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Priority Based Traffic Control

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Abstract

This document describes research, design, and implementation achievement to date for a method for adaptive traffic control based on vehicle priority, and a simulation to evaluate the effectiveness of the developed method.

Chapter 1

Introduction

Transportation is fundamental to the modern global economy, encouraging growth and job creation, trade, and quality of life. The success of road transportation and steady increase in the number of individual vehicles in use has resulted in an ongoing strain on societies to provide infrastructure capable of satisfying demand.

Widespread utilisation of road transport for commercial and private use has led to significant traffic congestion in densely populated, urban environments as demand outstrips the capacity of roading networks (European Commission, 2011). As the complexity of road networks increases, so too does the need for control systems to safely and efficiently manage access to shared road by competing flows of traffic.

Intersections with signal controls allow competing traffic flows to independently make use of the limited capacity of intersecting sections of two or more roads. To avoid collisions, allowing traffic to flow through a controlled intersection requires stopping all competing traffic flows also demanding the intersection. As a result, controlled intersection delay is one of the most significant causes of congestion costs in urban road networks.

This project seeks to improve cost effectiveness of traditional traffic control techniques by considering the individual costs associated with stopping or delaying vehicles approaching a controlled intersection.

1.1 Motivations

Urban congestion is a significant problem facing the New Zealand transportation industry. In 2013, an independent consultation commissioned by the New Zealand Transport Agency (NZTA) found that the increase in transport cost due to congestion within Auckland City could be as high as 1.2 billion dollars annually when compared to freely flowing traffic (Wallis & Lupton, 2013).

The New Zealand Ministry of Transport (MoT) 2008 transport strategy identifies affordability and efficiency as two primary goals of transportation development over the next three decades and recommends future congestion management strategies should more efficient use of existing network capacity without the need to add expensive new infrastructure. Improving the effectiveness of traffic signal controls at road intersections has potential benefits for all controlled intersections in New Zealand, at significantly lower costs than infrastructure changes.

Advances in wireless technologies suggests that inter-vehicle communication technology may be commonplace on New Zealand roads within the next decade. By simulating the possibilities of a fully connected transport system, we hope to encourage development in this area.

1.2 Problem

Modern intersection signal controllers seek to minimise delay by responding to vehicle demand at each incoming link. The implementation of individual traffic actuated systems differs, but common characteristics include the use of multiple pre-determined phase and cycle plans, created in advance by a traffic engineer. Isolated traffic actuated systems are limited in practice because of the need for traffic engineers to predefine plans, which are unable to adapt to real time changes in demand.

Adaptive traffic control systems, such as the Sydney Coordinated Adaptive Traffic Control System (SCATS), operated at all controlled intersections on New Zealand cities and highways; adaptively increment phase plans in response to near-real time traffic conditions and are successful for reducing delay within high demand road networks. Existing systems are limited to minimising the number of queued cars or average delay at an intersection.

When an approaching vehicle is stopped at a controlled intersection, a cost is absorbed by the occupants or owners of the vehicle. Costs incurred may be caused by the physical characteristics of a vehicle, for example: a stopped vehicle must use more fuel to accelerate back to a cruise speed; or by the impact of the delay on the vehicle occupants in terms of added commuting time.

As an example of this problem, consider a common "cross-roads" intersection, with two competing approaches. If a large, commercial freight vehicle running late for a ferry and a small family car returning home from a shopping trip are approaching the intersection on two competing roads, who should be given right of way? There is significantly more cost incurred if the truck is forced to stop at the intersection, including cost of fuel required to accelerate and the potential of being late for the ferry and missing a shipment. In a traditional vehicle actuated or adaptive traffic control system, there is no guarantee on who will be given the opportunity to pass first. The traffic controller is not influenced by the approaching traffic and, depending on the current signal phase timing, it is likely that both vehicles are forced to stop, or the truck is forced to stop.

This project presents a new methodology for adaptive traffic control that considers individual vehicles approaching or waiting at an intersection based on a dynamically calculated *priority* value, calculated using properties of each vehicle that can be communicated to a traffic controller using wireless devices embedded in vehicles.

