complexity Theory. The use of Complexity Theory within transportation is important as we have, ultimately, complex entities (humans) interacting with one-another, within the bounds of a physical universe, and bounded by human-centric laws, rules and regulations to promote equity and utility within transportation.

2.4.1 General Systems Theory

We start with a general definition of General Systems Theory:

> *Systems Theory: The trans-disciplinary study of the abstract organisation of phenomena, independent of their substance, type, or spatial or temporal scale of existence. It investigates both the principals common to all complex entities, and the (usually mathematical) models which can be used to describe them.(Heylighen and Joslyn, 1992)*

Heylighen and Joslyn (1992) indicated that Systems Theory was first proposed by biologist Ludwig von Bertalanffy in the 1940s and that:

> *Von Bertalanffy was both reacting against reductionism and attempting to revive the unity of science. He emphasized that real systems are open to, and interact with, their environments, and that they can acquire qualitatively new properties through emergence, resulting in continual evolution. Rather than reducing an entity (e.g. the human body) to the properties of its parts or elements (e.g. organs or cells), systems theory focuses on the arrangement of and relations between the parts which connect them into a whole (cf. holism).*

Skyttner (2001) says of Systems Science:

> *Systems science too has its specific point of view: to understand man and his environment as part of interacting systems. The aim is to study this interaction from multiple perspectives, holistically. Inherent to this approach is a comprehensive historical, contemporary and futuristic outlook.*

When Vogiatzis et al (Vogiatzis et al., 2003, Vogiatzis et al., 2004) and Ikeda et al (Ikeda, Vogiatzis and Wibisono, 2004a, Ikeda et al., 2004b, Wibisono, Ikeda and Vogiatzis, 2004) discuss the many *computational* aspects of the concept system *IMAGINATION*, one of the prime requirements was a system that was able to make decisions for transportation management based on historical and current data whilst being able to pre-emptively forewarn other system components of 'issues' that they may need to be aware of ahead of time in order to ensure that these other components could react faster.

Von Bertalanffy (2003) discussed the ideas of General Systems Theory (GST). He was concerned that science was being reduced to physics (and ultimately mathematics) and that there were certain biological phenomena that could not be described physically. Furthermore, he felt that scientists were not discussing their ideas across disciplines and that it was *'…difficult to get word from one cocoon to the other.'* (von Bertalanffy, 2003) Transport is a multi-disciplinary field of science, we hear this on a constant basis and we see evidence of this by the diversity (albeit dominated by transport economists and engineers) of researchers interested in the challenge of transporting humans and goods from one point to another.

von Bertalanffy went on to say:

> *... it is necessary to study not only isolated parts and processes, but the essential problems are the organizing relations that result from dynamic interaction and make the behavior of parts different when studied in isolation or within the whole. (von Bertalanffy, 2003)*

Transportation, being human-centric, is about the dynamic way individuals by way of personalised transport or by means of moving 'things' from Point A to Point B, the way we behave whilst on the road and the demands we place on goods and services which induce traffic flow; sometimes leading to transport infarctions which have the potential of bringing to a holt the socio-economic fabric of society.

Holism underlies the paradigm of Locality-Scope. The need to understand localised and system wide issues and events, to analyse and synthesise them within the context of themselves and with relation to all other components and entities forms the basis of advancing, in this specific instance, decision making within transportation management systems. However Langlois (1983) suggests that *'… holism is the doctrine that we should somehow study wholes* ***directly*** *without considering the workings of parts in a meaningful way.'* This suggestion is made with the back-drop that Langlois believes that to-date systems theory has not fulfilled its promise. Nonetheless, it does reinforce the notion of *Holistic-Component Dynamics* as described within Locality-Scope as a necessary tool for allowing one to manage any system, specifically transportation systems in this case.

Locality-Scope also aims to explain humanistic phenomena and therefore provide the framework for decision making. As has been mentioned before, Locality-Scope is a decision making paradigm, based on systems thinking, holism, emergence and the interaction of humans with their environment, therefore it is not unreasonable that as a part of the process of decision making, one must first **understand** the environment that one is attempting to manage.

Skyttner (2001) discusses this point and draws our attention to some of the differences between classical reductionist science of analysis and systems thinking:

> *Analysis gives description and knowledge; systems thinking gives explanation and understanding.*

This does not suggest any mutual exclusivity, rather it makes the point that here we have two parts of a whole. Analysis provides us with detailed description which helps with our ability to develop and formulate algorithms etc, and thus improve our knowledge of a given topic, whereas using the systems thinking paradigm we are able to explain why things happen the way they do and understand the underlying reasons for it being so. Together, they form a foundation for decision making.

Furthermore Skyttner (2001) states that for systems we develop *synthesis* which is the opposite to *analysis* and in fact is also performed in the reverse order, that is, synthesis is done by following these steps:

- Identify the system of which the unit in focus is a part;
- Explain the properties or behaviour of the system;
- Finally, explain the properties of behaviour of the unit in focus as a part or function of the system.

Our aim, then, is to study systems as a whole, to see the interaction of each entity with all other entities and then to explain the reasons for why this happens. However, we need to understand the *type* of system we are dealing with.

2.4.2 Biomimicry

Benyus states (1997):

> *Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.*
>
> *Biomimicry uses an ecological standard to judge the "rightness" of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.*
>
> *Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it.*

These basic principles form a platform for sustainable living; the aim, then, is not just to build *yet another computer system*, rather to develop the requisite tools for living in harmony with the natural world. It is necessary to find the ways to adapt the current transportation system and slowly transform it into a system that is healthy for us and the environment.

These things can not happen overnight; the view that somehow applying an idea that we believe will benefit humanity *immediately* will solve problems is a misconception: people do not want to be told what to do, how to do it, when to do it, or to do it at all. Is this then the *death knell* for sustainable transport? Hardly, what is necessary is for transformation to occur at a pace that the general populous is comfortable with. By looking at nature for the solutions to our problems and challenges, we can slowly adapt them for the way we *wish* to live and thus bring ourselves closer to an efficient, clean, sustainable, natural approach to transportation in general.

