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# Management of traffic USIng Control (MUSIC ) A case study of Papakura Town Centre.

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# The MUSIC and PRACTICAL Study

## Abstract

***M****anagement of traffic* ***USI****ng* ***C****ontrol (MUSIC ) is a new approach to designing traffic signal timing plans. It is a novel method of traffic flow control, by allowing signal timings to be optimised to meet a variety of traffic management goals. Using existing network traffic models, the MUSIC process optimises traffic signal settings, creates signal-timing plans, which meet given objectives/thresholds defined by for example, a local authority. It primarily overcomes the difficulty in trying to predict how drivers would alter their route choices in response to a changed signal strategy.*

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# THE MUSIC and PRACTICAL STUDIES

## 1 Introduction

This paper is based on a case study undertaken in Papakura, near Auckland, which demonstrates some of the key outcomes from the MUSIC method. The study investigated how the conversion of priority intersections to signalised intersections will affect the town's transport objectives.

To evaluate the problem MWH used a static simulation-assignment model (SATURN) together with its dynamic microsimulation model, to evaluate the area-wide effect once these intersection proposals were considered together. The study was undertaken in 3 phases namely:

| | | |
|---|---|---|
| Phase 1. | MUSIC #1: | Evaluation of the effects with minimal co-ordination and optimisation between signals. |
| Phase 2. | PRACTICAL: | Evaluation of the parking demand and integration with the MUSIC objectives. |
| Phase 3. | MUSIC #2: | Development of a co-ordinated strategy to meet the stated objectives. |

The outcome of the MUSIC #1 modelling shows that the existing network configuration with a large number of priority intersections marginally outperforms the proposed network in terms of efficiency objectives. In terms of reducing congestion in the future, the uncoordinated isolated signalised improvements makes the situation worse to the point where gridlock is likely to occur during high flow periods, particularly during the PM peak.
The MUSIC #2 study investigated synchronisation between all signalised intersections using an optimising strategy developed across dominant corridors to improve the attraction of trips towards the CBD parking lots, by applying the MUSIC optimisation approach. The overriding goal being to increase captivity of the bypassing trips by making trips towards the carparks as quick and accessible as possible. A monitoring study afterwards is intended to measure the success of the overall strategy.

## 2 Background

MWH New Zealand were appointed by the Papakura District Council (PDC) to use a traffic simulation model using both mesoscopic and microsimulation techniques to evaluate the combined effect of converting nine intersections, previously analysed as isolated improvements, to alter traffic flow conditions around the Papakura Town Centre. Some of the improvements that are proposed in a report by Hames Sharley (c2001) are intended to revitalise the town centre; others are as a result of ongoing traffic flow improvement studies. Other independent consulting engineers undertook the majority of the technical assessment of these improvements and these were originally evaluated in isolation of each other.

The original urban design report listed a number of key goals that do not directly affect traffic flow, to achieve the revitalisation. However, the goals relating to the road infrastructure were:

- *To encourage increased levels of traffic through the retail area;*
- *To prioritise traffic movements through intersections feeding the retail area, and*
- *To provide more opportunities for pedestrians by slowing traffic down using design concepts such as parking, signalised pedestrian crossings and other measures to improve access for pedestrians.*

In light of these suggestions, the PDC Asset Manager required an area-wide evaluation of the impact on traffic congestion once the proposed intersection upgrades were implemented.

MWH used a recognised static simulation-assignment model (SATURN) together with its microsimulation sister model (DRACULA), to evaluate the area-wide effect once the intersections were upgraded. Two time periods were evaluated, namely the:

- *interpeak (IP) that coincides with incidence of peak shopping trips, and*
- *the afternoon peak (PM) which simulated the highest period of traffic flow.*

The assigned vehicular trips crossing a sub-cordon surrounding the greater CBD were derived from the recently updated and validated 2001 PDC's TRACKS land-use model.

## 2.1 Study Targets and Goals

The purpose was to model three scenarios in a before-and-after situation to test the effect proposed intersection improvements would have on the traffic flow by measuring the:

1. *Traffic diversion away from the CBD*
2. *Congestion surrounding the CBD.*

## 2.2 The PRACTICAL Study

The Practical (**P**arking and **R**etail **A**ctivity **C**reated by **T**raffic **I**mprovements in the **C**entre **A**ssigned to **L**ast) study purpose was to gain an appreciation of the available parking during the peak shopping hours to determine any constraints, issues and usage so as to develop a suitable strategy. This study is not described further in this paper other than it will form the basis of a future monitoring and evaluation strategy to integrate with the implementation of the outcomes from the MUSIC studies.

