The LNM Institute of Information Technology

Optimization of Traffic Signals in Smart Cities

Optimization Techniques and Applications

Group 1 - A1/A2

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Overview

Optimization of Traffic Signal Settings in Smart Cities to settle the optimal traffic signal in entire city.

Goals

1. Determine the traffic signal settings to minimize the driver's average travel time.
2. Achieve the network equilibrium using the settings calculated at the above defined level.

Abstract

This study uses regression analysis to evaluate long-run traffic management system performance. Intelligent Traffic Signal Setting system is an established way to resolve or at least minimise traffic problems.

The issue of traffic management is a big challenge in front of today's evolving world. There are various schemes and methods introduced by government in order to handle the same.

In this project we have tried to handle this problem using the principles of optimization in order to minimise the traffic by optimizing the time consumed by vehicle at each traffic signal and thus in their whole journey.

Introduction

I. Problem Description

With the increasing population, we see traffic jams to be one of the major emerging problems of our daily lives. We have many statistics collected that clearly shows how long time is wasted each day in traffic jams.

> *"In London, Cologne, Amsterdam and Brussels, drivers spend more than 50 hours a year in road traffic congestions. This number is even higher in Utrecht, Manchester and Paris: 70 hours." reported by mapon.com.*

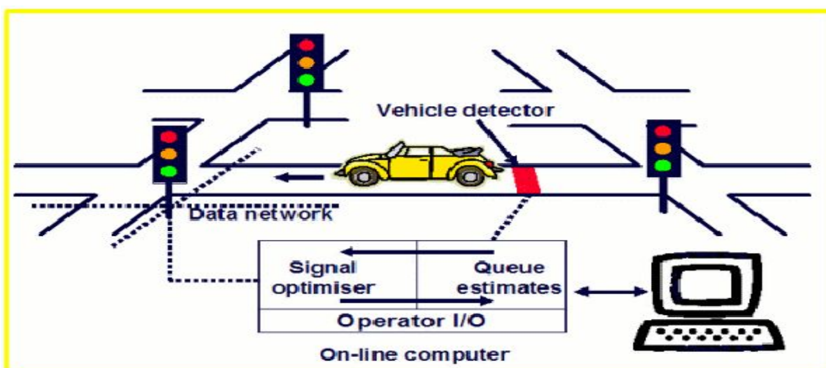
> *"A regular rush-hour driver wastes an average of 375 litres of gasoline a year due to traffic. The average cost of the time lost in rush hour traffic is $1160 per person." read by a US based reporter.*

We can clearly see the problems that have been coming. We see the waste of Time of people, Resources like Money, Fuels etc. thus, we see this problem must be resolved.

II. Problem Acknowledgement

We have proposed a solution to acknowledge this problem by this project. On the basis of case studies and sample data that we have collected, we expect this problem to be solved. We have done or approached the following things :-

- For making city smart and optimal traffic management possible, we install cameras and sensors on every roads and turnings so that data of every intersection near each traffic light can be obtained.
- After we get data at each place, we have applied optimisation techniques to get the optimal time so that at each traffic signal maximum vehicles dispatch at given interval of time and they have to wait minimum possible.
- Now by using GPS Navigation, we can get the number of traffic signals that come in drivers path.
- After we get number of traffic signals and waiting time at each traffic signal we can minimize it using some algorithms so that driver takes minimum travel time
- Thus, by this way we solve this problem and save our resources.



III. Project Description

The main contributions of this report based project are summarized as follows:

- The paper proposes an optimization-based framework for determining adaptive traffic signal time settings in smart cities.
- The paper formulates a comprehensive optimization model, which optimizes and coordinates split time, cycle time, phase sequences and offsets simultaneously for traffic signals at all intersections.
- The paper decouples the problem and find near-optimal solutions with reasonable computation efforts using MATLAB.
- The paper develops a microscopic simulation-based dynamic traffic assignment model for capturing the network equilibrium in traffic flows.