2.4.3 Bringing it all together

General Systems Theory provides us with the mechanism by which we can think about transportation holistically. It gives us an approach that is formalised and takes into account the inherit complexity involved. Biomimicry provides the platform for any solution found to be applied in a sustainable manner; one that is *on-par* with nature and the natural world, and one that allows us to integrate nature into our solutions without sacrificing the level of comfort and standards of living we currently enjoy.

3 Organic Transportation: a new transportation science

From the discussion in the previous section, we can deduce that transportation systems are a type of eco-system inhabited by organisms. If, as stated earlier, transportation is human-centric, then it is natural to refer to transportation in an organic way.

In as much as Locality-Scope is a decision making paradigm, it exists within this new type of science, being *Organic Transportation*.

Organic Transportation, then, can be defined as follows:

> *Organic Transportation is the study of transportation systems as forming* ***organisms*** *of interacting entities within a transportation eco-system. The various organisms are formed from multifarious interests and segments of society that use particular aspects of the transportation eco-system to their benefit and that these interactions can lead to eco-system decay or even infarction if not managed properly and thus has the capacity to adversely affect extraneous systems/eco-systems. These organisms are potentially polymorphous and the micro-organisms (individuals) that form them can exist in one or more such organisms at the same time.*

Viewing transport, then, as an organism, leads to the notion of transportation systems as complex, non-linear and non-deterministic systems that must exist within certain resource-limited boundary conditions and that an imbalance within the system has the potential to significantly impact on itself and the society which it is designed to support.

By applying Systems Thinking, Bio-mimicry and Sustainable processes to transport means that there is at the very least a tacit acceptance that transportation is a component of the environment and that by balancing its impact on the environment with the need for society to move forward will ensure its effectiveness in the long term. That being the case, then treating transportation as an organism, such as one would with any *living* creature, can lead to developing transportation that is more in harmony with the natural world. More about Organic Transportation will be discussed in a later paper.

Concurrent Holistic-Component Dynamics, within the context of Locality-Scope, is an attempt to understand and balance the system holistically and specifically at the same time whilst being mindful of its impact on and its place in the natural order.

4 What is 'Concurrent Holistic-Component Dynamics?

4.1 Introduction

We now come to the heart of the topic being presented. Concurrent Holistic-Component Dynamics (CHCD) started its life as Simultaneous and Dynamic Network Scalability (SDNS)(Vogiatzis, 2005) and at that time the main aim of SDNS was modelling based on events that are viewed simultaneously at every level between the macroscopic level/context and the microscopic level/context without loss of generality. This notion has not changed, but it is applied to more than just what is 'happening' on the network itself. Regardless of whether it is the movement of people, goods or vehicles, or changes in Green House Gas (GHG) emissions, the ability to monitor the transportation system as a whole in its holistic sense and then specific parts of the system when the need arises allows for a *cross-focal* analysis of transportation. So, in this sense, CHCD is the ability to monitor the system holistically, without the need to worry about what is happening at a 'lower' *component* level, and then as required, *zero-in* on a particular aspect of interest and analyse the situation at that level, solve any problems that may be there and then go back to monitoring at a holistic level.

To develop a macro-model, we generally/typically use aggregated information. We are not necessarily interested in individualised movements of people or vehicles or emitted particulates; rather we are interested in how the overall data provides us with a global picture of the area of interest. To develop a micro-model, on the other hand, we *are* interested in each specific movement of the person or vehicle and the movement of particulates.

In either case, when we develop a macro-model, the necessary aggregation leads to a loss of generality, unless we have access to the original data. That is, once aggregation occurs we can not necessarily go the other way. There are, of course, many techniques one can use to disaggregate data, however in the case of transportation systems management, we may have lost critical information such as route choice and trip chaining, and thus we are left with some ‘statistical’ understanding of the state of the system before aggregation which is, in some cases, less than acceptable.

4.2 What sort of information are we interested in?

When discussing the control of vehicles within a transportation system we might suggest that we want to know the movements of each vehicular entity (this includes motorcycles, bicycles, passenger vehicles, buses, trains, rigid trucks, etc), when discussing freight forwarding we may be interested in the types of containers used, what consignments they hold and where they are going. If one is interested in GHG emissions then we may be interested in land use and zoning, the location of high pollutant industries and the road corridors along with the vehicle fleet that services them.

In holistic transportation systems management, we are interested in all of these. For example, there may be a school near an industrial zone. Then knowing the volume of emissions from vehicles and industry, along with the chemical mix, is as important as the number of vehicles that pass through the school zone. For this particular suburb, we may have as key criteria for action the level of vehicle emissions and industry emissions. Should these exceed a preset value for the day, then action is taken to, in the first instance, re-route all unnecessary vehicular movements through that area, and then maybe inform certain industrial operations that they need to curb their activities. This is all well and good, but what about the economic impact of such a decision? The point of CHCD is that one needs to *balance* the requirements of all concerned, that is, in such a case, there may be provision to compensate industry for any loss of productivity if they deem the environmental impact of the higher than normal levels of pollution as being more important.

There are no easy answers here; this is not about a blanket solution that does not take into account the needs of all.

One of the great difficulties will always be what data to use, how available it is, and when is the best time to use it. Data collection and analysis is costly and time consuming, and resources cannot always be provided for it. On the other hand, there are opportunities to access some data, such as traffic movement data, that may be monitored routinely for other purposes (e.g. urban traffic control), but not put to further use once the immediate application is over. Data of this kind represents an under-utilised if not ignored resource. The general problem until the advent of advanced ITS technologies was the means for efficient utilisation of the data. There are consequent problems about the usage of data on specific individuals for purposes beyond which the data was originally collected (e.g. see ITS Australia, 2001), but for data such as vehicle counts or intersection performance this is not the case. The difficult with such data has been the practical one of access and extraction from extremely large databases (e.g. Rice, 2004).