# 3 Initial Modelling approach – MUSIC # 1

A SATURN/DRACULA[1] traffic modelling software was used to evaluate the traffic impacts and to measure the success of achieving the study objective.

To evaluate the effect of isolated junction control and their individual settings on an area-wide basis, a SATURN traffic simulation/assignment model was built from the available data and site inspections. The area model was used to analyse and identify overcapacity junctions and poor progression on key routes, so as to eliminate any negative effects not previously

[1] (**S**imulation and **A**ssignment of **T**raffic to **U**rban **R**oad **N**etworks/) and (**D**ynamic **R**oute **A**ssigning **C**ombining **U**ser **L**earning and microsimul**A**tion).

revealed in the intersection studies. The microsimulation component of SATURN (DRACULA) simulates traffic as they respond to the proposed measures on an individual vehicle-by-vehicle basis. Both models share the same data structure, creating seamless interaction between the two models. This is an advantage over previous attempts at using a mesoscopic and microscopic model as tools to optimise signals setting[2]. (Transyt 11 and Aimsun). This interaction of models used are illustrated in the table below.

**Table 1: Model structure**

| INFORMATION SOURCE | DESCRIPTION OF INFORMATION AND PROCESS |
|---|---|
| **PAPAKURA DISTRICT COUNCIL** | Use the reports, SIDRA models, mapping and drawings of intersections to build a SATURN/DRACULA model. |
| **TRACKS MODEL** | Required to produce the necessary input files to the detailed SATURN model |
| **SATURN MODEL** | Detailed representation of road network, lane configuration and junctions. Calculation of delay and efficiency indicators to assess relative success in meeting objective. Identification of bottlenecks and optimisation of signalised junctions done at a detailed level.<br>This model produces a graphical output of flows and diversion and creates output files for the microsimulation in DRACULA. |
| **DRACULA MODEL** | Detailed display of the interaction of individual vehicles with each other and the road layout. Visualisation of bottlenecks on road links and at junctions.<br>Provides insight to modify SATURN model to optimise layout or signal phasing to improve result in next iteration.<br>Calculation of efficiency result and statistics. If satisfactory then stop, if not then re-run SATURN. |
| **TRANSYT MODEL** | **Optional:** TRANSYT will be used if the SATURN optimisation does not provide the desired diversion effect that meets the study objective. It is a more robust modelling package that optimises the signal phasings in a more detailed manner. |

The signal optimisation routine within **SATURN** is not as sophisticated as that used in **TRANSYT,** but uses the same cyclic profile routines for estimation of traffic progression. Due to the large number of unknowns it was unclear whether it would be necessary to use **TRANSYT** to assist with the optimisation, but the option exists to use this software to help develop a more robust solution in future if necessary.

### 3.1.1 Model Accuracy - Calibration and Validation

The SATURN model was calibrated for the Interpeak period to replicate observed flows as closely as possible. The model was validated against an independent data set against the UK DETR standard, which is slightly higher than normally required by the Transfund PEM.

[2] An Integrated Traffic Model for Auckland Cities, 2003, Transfund RR 243.

### 3.1.2 Scenarios

**Table 2 : Scenario Description**

| No. | Scenario | Description |
|---|---|---|
| 1 | **Existing network:** | The current network configuration as at January 2004 that is used as the base conditions to compare all future scenarios to. |
| 2 | **Suggested network improvements** | This scenario is based on the proposed changes to the network together with other traffic engineering improvements suggested by the PDC. No signal synchronisation (co-ordination) or optimisation routines were implemented in this model.<br><br>The signal cycle times and green splits are as they were modelled in the isolated studies. |
| 3 | **Optimisation to scenario 2-network** | Two iterations were proposed to achieve a satisfactory degree of diversion of traffic that meets the study objective. A single iteration represented running SATURN with its signal offset optimising routine to improve progression of traffic on the key route into the CBD. The diversion was inadequate, and the process was iterated a second time using the green split optimiser and then freezing this and re-running the offset optimiser. |

As a result of the initial testing, a number of new changes to the intersection configurations were proposed, and in some of the cases the models were improved step-wise to understand the sensitivity of the individual improvements better.

### 3.1.3 Signal Co-ordination and Optimisation Routine:

The proposed changes to junction control and signal settings have been previously evaluated as isolated junctions; it was proposed that some optimisation of all junctions on a co-ordinated basis will be required to achieve and evaluate the stated objective.