1.3 Priority Based Signal Control

Vehicle priority modelling allows for consideration of a wide range of vehicle and motorist properties, including size and weight, fuel efficiency, number of passengers, individual passenger urgency, and purpose of transit. Inter-vehicular, short range, ad hoc communication is used between vehicles and a traffic controller in order to receive responsive, real-time information about the location and properties of vehicles approaching an intersection.

1.4 Contributions

This paper presents three primary contributions to the field of traffic signal control research and implementation:

- **Vehicular Priority Model**, a model for estimating the priority of individual vehicles within a road network; based upon passenger urgency, cost of stoppage, cost of delay, and passenger occupancy.

- **Priority Based Traffic Control Algorithm**, an on-line algorithm for determining signal phase times at a controlled intersection based on priority of real-time traffic, determined by one-way, vehicle-controller communication.
- **Open-Source Simulator Implementation**, an implementation of the Priority Based Traffic Control algorithm above, as well as modifications to the Movsim Traffic Simulator to allow adding of new traffic control strategies to be tested.

Chapter 2

Motivations, Background and Related Work

2.1 Terminology

Traffic control engineering involves specific terminology to refer to different signal controls, timing plans, and controller types. This section offers a brief introduction of traffic signal control and terminology that may be used throughout the remainder of this report.

Modern intersections with traffic signals are controlled by a roadside *signal controller*. Controllers switch power to signal lanterns and determine the sequence of display for each set of lights, operating under the safety requirement that no two conflicting flows receive green signals simultaneously. A typical controller operates lights in sequences called *phases*, which are dynamic length allocations of green light time to a set of non-conflicting flows at an intersection. Typically, modern controllers include the following fixed or dynamic time allocations within a phase:

- *late start time*, a fixed length of time a green light may be delayed for safety of other movements (e.g. pedestrian protection)
- *minimum green time*, a fixed length of time that a phase must operate before changing
- *inter-green time*, a fixed length of time required to operate amber and red signals at the end of a phase, typically at least 6 seconds.
- *extension green time*, a dynamic length of time allocated to a phase determined after all required fixed times have been deducted from the total phase tie.
- *maximum green time*, if the addition of the previous four time allocations exceeds the fixed maximum green time the phase is forced to change.

A *cycle* (or *plan*) is an ordered sequence of one or more phases which is repeated by a controller. A fixed cycle traffic controller runs each phase for a fixed length of time within a static cycle. An actuated traffic controller can respond to sensor inputs from lane road loops and skip phases that are not in demand. Adaptive traffic controllers differ in implementation but typically can extend or shorten the length of a phase if a queue is completely cleared midway through a phase. The length of a cycle of an adaptive controller can be adapted to demand, typically running for a shorter length of time during quiet traffic and increasing in length to reduce queuing and satisfy high demand peaks (Thomson & Moriarty, 2013).

An intersection has a given *capacity*, defined as the maximum sustainable flow rate at which vehicles or pedestrians can travel through the intersection in a given time period.

Capacity is dependant on the geometric layout of an intersection (e.g. width of road, number of lanes), driving and surface conditions, and traffic conditions. The *degree of saturation* of an intersection is a ratio of arrival flow rate with respect to capacity of each approach for a given period. Arrival flow rate, also called *demand flow*, refers to the number of vehicles or pedestrians arriving during a given period, measured from the back of a queue (Akcelik, 2004). A section of road is said to be saturated if the traffic flow is equivalent to the capacity of the road at a given speed, such that any increase in flow will have a negative impact on the flow through the system. Any section of road where demanded traffic flow exceeds capacity is said to be *congested* (Wallis & Lupton, 2013).

2.2 Signal Control Optimisation Techniques

This section provides a review of published literature on existing implementations of adaptive traffic control systems in use globally and within New Zealand, and identifies the benefits and limitations imposed by the use of these systems. Information related to the Sydney Coordinated Adaptive Traffic System (SCATS) is partially based on personal experience at the NZTA Wellington Traffic Operations Centre, in Johnsonville.