5 How is CHCD used?

By the name, one might think that this is something that occurs in real-time. Although the heritage of the notion began as a way of managing high volumes of real-time data, this is not its ultimate purpose.

CHCD is the *balancing* component to Locality-Scope; but balance in what way? There are times when for the system to be in balance, we need the global system to be out of balance whilst we balance a component region. Once that component region has settled, the whole system should have also settled into overall balance. Furthermore, the notion of balance is more than just getting volumes and travel times right. Any number of balance priorities may need to be considered; thus balance can be defined as:

> *Balance is finding the best mix of solutions that satisfy the greatest number of needs/problems without significantly impacting on the ability for each member of society to fulfil their daily tasks.*

Consider for a moment a typical region within a transportation region: it might contain a residential zone, light industrial zone, a shopping complex that acts as a significant attractor within the region, and several schools and old-age facilities. We also typically have some arterial roads, collector roads and local streets. Schools in the area may have been placed on the arterial links because of historic population distributions; however they now are located close to the light industrial and shopping zones.

Vehicles moving through this geographic region are not necessarily local. For instance, the arterial road may well act as a freight corridor and thus the origin and destination of these vehicles may occur outside of the regional boundaries.

Important inputs for balancing the needs of the link in relation to the needs of the wider community include:

- Identifying the types of traffic and the vehicle fleet that use the road network within the region
- the need to enforce legislative requirements on the road network and the particular links in question
- the land use at each sub-link level that makes up the link/land use profile for the link in question and its association with other roads in the vicinity, attractors, route choice and the needs of the members of the communities that line the link.

Thus the more information that is collected, analysed, and stored with the necessary inferences developed leads to the provision of a balanced solution for specific links in relation to each other (component) and in relation to the needs of all (holistic) ***without loss of data generality***. Whilst component requirements are not being breached, only the holistic needs for a region, and the various levels leading to the whole network, need to be monitored leading to a reduction in monitoring resources.

It is important to note that a region need not be a geographical region; rather a region is an abstract notion that can refer to any collection of similar natured entities that can be grouped for the purpose of simplification. Thus a geographical region is a collection of entities within a certain distance from each other or contained within a drawn border for some reason of ‘convenience’ whereas a pollution region, although may be geographical in nature, may be the collection of all industrial emissions points within a certain distance from one another and this may cross several geographical regions.

So, for CHCD to function, regions need to be defined, the nature of these regions needs to be explored and quantified, the ability to monitor these regions on an ongoing basis needs to be established, and dynamic regional conflict resolution policies need to be established and implemented so as to ensure the network remains in balance. These regions and their associated conflict resolution policies form a type of interlinked hierarchy; that is, it is possible for a lower level to communicate with a higher level within the hierarchy without passing directly through any intermediate levels. Furthermore, regions of the same level can overlap thus forming a vertical, horizontal and temporal (continuous and discrete, depending on the application) collections of regions, and conflict resolution policies based on:

1. The type, frequency, structure and complexity of the decisions to be made;
2. The characteristics, abilities and requirements of the decision makers (*viz, automated or human*); and
3. The institutional and political contexts in which the decisions are needed. (Chambers and Taylor, 1999)

Ikeda, Vogiatzis and their colleagues (2004b, 2004a, 2004, 2004) discuss technical solutions to this problem, but here we are more interested in a theoretical solution that is independent of specific technical implementations.

6 Moving towards building the elements of CHCD

Understanding traffic and the transportation network is the first step towards building the elements of CHCD. How does traffic behave at different times of the day, what impact does weather have, what is the primary use of the road in question and how many incidents occur on that section of the network? These are just some of the many questions that first need to be answered.

The development of a knowledge base for transport is not a new concept; Clement, Woolley and Taylor (1996) and Vogiatzis, Ikeda and their colleagues and many others all discuss the importance of knowledge engineering in the management of transportation systems.

The types of knowledge bases available for transportation are also numerous; inter-modal transport, freight, etc; in each area of transportation, it is possible to point to some effort or another that works towards quantifying knowledge in some way. So, how does CHCD differ?

CHCD relies on more than just stored knowledge accessible by either internal computer programs or by operators; rather the development of various expert systems and other artificial intelligence (AI) techniques that can provide *value-add* supports the knowledge management component of CHCD and thus allowing for providing a set of optimal solutions that can then be assessed by operators who will then make the final decision on what is to be implemented. Interestingly, though, is the fact that to develop the necessary framework for CHCD one does need to analyse data and thus this does lead to the need for a computerised system. However, in this case, the computerised system is a tool for developing the framework and is expected to be different to the final implemented computerised system that *is* the framework in action.

As mentioned in previous sections; CHCD focuses on analysing low-level (microscopic), high-level (macroscopic) and all 'in-between'-levels (mesoscopic) *at the same time*. For this to occur, one needs to collect and analyse a variety of data from disparate data sources. To manage and store this data is a difficult task.

6.1 Some initial analysis

To begin the process of developing the expert system that supports the notions of CHCD, it is important to first develop a knowledge-base of traffic behaviour. The collection and analysis of fundamental data, such as data that is routinely collected from Urban Traffic Control (UTC) systems, is a 'first port of call' if one wants to understand the movement of people and goods within a transportation system. The problem with collecting such data is the sheer volume that is available and the difficulty associated with its analysis. Depending on the way in which a UTC has been configured, one can quickly reach data sets containing in excess of the order of thousands of million records. So, the construction of the expert system starts with the necessity of developing computerised database systems capable of storing and analysing such large data sets.