The **SATURN** model is capable of 4 different types of assignment simulations as well as simulating and optimising the signal offset settings at junctions, if the required objective is not achieved. The nature of traffic in Papakura during the peak did not quite reflect a typical urban congested assignment, thus justifying a Wardrops Equilibrium (UE) assignment. Based on the author's previous research on route choices[3], it was decided to allow for the variation in perceived costs, hence route choices, and therefore a Stochastic User Equilibrium (SUE) assignment was thought to be more appropriate. In deciding which assignment method to use, Dirck van Vliet[4] recommends a useful measure of congestion is the "epsilon-2" parameter calculated by the SUE assignment. This is the ratio of the excess travel costs due to congestion (total vehicle-hours at congestion less total vehicle hours at free flow) relative to the total vehicle costs under free flow conditions. As a rule of thumb if epsilon-2 is less than

[3] JJ Bezuidenhout (2000*) Investigating the Variance in Drivers' Route choices in the AM and PM Home-based work trip*. MSc (Eng) Thesis, University of Leeds, England.
[4] Saturn User Guide, page 7-13.

25%, then use SUE; if greater than 25%, use Wardrop's or Deterministic User Equilibrium (DUE). In all the cases the Epsilon-2 value was under 5%, thus meaning the modelled network was lightly congested.

All three scenarios were run and generally the results were of the same magnitude in that they all diverted traffic away from the CBD.

### 3.1.4 Model runs

As mentioned above, scenario 2 tested the proposed improved network as is with no optimisation or co-ordination whereas scenario 3 used the original cycle times, but with the optimisation routine.

The third scenario tested a limited refinement by optimising the signal offsets in order to obtain better co-ordination between adjacent signal sets. A further refinement developed during the study was to use SATURN's green split optimiser. This routine is to be used with caution as it could overestimate the benefits. The dynamic assignment and iterative improvement to green splits assumes that there is a large degree of co-operation between signal setters and drivers, and that drivers are sensitive to small changes in the signal settings. It was decided that if the optimiser were limited to a single iteration in conjunction with two-passes of the offset optimiser, the magnitude of change on route choices, using a responsive signal strategy, would be useful to increase our understanding of modelled driver's responses to signal changes.

The following process was used in the optimisation routine during scenario 3 testing:

1. *Run the simulation assignment in SATURN using a Stochastic User Assignment using the Equisat algorithm to calculate offsets in SATURN. A single iteration was run using this routine. The algorithm is a well-known procedure used by TRANSYT software to optimise the saturation flows at signals, on an area-wide basis.*
2. *The second run included another single pass assignment optimisation run, this time optimising green splits between phases (NZ - stages) as well as single cycle of the offset routine to include the new green times in the optimisation process.*

### 3.1.5 Outcomes of the MUSIC #1 study


**Figure 1: Map of Town Centre**

The result of both scenario 2 and 3 were similar in nature, and are illustrated in Figure 2. The plot shows the difference in the volume of vehicles between scenario 2 and 1, with the blue lines indicating less traffic in scenario 2 and green indicating more traffic. The result of the scenario 3 testing was very similar to that encountered at scenario 2. Overall the diversion effect is amplified, drawing traffic away from the town centre.

The plot confirms that the desired effect of attracting traffic through the town centre by altering the intersection configuration has not been successful.

Most of the intersections that are to be signalised have increased diversion away from the town centre. The largest diversion is created at the intersection of Gt. South Road and Wellington Street for northbound traffic and Clevedon and Marne Roads for Westbound Traffic.