2.2.1 Sydney Coordinated Adaptive Traffic System

SCATS is a centralised, coordinated, adaptive traffic control system (Lowrie, 1982). In New Zealand, all controlled intersections operate on isolated control or within a coordinated network under the Sydney Coordinated Adaptive Traffic System (SCATS). SCATS operations within New Zealand are controlled by the New Zealand Transport Association (NZTA), for state highways and inter-city motorways; and local body councils where appropriate.

SCATS operates on a networked computer with two-way communication to individual SCATS connected traffic controllers over broadband (or modem) connections. SCATS interfaces with roadside traffic signal control units, requesting phase times, skipping phases, or adjusting cycle lengths on an adaptive basis. A traffic control engineer can monitor traffic demand and flow rates for an intersection and manually adjust SCATS calculated phases or cycle lengths if required.

SCATS incrementally adjusts the planned phase times of a traffic signal controller by responding to traffic data collected by the signal controller during the previous cycle. Inputs to SCATS from each individual controller include the number of vehicles and flow rate per each intersection approach, the expected and actual phase times, and the degree of saturation for the intersection. The SCATS system calculates and requests phase times and cycle lengths to minimise the degree of saturation of an intersection, defined as the ratio of effectively used green time to total available green time (Wolshon & Taylor, 1999). The proportion of effectively used green time is typically increased using longer cycles and higher split times for high demand approaches.

In a coordinated traffic control system, emphasis is given to ensuring that green times between two nearby intersections are scheduled in such a way as to allow for synchronised green phases, preventing vehicles arriving from an upstream intersection being required to stop downstream. The effect of this synchronisation is colloquially known as a "corridor of green" and will be familiar to most New Zealand inner city motorists. SCATS intersections are organised into groups called subsystems, typically based on proximity. A traffic control engineer identifies a critical intersection within each subsystem in a road network. The cycle time is optimised for the critical intersection and neighbouring intersections adopt the same cycle time to provide naive coordination of phases and ensure undersaturation of the critical intersection (Kilby & Johnson, 2010).

In practice, SCATS is limited by the ability to adjust timings only at the conclusion of a cycle, and the relatively small incremental adjustments made between cycles. During peaks of high intersection demand, the time for a cycle length increases, typically as long as 120 seconds or higher. Adjustments made to phase and cycle times at the end of each cycle are typically within the range of 5%-10%. As a result, SCATS can be slow to respond to disruptive periods of high demand and requires manual intervention from traffic engineers to handle such situations, for example, sporting or musical events with large numbers of fans entering and leaving a stadium at the same time.

2.2.2 Splits-Cycle-Offsets-Optimization-Technique

The Splits-Cycle-Offsets-Optimization-Technique (SCOOT) is an adaptive traffic control system first developed in the 1980s and deployed widely in the United Kingdom.

The primary objective of SCOOT is to minimise the sum of the average traffic queues in an area. A limit of this optimisation is the complete reduction of queues in a network, such that every approaching vehicle receives a green signal, not possible in practice. (Bell, 1992; Robertson & Bretherton, 1991). SCOOT modelling is based on construction of so called "cyclic flow profiles", online relative to real-time demand measured by detectors upstream of an intersection. A cyclic flow profile is a measure of a one-way flow of vehicles past a point (e.g. stop line) during a time step of a signal cycle. The use of cyclic flow profiles generated online in respond to actual traffic demand is promoted as an advantage of SCOOT over fixed-plan adaptive systems such as SCATS, as SCOOT does not require a traffic engineer to predetermine a set of plans to model traffic flow or congestion at an intersection.

The SCATS and SCOOT control systems are also limited by the reliability of communication links between signal controllers and the central optimiser. If communication is interrupted or lost, signal controllers will revert to a fallback mode, using predefined plans designed by a traffic engineer. In order to maintain integrity of a network in the event of communication loss, fallback plans are updated regularly by traffic control engineers using historical time of day data collected over a reasonable time period, a costly operation which requires continuous maintenance. In addition, SCATS and SCOOT both rely on the use of inductive loops installed within the pavement of a road at intersection stop-lines or at an upstream location, which must be replaced each time the surface of the road is maintained (Bell, 1992).