As a first step, data from the ACTS (Adelaide Coordinated Traffic System, a customisation of the Sydney Coordinated Adaptive Traffic System, SCATS) UTC system was collected from all the regions of metropolitan Adelaide. The resultant dataset was for the time period of May-August 2005. Using the NEXUS II implementation (Fehlmann, Kelly, Mitchell and Vogiatzis, 2006) of the NEXUS: Transportation Research System (Vogiatzis, 2006) analysis of five minute vehicle counts for all intersections within the Adelaide Metropolitan area was performed. A compute cluster of four computers using the Windows Server 2003 operating system, PostgreSQL 8.1 Object-Relational Database and the ExtenDB Parallel Server middleware was implemented to query the dataset.

A great deal of time has been spent on finding an analysis solution to the problem of very large data sets. VLDB (very large database) technology is important in the analysis of traffic signalling data. Although it is easy to analyse day-by-day data, any attempt to analyse data over long periods such as monthly, quarterly or yearly data over the entire metropolitan region is not so simple. Running statistics provide a way of simplifying the task; however the ability to access raw data directly as required provides the greatest flexibility. Thus providing facilities that efficiently report on very large data sets (e.g. exceeding 100 million records) is essential in move towards artificial intelligence control/management of signalling systems.

The resultant data from the above query was then further analysed to create the following morning peak intersection traffic volume profiles for the southbound arterial route comprising Port Wakefield Road and Main North Rd for the given date range. Figure 1 shows this route highlighted on a GIS map covering the northern half of the metropolitan area.

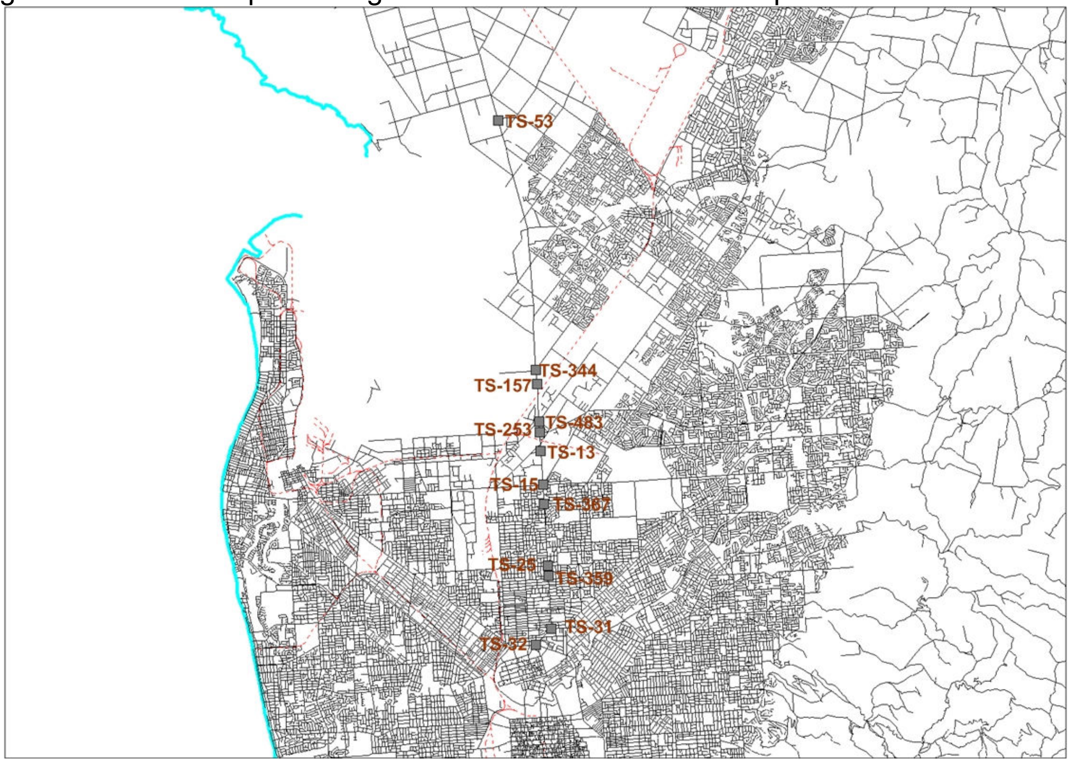

Figure 1 Map of the Study Area, showing the survey route with colour coded intersections

Figure 2 shows the intersection traffic volume profile for intersection TS 53, the intersection of Port Wakefield Road and Waterloo Corner Road, the most northerly of the intersections analysed. This plot shows the average five minute vehicle counts for the AM peak direction detectors on the approaching leg for the intersection over time (07:00 – 10:00). The plot thus shows the average variation in total traffic volumes at the intersection over the time period, and reflects the variation by time of day in these counts. Further analysis of the data can be undertaken to study variations on given days (e.g. every Wednesday) or to study turning movement (depending on detector configuration) at the intersection.