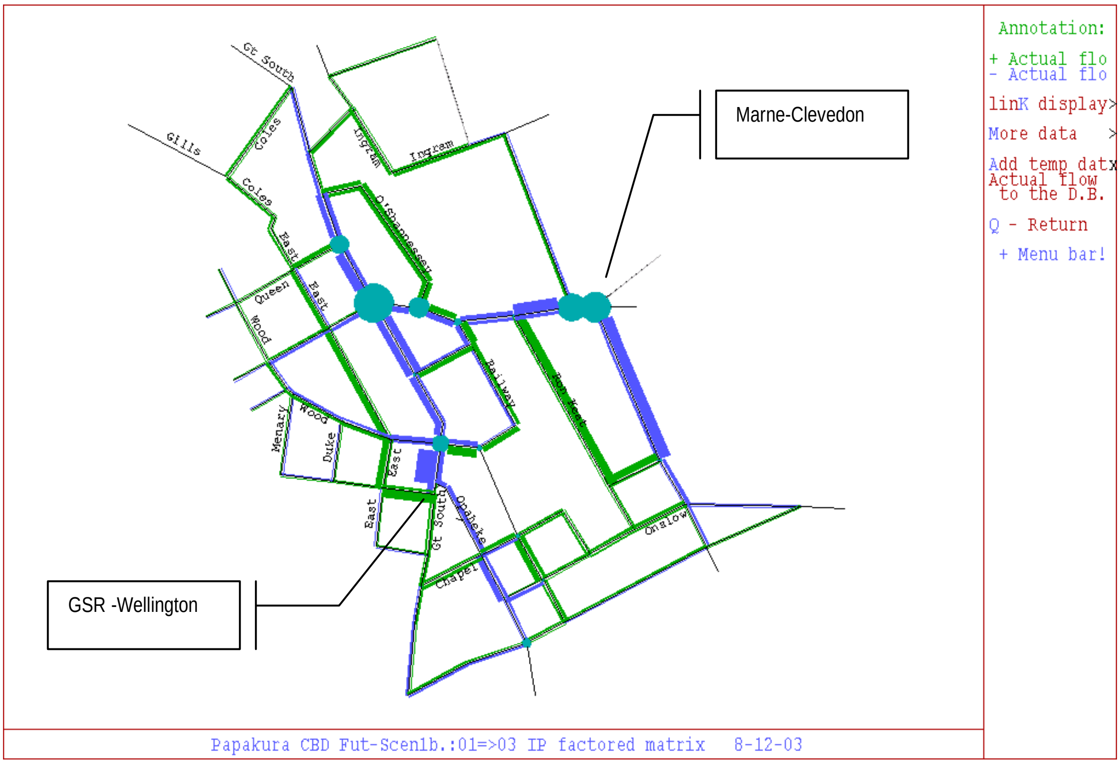


**Figure 2: Volume and delay difference - Scenario 2 minus Scenario 1**

It has also introduced rat running (diversion of traffic from a major to a minor route to avoid delays) along Ron Keat Drive (shown green) by making the route along Marne-Clevedon road less attractive (in blue) to negotiate. This is not an unsurprising result as the interpeak flow volumes are relatively light and therefore well within the capacity of roundabouts and priority intersections.

By introducing signals, it immediately introduces a minimum delay time irrespective of available gaps in opposing traffic streams. The assignment of traffic in the model is biased towards cost and time minimising route choices. However, the use of a stochastic (random) user assignment means not all drivers have perfect knowledge of the costs and conditions, thus allowing more freedom in the selection of routes that are possibly driven by route choice factors other than cost and time. The same behaviour and amount of diversion is observed in the PM model run.

Comparisons between the SATURN and microsimulation modelling

**Table 3: IP Network Performance Statistics from Static Assignment Model**

| IP SCENARIO | 1 | 2 | 3 | |
|---|---|---|---|---|
| Model Name | CAL 2a | FUT 1b | FUT 3 | |
| Transient Queues = | 40.4 | 49.7 | 50.9 | Pcu. Hrs./Hr. |
| Over-Capacity Queues = | 4.6 | 1.2 | 1.6 | Pcu. Hrs./Hr. |
| Link Cruise Time = | 123 | 125.7 | 125.9 | Pcu. Hrs./Hr. |
| Free Flow = | 123 | 125.7 | 125.9 | Pcu. Hrs./Hr. |
| Total Travel Time = | 168 | 176.6 | 178.3 | Pcu. Hrs./Hr. |
| Travel Distance = | 5807.1 | 5859.9 | 5876.2 | Pcu. Km./Hr. |
| Overall Average Speed = | 34.6 | 33.2 | 32.9 | Km/h |
| Fuel Consumption = | 557.5 | 603.1 | 604.9 | Litres |

PCU = Passenger car units (i.e. vehicles)

**Table 4: IP Network Performance from Microsimulation Model**

| IP SCENARIO | 1 | 2 | 3 | |
|---|---|---|---|---|
| File | *CAL2a | *FUT1b | *FUT3 | |
| Queuing Delay | 69 | 115 | 98 | Veh.Hrs |
| Cruising Time | 98 | 106 | 103 | Veh.Hrs |
| Total Travel Time | 168 | 222 | 202 | Veh.Hrs |
| Travel Distance | 5358 | 5719 | 5565 | Veh.Km's |
| Average Speed | 31.78 | 25.74 | 27.54 | Veh.Km's/Veh.Hrs |
| Performed Flow | 5072 | 5012 | 5142 | Veh.Km's/hrs |
| Fuel Consumption | 423 | 495 | 269 | Litre |
| Total Co Emission | 9.84 | 11.20 | 6.14 | Kg |
| Total Nox Emission | 30.22 | 35.7 | 19.3 | Kg |
| Total Hc Emission | 3400 | 3886 | 2142 | Kg |
| Average Trip Length | 1.018 | 1.091 | 1.063 | Km's |

VEH = vehicles

From the above two tables we can see that scenario 2 and 3 is less efficient than the existing network.