2.3 Lookahead Based Control

Recent work has explored alternatives to phase based control. van Katwijk, et al. (2008) present a "movement-based" lookahead optimisation algorithm that allows vehicle demand to pass through an intersection in distinct *movements*, which represent a passage of traffic from an approach lane to another exit lane, rather than structured phases or stages which are typically predefined sets of one or more movements. Movement-based control allows for clearance of more approaches by starting and ending individual movements of non-conflicting movements of traffic rather than a entire phases. The use of movements in control optimisation reduces the search space required by a decision tree, allowing a signal controller to look ahead to a N-second event horizon.

Similar algorithms implementing lookahead optimisation techniques have also been explored using traditional phase control, seeking to minimise total delay at an intersection, with significantly improved results over Webster's method (Porche, et al., 1996), although this work is limited by lack of comparison with traffic actuated or adaptive controllers.

2.4 Inter-Vehicular Communication

The ubiquity of mobile communication devices and modern wireless capabilities have offered new possibilities for inter-vehicle communication within road networks. Previous research suggests that short-range wireless communication devices installed in road vehicles can be used to form mobile ad-hoc networks between near proximity clusters of traffic (Gradinescu, et al., 2007; Nadeem, et al., 2004; Yang, et al., 2004).

Gradinescu et al. (2007) discuss an implementation for car-to-car communication and car-to-controller communication as a replacement for loop detection used by adaptive traffic controllers. In the author's implementation, vehicles periodically transmit information about themselves and other nearby vehicles to a traffic controller using one-hop broadcasts. A traffic signal controller maintains a record of each known vehicle within range and optimises cycle length and phase timings based for the succeeding phase based on real-time information from each approach. Experimentation results of the study suggest that adaptive traffic control using a simple traffic actuated method out-performs a predetermined phase controller by a significant factor when total intersection delay is the primary measure of effectiveness at an intersection. While these results are promising, the work is limited in scope by the use of a predetermined phase time controller as a baseline for experimentation. The increase in performance measured by the authors does not take into account the advantages of existing traffic actuated or adaptive controller schemes over an isolated, fixed-cycle controller; which are likely to be significant.

Wireless communication between vehicles and signal controllers can provide more information at an earlier stage of approach than loop detectors, including characteristics of a vehicle (number of passengers, size, weight, type of activity), speed of approach and current position. Research in this field has explored the use of vehicle-to-vehicle communication for early warning safety systems, collision avoidance, and as a means of informing vehicle passengers about road network conditions; suggesting widespread benefits for use of the technology beyond traffic modelling at intersections (Nadeem et al., 2004; Yang et al., 2004).

Chapter 3

Design

The following chapter discusses the assumptions, models, and design methodology of the Priority Based Traffic Controller (PBTC) system, and the developed simulation tool. The project outcomes discussed in this chapter are:

- design of an appropriate model of individual vehicle priority,
- design of a simulation tool as a platform for implementing the PBTC system,
- design of a phase control PBTC algorithm, to be operated on a 2 phase intersection,
- evaluation methodology and relevant measures of effectiveness used to compare the performance of the PBTC system to existing alternatives.

3.1 PBTC System Architecture

3.2 Priority Modeling

Representative modeling of the priority of vehicles and passengers approaching an intersection was required to effectively design, develop and evaluate the PBTC system within a realistic setting.

The priority of an individual vehicle is defined as the cost, measured in cents, of stopping or delaying the vehicle at a PBTC controlled intersection. A number of heuristics have been aggregated to produce a single cost value:

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Emphasis has been placed on approximations of cost components that can be calculated efficiently, in real-time, by a traffic light controller. While accurate measurements for the stopping cost and journey fuel consumption can be made after a vehicle has passed through an intersection, it is not possible to produce an accurate model for estimating fuel consumption for each approaching vehicle as speed and acceleration, and as a result fuel consumption, is dependent not only on the physical characteristics of the vehicle and driver behaviour, but also the speed and acceleration of surrounding vehicles. In order to develop

realistic approximations of cost components, the following assumptions have been made about the physical characteristics of vehicles and driver behaviours:

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3.3 Simulator Design

3.4 Optimisation Algorithm Design

3.5 Evaluation Methodology

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Appendices

Appendix A

Gantt Chart of Project Achievement

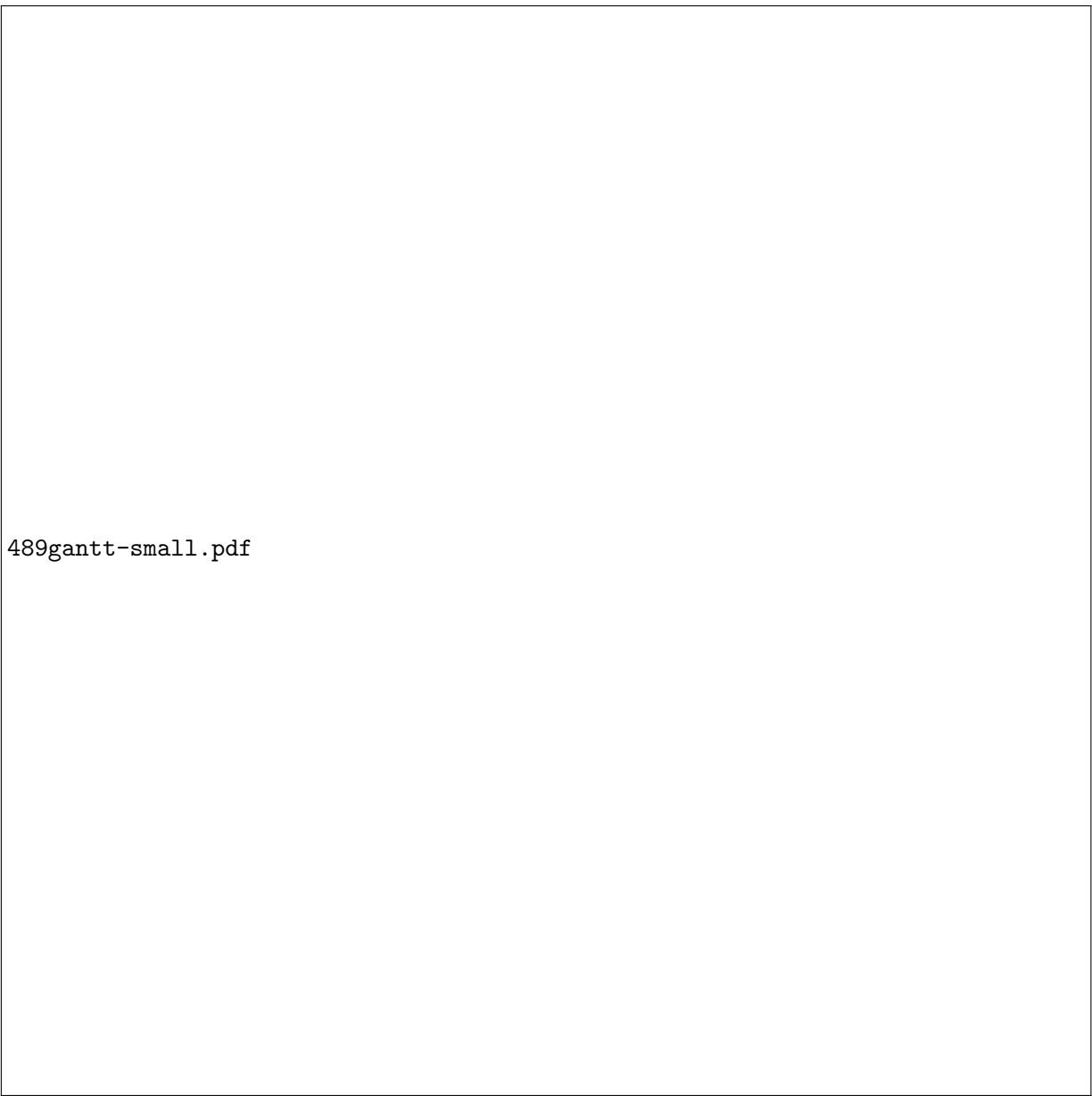


Figure A.1: The Gantt chart above shows expected approximate work breakdowns for the trimester break and trimester two. Velocity of the project (work completed per week) is expected to be significantly higher during the trimester break than period after the beginning of trimester two. It is expected that the time allocations provided are sufficient for the required work.