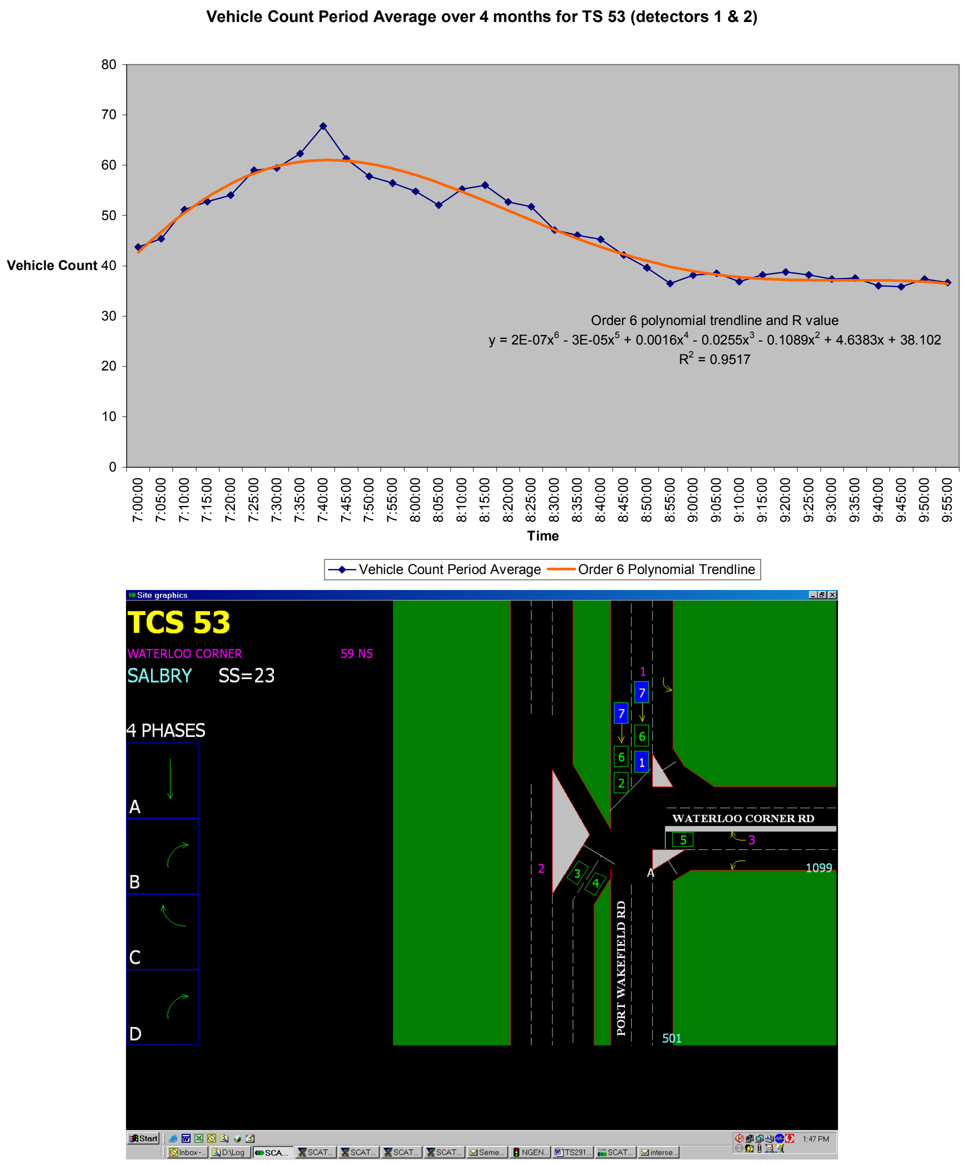

Figure 2 Intersection traffic volume profile (mean five min vehicle count over a four month period) at the intersection TS 53 (Port Wakefield Rd/Waterloo Corner Rd) extracted from ACTS VS data file and the intersection diagram from SCATS. The chart also graphs the polynomial trend line curve (red/smooth line).

Figure 3 shows the family of traffic volume profiles for four (five if one includes Figure 2) of the intersections only on the survey route. All of these data were extracted from the routinely collected, historical traffic counts monitored by ACTS(/SCATS) without the need for special data collection. The database used to produce these graphs (Nexus) has been developed in the TSC primarily by Vogiatzis (2006), and more recently by two groups of three 4th year/Honours Software Engineering students under the supervision of Vogiatzis and Wahlstrom, being Fehlmann, Kelly, Mitchell (2006 team) and Chaudry, Shuttleworth and Malallah (2005 team) (Vogiatzis et al., 2006). To produce the initial results, 344 million records were uploaded to the database cluster; these records represent four months of five minute vehicle count data for all of the Adelaide Metropolitan regions (nine in total) between May and August 2005. The upload time for the data into the cluster was approximately 30 minutes after the data had been converted into the appropriate database format. The transformation process took approximately three to four days, however since then a new technique has been established in which to upload seven regions of Melbourne VS 15 minute vehicle count data that spans two years has taken approximately eight hours (Kelly and Vogiatzis, 2006). Once the data has been loaded, a sub-set of data was produced totally approximately 900,000 records in about 3.5 minutes. Each graph below takes about five to ten minutes (including the time to run the query on the sub-set) once the appropriate SQL has been established. The time to establish the correct SQL is dependent on how one wants to view the data. In all, to produce the 12 graphs (four of which are presented in Figure 3 due to space limitations) below, has taken (assuming the new technique) about a day and a half.