# 4 New Modelling Approach – MUSIC

Based on the lack of response in reaching the desired objective of drawing more traffic towards the retail centre, or even replicating the previous traffic level or efficiency, the client wished to evaluate the implication of various grouped implementation schemes that would upgrade the road network in 3 distinct corridors. A second modelling strategy study, which tests each of the 3 corridors independently of each other, would determine the most effective one to implement first. This analysis is undertaken in conjunction with impacts of recent land-use changes and is still underway. The results of this study would be presented at the conference.

As part of further experimental work undertaken by the author, a new process (MUSIC) was adopted to see if the present level of traffic could be replicated within the retail area and also achieve a more efficient network than at present. The motivation for this objective is that retailers often perceive any reduction in vehicular traffic within the retail area, due to network changes and improvements, as impacting negatively on their business income (loss of passing trade argument). However, this debate does not form part of this paper, but it is safe to note that there are ample examples across the world that supports the contrary.

The MUSIC[5] study described by an ESPRC research project undertaken by the Universities of Leeds and York in partnership with the Hague Consulting Group, and is described below.

## 4.1 The MUSIC Process (Management of Traffic USIng Traffic Flow Control and Other Measures)

The original MUSIC study aimed to demonstrate a novel method of traffic flow control, showing that it can be effective in taking correct account of travellers' responses to changes in signal timings, while allowing signal timings to be optimised to meet a variety of traffic management goals. Two of the three " Before and After" demonstration sites (York, Porto and Thessaloniki) used to measure the outcome of the MUSIC process, were very successful. It was noted that the plans derived from modelling were beneficial, but also that the current optimisation procedures are heuristic rather than truly correct mathematical optimisation procedures.

### 4.1.1 **Concept**

In brief, P0 (Smith,1979)[6] defines a pressure **P = sd**. Where **s** is the saturation flow of a link and **d** is the delay to vehicles on that link. Signal stages, which have greater pressure on them, are then given greater green time until the pressure is equalised on all links that have flow.
While P0 can be shown to be optimal given certain assumptions, it can be further improved by combining it with pricing. It can be shown that, under certain natural conditions, the combination of delay-based pricing and P0 can produce an optimal control set. This method, known as the "MUSIC optimisation technique" can be defined by the following stages:

**Stage 1**: Agree measurable objectives that quantify some relevant aspects of the local transport policy;

**Stage 2:** Translate data from an existing network model;

**Stage 3:** Use an off-line optimisation procedure to create new time-of-day traffic signal timing plans which aim to meet these measurable objectives while attempting to take some correct account of travellers' future choices;

**Stage 4:** Test the new timing plans in the existing network model;

**Stage 5**: Implement the traffic signal timing plans on-street; and

**Stage 6** (optional): Conduct "Before" and "After" studies to assess the degree to which the objectives agreed in Stage 1 have been met.

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[5] M Smith (1999) MUSIC final report for publication, University of York, England.

[6] Smith M.J (1979) *A local Traffic Control Policy which Automatically Maximises the overall Travel Capacity on Urban an Urban Road Network,* Proceedings of the international Symposium on Traffic Control Systems (Berkeley).

It has long been known that Urban Traffic Control (UTC) can have a significant effect on driver route choice but practical applications for this have been limited. While some signal control policies, for example $P_0$, have sought to take advantage of this, typically they do so only with an eye to reducing vehicle delay. The EU funded MUSIC project aimed to demonstrate a range of possibilities for traffic demand management (TDM) measures, which can be implemented, using cities' existing UTC system. The research project used a specially developed software model known as STEER (**S**ignals/**T**raffic **E**mulation with **E**vent-based **R**esponsiveness) to produce fixed-time signal timing plans which are then evaluated in a number of software models. These plans are then implemented on street and monitored with before and after studies.

Using a customised algorithm that utilises a combination of deterrence functions and signal timings the network was optimised to respond to drivers responses to route choices and hence derive an optimised setting for the signals to meet the stated objectives.

### 4.1.2 The MUSIC process

Central to the MUSIC project is the MUSIC process for off-line creation of fixed-time signal plans. The MUSIC process has its origins in Smith's (1979)[7] policy P0 and in the idea of delay-based road pricing.

P0 is the well-known idea that signals can attempt to route vehicles onto roads, which have greater capacity by giving more green time to routes with greater capacity. In essence the method is to assign a "pressure" to each stage of a signal based upon the following formula:

$$\mathbf{P = s_1 d_1 + s_2 d_2 \ldots}$$

where P is the pressure on the stage, $s_1$ is the saturation flow of the first link which is green during this stage, $d_1$ is the delay experienced by the average vehicle on the first link which is green during this stage and $\mathbf{s_2}$ and $\mathbf{d_2}$ are the equivalent quantities for the second link which is green during this stage.

The policy P0 then attempts to assign more green times to stages which have higher pressures until (it is to be hoped) the pressures on all the stages equalise.

Delay-based road pricing is the policy of charging drivers based upon the amount of time they spend queuing. Delay-based pricing, whatever its other effects, is an extremely efficient way of causing drivers to avoid congested routes.

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7 Smith M.J (1979) *A local Traffic Control Policy which Automatically Maximises the overall Travel Capacity on Urban an Urban Road Network,* Proceedings of the international Symposium on Traffic Control Systems (Berkeley).

Studies have shown that, even ignoring the peak-spreading and elasticity effects of road-pricing, it produces a considerable reduction in travel time on a network. The MUSIC signal plan design process is therefore this:

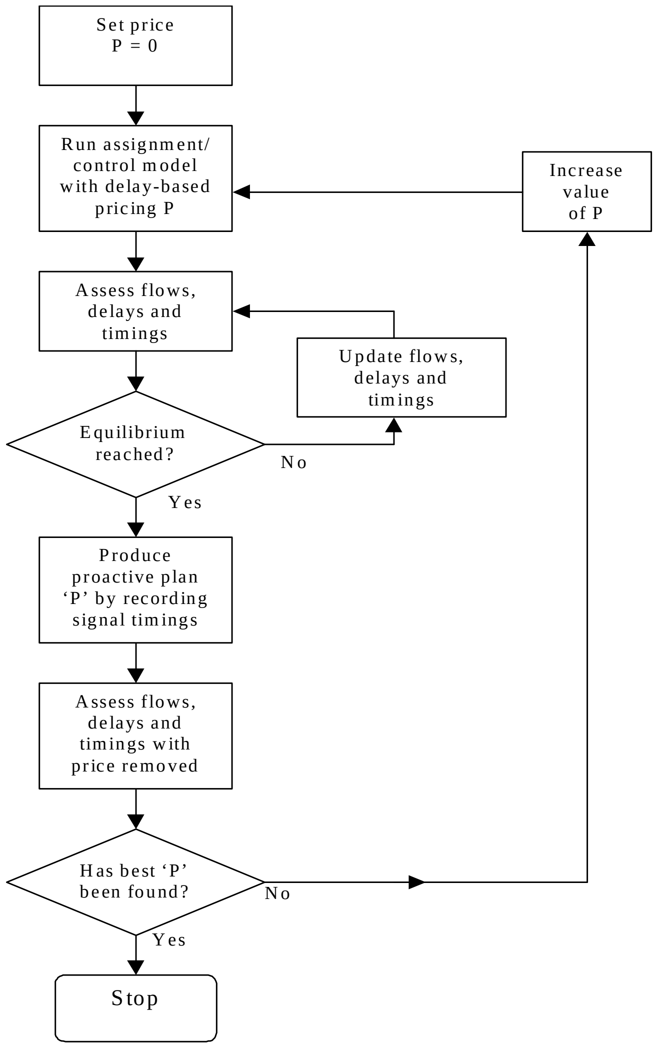



**Figure 3: The MUSIC Optimisation Procedure**

1) **Impose** a delay-based pricing on the simulated network with a small price p. This should force drivers onto optimal or nearly optimal routes.
2) **Adjust** signals according to P0. We should now have signals, which are set to favour drivers who are on optimal or nearly optimal routes.
3) **Freeze** the signals and remove the pricing. Allow the vehicles to pick their optimal routes through the city. The signals are now set to "guide" vehicles onto optimal routes.
4) **Increase** price p and go to step 1. Repeat until an optimal pricing level p has been located.

This method has been found, on a variety of networks, to produce signal timing plans as good as, or better than, the traditional policies P0 and equi-saturation. (In fact, when the pricing level p is zero, it can be seen that the policy is the same as P0).

#### 4.1.3 The Results of the MUSIC #2 experiment

The results of the MUSIC optimisation experiment tested pricing strategies ranging from 5c/minute and kilometre to 170c/minute and kilometre.