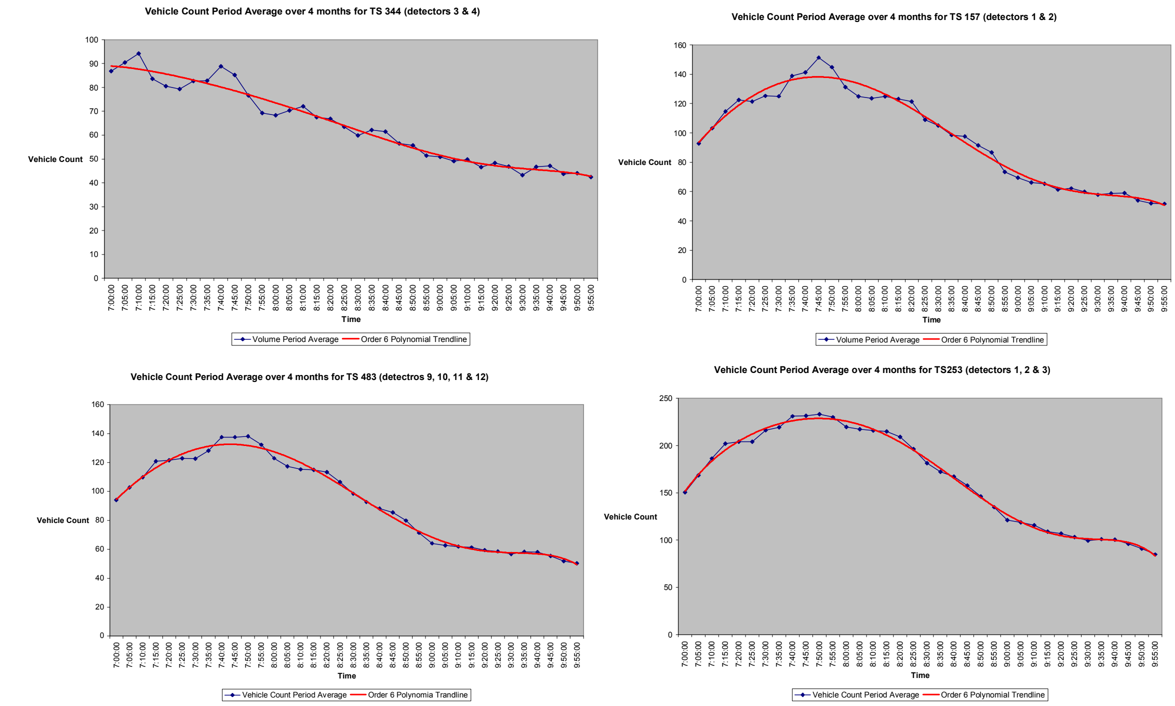

Figure 3 Four of a total of 12 (not all shown due to page limitation) intersection profiles comprising the southbound morning peak route along Port Wakefield Rd/Main North Road in the northern suburbs of Adelaide, in order of intersection heading from North to South: analysis of the pilot data investigation.

A number of interesting things to note: 1) at this initial stage of analysis, no attempt at identifying ‘significant events’ or ‘incidents’ was made, this was, after all, a pilot investigation; 2) the meteorological data for each day of the analysis was not considered, although these could be merged into the database and used to examine the impacts of different weather events (e.g. rain) on traffic performance[1]; 3) although detector faults and ‘no signal’ analysis was performed, the values presented are purely averages for the peak direction through the intersection excluding detector fault and detector alarm data; 4) no analysis relating to the individual effects of non-route traffic entering the route was considered although the MASTEM Model (Holyoak, Taylor, Oxlad and Gregory, 2005) was used to briefly investigate the best route to apply the pilot investigation. The cumulative effects of traffic feeding on to the route are however included.

Even though this is a ‘first run’ analysis, it does show some interesting features: 1) each graph generally has a ‘singular’ peak; and 2) the timing of the singular peak generally moves temporally, with the peak being ‘later’ as distance between the intersections in question and the CBD reduces (see Figure 4).

In Figure 4, we have a plot with linear regression of the time at which the maximum five minute vehicle counts occurs in the study route. If one looks at the linear regression (blue/straight line), one can see that as the distance between the intersection and the CBD is

[1] It may be postulated that unusual or sever weather events can have significant impacts on traffic flows on the network over short periods of time. The analytical tools in developed in CHCD can be used in future research to study any such impacts.

reduced, the time for a maximum to occur at the given intersection is later during the morning peak. We expected this to occur, for a number of reasons, including but not limited too:

1) travelling into the city; those who live closer to the CBD have less distance to travel hence leave later for work/task and vice-versa; and
2) as vehicles travel along a given corridor, one suspects that the concentration of vehicles increases as one gets closer to the city (that is, those who live further out are mixing with those who live further in), so roads reach capacity sooner making travelling along those routes more time consuming.

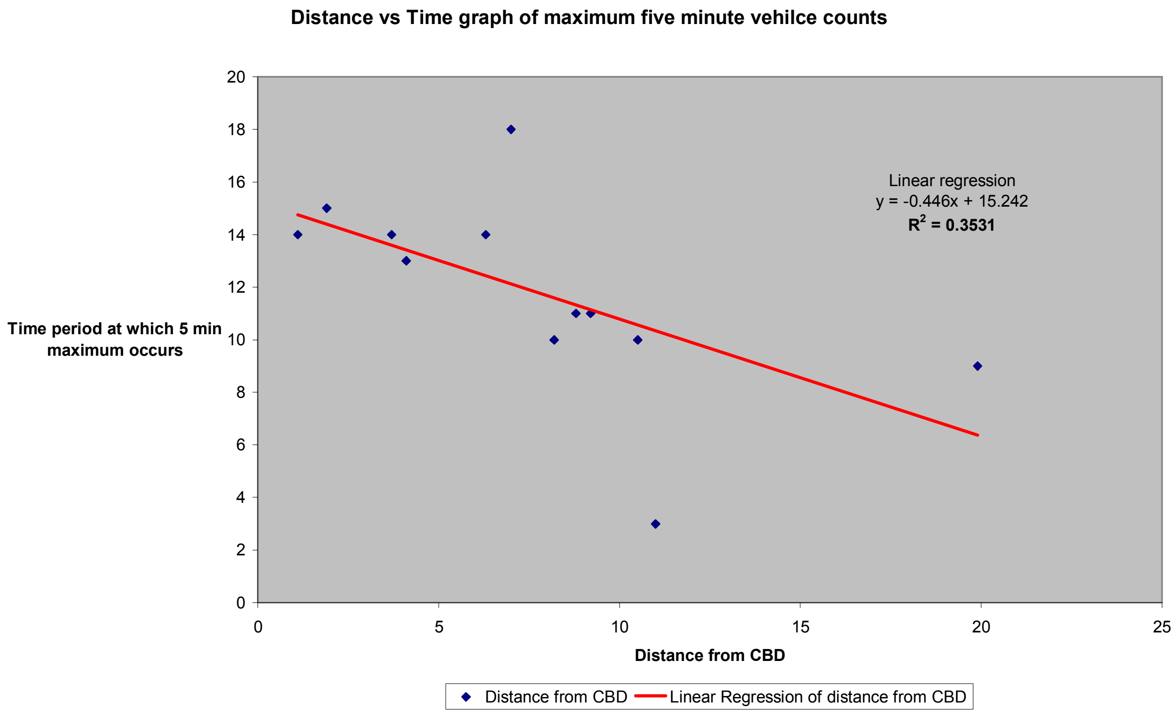

Figure 4 Plot of the time at which the maximum AM Peak vehicle counts occurs at each intersection (based on distance) along the study route with linear regression.