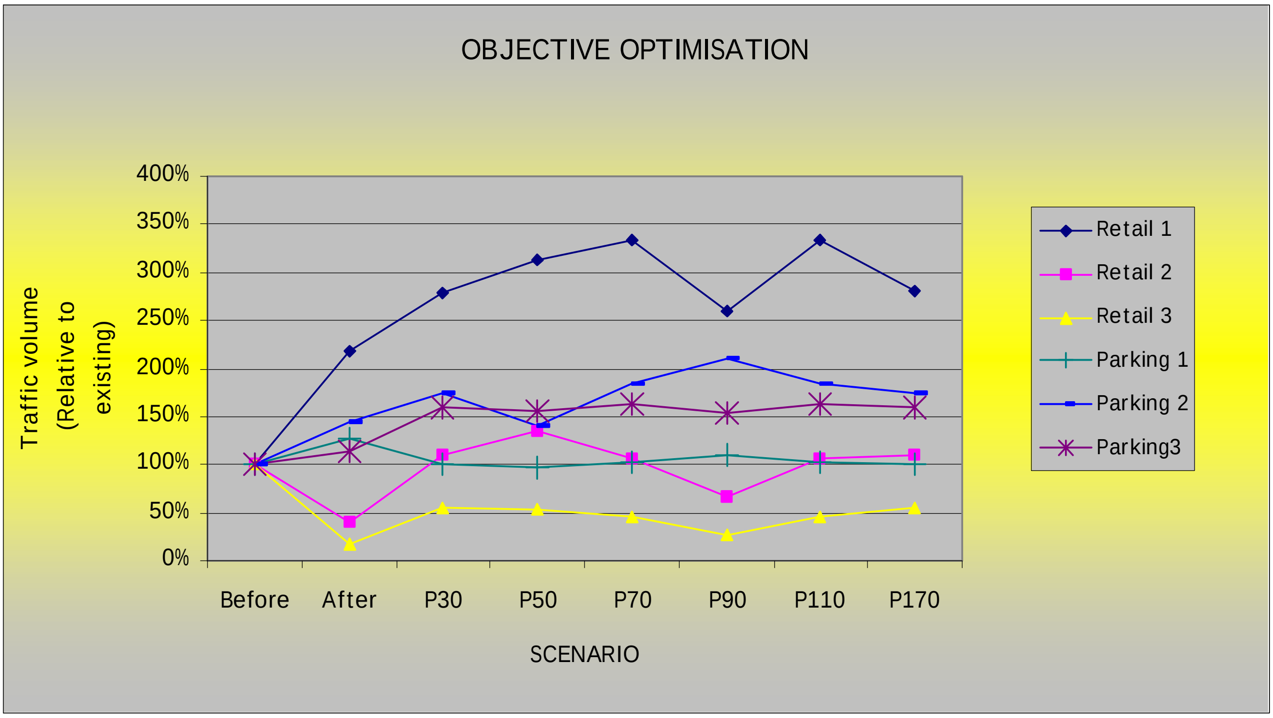
The objective here was to determine which group of signal timings, and without sacrificing network efficiency, would:

1. *increase traffic volumes around the periphery of the town centre near large parking areas.*
2. *return the state of traffic to the same levels prior to any network changes.*

The signal strategy (timings, offsets and phasing) that best meet the objectives are shown relative (as a percentage) to the original network results. The efficiency results are shown in table 5 below and are also graphed in the following figures 4 and 5 to illustrate the change in network flow, as timings and offsets were changed for various levels of price distortion. The figure shows the flows on selected links that measures how close the optimisation process is to the stated objective and to determine the appropriate signal pair and matching flow, the criteria below was used:

1. ***Objective 1** – maximise traffic on the parking links and minimise flow on the retail links*
2. ***Objective 2** - maximise traffic flow on the retail and parking links.*

**Figure 4: Individual Traffic Flow on Selected Links**



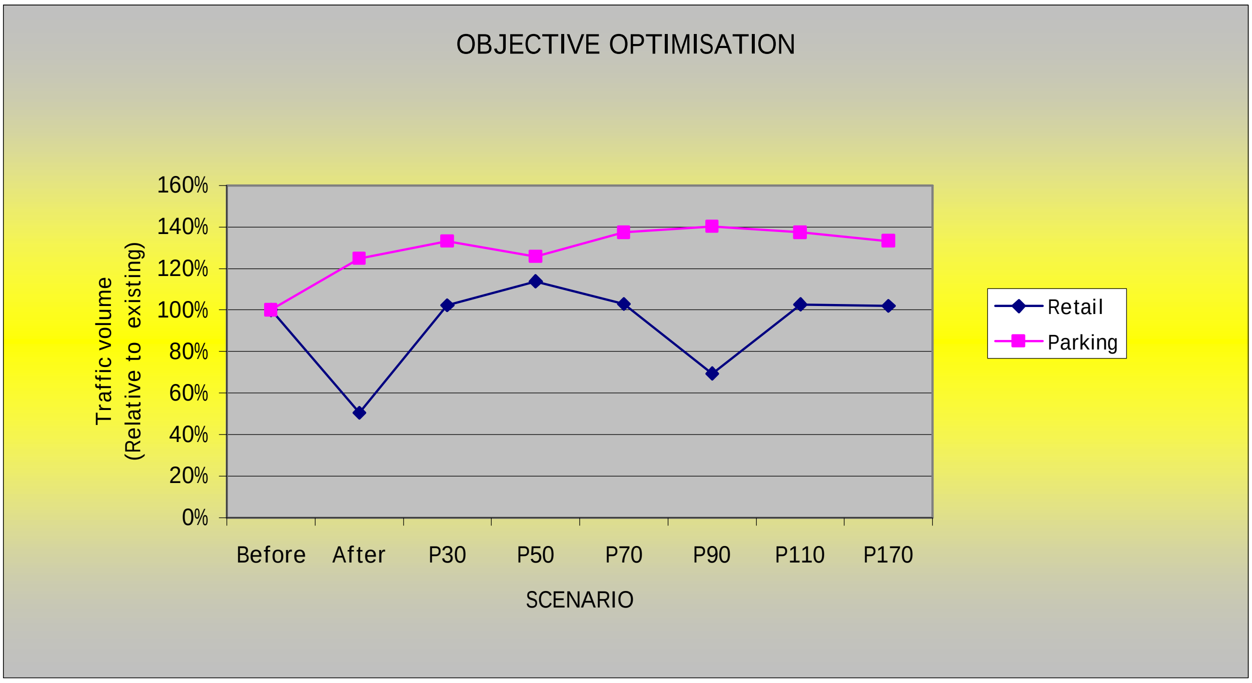



**Figure 5: Summed Traffic Flow on selected links**

From inspection of the above 2 graphs and to meet objective 1, we can see that the signal timings for P90 maximises the flow on the parking links, and minimises flow on the retail links where conflict between vehicles and pedestrians is the highest. To meet objective 2, in order to appease the retailers, either P50 or P110 timings could be used.

However, from inspection of table 5 below we see that all the P*n* scenarios outperform the proposed network (Sc3) and almost return it to the same level as the original network in terms of efficiency. Scenario P110 being the most efficient in meeting objective 2.

**Table 5: PM Network Performance from SATURN**

| SCENARIO | Sc 1 (before) | Sc 3 (after) | MUSIC P50 | MUSIC P90 | MUSIC P110 | Unit |
|---|---|---|---|---|---|---|
| Transient Queues = | 74.4 | 85.8 | 78 | 76.2 | 75.3 | Pcu. Hrs./Hr. |
| Over-Capacity Queues = | 5.6 | 7 | 0 | 0 | 0 | Pcu. Hrs./Hr. |
| Link Cruise Time = | 163 | 172.5 | 172.2 | 173.5 | 172.8 | Pcu. Hrs./Hr. |
| Free Flow = | 163 | 172.5 | 172.2 | 173.5 | 172.8 | Pcu. Hrs./Hr. |
| Total Travel Time = | 243 | 265 | 250 | 251 | 248 | Pcu. Hrs./Hr. |
| Travel Distance = | 7990 | 8028 | 7898 | 7969 | 7945.5 | Pcu. Km./Hr. |
| Overall Average Speed = | 32.8 | 30 | 31.6 | 32 | 32 | Km/h |
| Fuel Consumption = | 825 | 887 | 853 | 856 | 846 | Litres |

# 5 Conclusion

The study has highlighted the following key issues:

- When undertaking a revitalisation of a town centre it is vital to clearly set out objectives that are not in conflict with each other.

- Conventional trial and error signal optimisation methods do not always yield satisfactory results, mostly due to difficulty in accounting for changes in driver's route choices once signal plans are implemented.

- Predicting driver responses and behaviour using mathematical algorithms are very difficult. However, by using existing tools, such as area-wide traffic models, in new and novel ways such as demonstrated by the MUSIC experiment can result in superior results than compared to merely applying these tools in the usual fashion using standard approaches.

- A key to the success in modelling future behaviour of drivers must be supported by a monitoring strategy in order to refine our predictive processes that are often based on intuitive assumptions from the outset.

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