Specifically, from Figure 4, we can see that the relationship between the time at which a maximum vehicle count occurs and the distance of the signalised intersection from the CBD may be represented by a direct proportionality for example:

$$T \propto d \qquad (1)$$

However with R^2 = 0.3531, the correlation does not appear to be strong. Furthermore, as can be seen from Figure 4, flows at the two intersections below peak at the same time, and they are:

- intersection TS 483, (Churchill Rd and Port Wakefield Rd), where two freight corridors intersect and which is in the vicinity of heavy and medium industrial zones)
- intersection TS 253, (Diagonal Rd and Port Wakefield Rd), approximately 400m from TS 483.

This could be an indication that the link itself has reached capacity between these two intersections. The apparent 'similarity' for the peak maxima for TS367-TS32 could also be explained by the link having reached capacity. Brief further investigation has shown that the differences between the maximum vehicle counts and the vehicle count in the period five minutes before and after the maximum are all within 10% of each other for all the study intersections, thus lending weight to the view that the intersections are at capacity and therefore the values may not be as significant as one would hope. Further investigation would include the necessity to normalise for the capacity of the intersection, looking at specific movements rather than all the movements, and using cycle-by-cycle counts rather than five minute vehicle counts (Zito and Vogiatzis, 2006).

The movements at TS53, being the outer most intersection and on the fringe of the Metro Area may not all be directly to the CBD, but from a macroscopic perspective it can be seen it nonetheless has an influence on the overall movement South (even if only a small one); this needs to be investigated further as a part of a planned study project. TS25 and TS359 both peak at 0800 and 0805 respectively; the distance between TS25 (on the corner of Regency and Main North Roads) and TS359 is approximately 370m, with two major shopping complexes being situated on the Southern side of Regency Rd, being the North Park Shopping Centre on the western side of Main North Rd and Sefton Plaza on the Eastern Side. The land associated with the link between TS 359 and TS 31 (Main North Rd/Nottage Tc) is used primarily for retail businesses including motor-vehicle traders, several large electrical appliance stores, a large office stationer, and various other local businesses. The fact that a peak occurs at TS25 at 0800 and then at 0805 at TS359 when the distance between them is so short is of interest when considered with the fact that the peak at TS31 which is about 2km away from TS359/TS25 occurs at 0810. Naturally, this could also be explained by the fact that the resolution we have is only at five minute intervals and that investigation of the Strategic Monitor (SM) records (Roads and Traffic Authority New South Wales, 2003) which provide cycle-by-cycle data may demonstrate a more accurate landscape. These assumptions need to be further investigated before a qualified reason can be given.

6.2 The consequence of the pilot investigation

This pilot investigation has shown that using a VLDB technology approach, we can begin the process of better understanding how traffic moves within component aspects of the network and thus support the development of a holistic/systems-component approach to transport system management. We have been able to show that there is a relationship between the time of day that a peak occurs at a given intersection and its distance from the centre of a major attractor (in this case the CBD of Adelaide) during the AM peak. It is now possible for us to expand the pilot study by looking at the evening peak vehicle counts, and the counter-peak vehicle counts for both the AM and PM peaks. In addition, we are able to look at where freight corridors are located on the study route and their proximity to freight attractors (such as warehouses, distribution centres, etc).

We have some immediate questions to ask such as: why at TS15 (the intersection of two arterial/major roads known as “Gepps Cross”) do we seem to have a reduction in vehicle counts compared to the intersections immediately preceding it to the North? Also, at the same intersection, why does the peak occur at 0825, 40 minutes after the peak at TS13 which is the immediate upstream intersection, and 20 minutes after the peak that occurs at TS367 which is the immediate downstream intersection? Another immediate question may be why does TS53 peak 20 minutes after TS344 which is the immediate downstream intersection?

Ultimately it has perhaps led to more questions than answers: questions that may not have been practical to ask or possible to pose in the past now has a forum for investigation. The time to it takes to ask these questions of a database with such large datasets has been reduced to minutes or hours rather than days, weeks, or even months.

The relationship between route choices, design of the road network, placement of attractors such as shopping complexes, time of day, weather, and significant events all have an impact on the results presented above. The four monthly averages was an attempt to ‘smooth out’ some of these factors; nonetheless, it can be seen even from these averages that the traffic travelling during the morning peak can easily be affected by events and activities on or near the link of interest. How should one, then, treat the TS483 – TS15 link? Should it be different to the TS15 – TS31 link? What effect does balancing the TS483 – TS15 link for freight have on passenger travel that wishes to travel into the CBD via the TS15 – TS32 link? Furthermore, should we, during the morning peak, optimise for passenger travel on the TS483 – TS15 link even though it is a freight corridor and what impact will this have on freight schedules?

The answers to these simple but important questions lie in a holistic balance for the entire network and for a component balance of the individual link. As each of these 'areas of interest' can be considered a whole in its own right, the combination of 'balance of priorities' and thus the mix of local holism/componentism compared to network global holism/componentism has the potential to lead to conflict that can only be solved by developing inter-locking policies that can be applied on a case by case basis rather than developing only broad-brushed policies that act as a blanket to the network as a whole.

The NEXUS database (Vogiatzis, 2006, Fehlmann et al., 2006) opens up the possibility for more complex analysis due to its ability to process very large data sets in a short time. The combination of the traffic count data from SCATS VS files with the intersection performance data in the corresponding SM files will allow the analysis of the development of congestion in the network, and the estimation of link travel times. Work using the SM data for travel time and traffic congestion is not new; VicRoads (Wall and Powell, 2006) and their commercial partner have developed such a product already. Downloading data at the end of each cycle directly from the SCATS central computer; analysing the data statistically with relation to existing statistics and producing travel times which are within 10% of a probe vehicle run and producing results within a cycle-time (generally much less than a cycle-time according to Powell). The apparent difference (details of the internal algorithm/s where not made available) is that they build upon previous statistics using the Degree of Saturation, Cycle-time, Phase Split, and other internal variables. *The difference here is that we have the ability to quickly analyse **raw** data across varied date ranges, providing time of day, daily, specific day, weekly, monthly, quarterly, and yearly statistics* which are combined with travel time and emissions for any route (including non-signalised intersections). The ability to incorporate existing TSC incident detection algorithms and to add weather data is available when it becomes necessary and so too with land-use; just to name a few. Although both systems have been designed to function at incredibly high speed, the Travel Reporting and Integrated Performance System (TRIPS)(Wall and Powell, 2006) is specifically focused on providing a solution for real-time congestion monitoring and travel time performance, and although also provides a comprehensive suite of reports, these are focused on a narrow view of the network (being the roads and the relative congestion/travel time) associated with those arterials being monitored. It is a commercial product with a commercial focus; NEXUS is a research tool designed to provide researchers, and later transport authorities and consultants, with a totally flexible reporting tool designed to look at scenarios of interest and to analyse micro-simulation model output in conjunction with historical data collected; one that can take into account the city itself and the activities along-side the movement of vehicles, people and goods.

7 The pilot investigation forming an initial foray into creating the CHCD framework

From Section 5 we have:

> *Thus the more information that is collected, analysed, and stored with the necessary inferences developed leads to the provision of a balanced solution for specific links in relation to each other (component) and in relation to the needs of all (holistic)* ***without loss of data generality****.*

That is, a primary focus of CHCD is the ability to:

- Deal with vast databases in the form of VLDB for the macroscopic, through to microscopic analysis of all transportation data;
- Use the *raw* data as a starting point, without loss of data generality, to build macro models that allow a holistic understanding of the transportation system based on

micro- and meso-scopic models. These holistic models are derived from the analysis of component (micro/meso) and raw data *at the same time*; and
- Translate such combined analysis into system rules and boundary conditions which form the basis of a transportation system expert system, including the requisite knowledge-bases that support it.

Just to name a few.

In Section 6, our focus was on a specific link, in this case a 20 km section of road running North from the Adelaide CBD, and we focussed on the use of morning peak five minute vehicle counts. This analysis was performed for two primary reasons:

1. It was important to see how traffic behaved (using a somewhat contrived test scenario) along the link as a means of identifying how one can begin the process of rule creation; and
2. Understand the fundamental issues associated with attempting to analyse data across a large period of time quickly and effectively (in the case that this will form a part of a real-time policy advisory, link monitoring/management system).

We can see that, indicatively, there is some correlation between the relative distance of an intersection and the centre of an attractor along a link. From the data, we can see that there is some relationship between when a peak occurs at an intersection and the location of immediate upstream and downstream intersections, and naturally (as expected) we can see that there is generally a singular peak which is preceded by a sharp ascension slope followed by a long decay.

How then, do the results of Section 6 fit into the CHCD framework for developing a range of optimal solutions?

In the first instance we can, say, derive the following basic candidate rules[2]:

1. Peaks at intersections are singular and quantifiable;
2. They occur earlier during the day the further out the intersection is from the CBD;
3. Any given link can have one or more sub-links; these sub-links potentially behave differently, depending on how the links are defined and coded within the network model (see Clement, Woolley and Taylor (1996));
4. The percentage difference of vehicle counts in a five minute block preceding and after a peak vehicle count is nominally within ten per cent of the peak count.

Assuming for a moment that based on the analysis of Section 6 we can say that these results have been verified; then it is possible to look at developing a policy for managing traffic along the link such as:

- Given the known time range for peaks to occur at a given intersection, each such intersection will have a peak cycle plan operating in the five minutes before and after the known peak time range;
- Based on the geographical region of the intersection, and its role within the link, the peak cycle plan allocated will be specifically designed for the intersection and the region in which it belongs;
- When individual intersection vehicle count nominal conditions are exceeded, focused *micro-analysis* will replace *macro-analysis*.

As noted before; we are not at a stage where categorical statements of rules and policies can be evaluated along-side actual traffic behaviour; rather that there is a need for a holistic balancing of the transport system *without* neglecting the individual components of the system (which is performed *simultaneously*) and that we now have the technology that will

[2] It should be noted that these rules are being developed from unverified statistics and as thus are **only for illustration purposes**. That is, a great deal more investigation and analysis is required before these rules would be considered acceptable for inclusion, and in fact, it is expected that they would be subject to significant change by the end of a study.

allow us to, in real or batch time, perform this analysis and build the range of solutions that take into consideration the needs of all and the individual in a *balanced, fair, equitable, and reasonable* manner.

8 Future work

An important aspect of the development of CHCD is the development of the knowledge-base/expert system for transportation. Continued analysis initially of this section of road, building a better understanding of how and why the results obtained exist will form the backbone of developing the rules and policies for CHCD.

To perform this analysis, notions of network vulnerability, freight logistics/city-logistics, and environmental analysis will be applied to the current and new datasets in conjunction with simulated trials, slowly expanding to more and more of the road network thus building a knowledge-base that can be applied within an expert system to assist with the requisite balancing of the network in cooperation with local transport authorities and with transport planners.

9 Conclusion

CHCD has the potential benefit to provide the *glue* for a holistic understanding of transportation systems. By being the *balancing* force for Locality-Scope, it is something that can be applied both in real-time and in batch-time and is supported by the development of knowledge-bases and expert systems.

Furthermore, it has the potential to provide the framework for balancing transportation networks using multi-criteria/multi-purpose policies that overlay each other forming a layered approach to transportation that is based on more than volumes, travel time, or economics; rather it provides the approach that all these and more can be taken into consideration along with the needs of the environment and populous.

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