Model - I

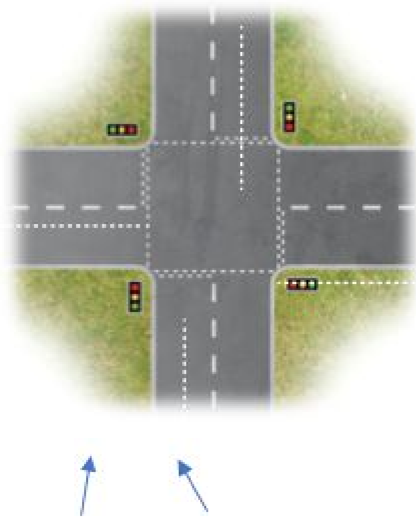
There is a four lane crossroad, having two lanes (one for incoming traffic, i.e. the right side and the other one for outgoing traffic, i.e. the left side). Each of these four roads has a traffic light facing it and directing the traffic (Let us say, T1, T2, T3, T4). Each traffic signal has a red and a green light. The traffic signal counts down to 0 from the value it initially contains.

We assume that at a particular time, a certain number of vehicles are present at a particular lane. We also assume the number of vehicles that leave a particular lane per second when it's corresponding light turns green. Using some sensors, we record that data for each day. We then subtract the number of cars that leave a lane, when its corresponding signal turns green, from the number of cars initially present in that lane taken. We calculate this value for all the four lanes and add them together and form an equation which is to be minimized. Using this data, we try to find and optimize the time for which each of the traffic light is operating.

Also, we divide our model into two sub-models, that is for:

- Office Hours **(8 AM to 8 PM)**
- Non-Office Hours **(8 PM to 8 AM)**

The number of vehicles in office hours is higher than that in the non-office hours. Also, the constraints are taken as mentioned. We solve both the cases separately considering all the four traffic lights for each case and applying the optimization to find the optimum value for each of the four traffic lights such that the traffic at the junction is minimized.



INCOMING TRAFFIC (moves upward)

OUTGOING TRAFFIC (moves downward)

Let us consider the following variables:-

- X_1 = average number of cars at signal T1
- X_2 = average number of cars at signal T2
- X_3 = average number of cars at signal T3
- X_4 = average number of cars at signal T4
- Y_1 = average number of cars that leave the signal T1 (when green) per second
- Y_2 = average number of cars that leave the signal T2 (when green) per second
- Y_3 = average number of cars that leave the signal T3 (when green) per second
- Y_4 = average number of cars that leave the signal T4 (when green) per second
- t_1 = the starting value in the signal T1's decrement-counter
- t_2 = the starting value in the signal T2's decrement-counter
- t_3 = the starting value in the signal T3's decrement-counter
- t_4 = the starting value in the signal T4's decrement-counter

Number of cars that pass through lane **i** in 1 second when signal is green= $\mathbf{y_i * t_i}$
Therefore, the number of cars remaining in a lane after signal turns red = $\mathbf{x_i - y_i * t_i}$

Therefore, the objective function Z is:

$\text{Min}(Z) = \Sigma(x_i - y_i * t_i)$ for $i \in \{1,2,3,4\}$

MODEL 1.1 FOR OFFICE HOURS (8 A.M. to 8 P.M.)

Following are the value assumed:

- X_1 = 500 cars
- X_2 = 450 cars
- X_3 = 300 cars
- X_4 = 350 cars
- Y_1 = 3 cars/sec
- Y_2 = 3 cars/sec
- Y_3 = 2 cars/sec
- Y_4 = 2 cars/sec

Objective function :

$$\text{Min}(Z) = (500 - 3t_1) + (450 - 3t_2) + (300 - 2t_3) + (350 - 2t_4)$$
$$= -3t_1 - 3t_2 - 2t_3 - 2t_4 + 1600$$

Sub to:

$t_1 \geq 3*t_3 + 5$
$t_2 \geq 2*t_4$
$t_1 + t_2 \geq 95$
$t_1 \geq 30$
$t_2 \geq 30$
$t_3 \geq 15$
$t_4 \geq 20$
$t_1 \leq 115$
$t_2 \leq 105$
$t_3 \leq 80$
$t_4 \leq 85$

Writing the equation in standard form

$$\text{Min}(Z) = -3t_1 - 3t_2 - 2t_3 - 2t_4 + 1600$$

Sub to:

$-t_1 + 0*t_2 + 3*t_3 + 0*t_4 \leq -5$
$0*t_1 - t_2 + 0*t_3 + 2*t_4 \leq 0$
$-t_1 - t_2 + 0*t_3 + 0*t_4 \leq -95$
$-t_1 + 0*t_2 + 0*t_3 + 0*t_4 \leq -30$
$0*t_1 - t_2 + 0*t_3 + 0*t_4 \leq -30$

$0*t_1 + 0*t_2 - t_3 + 0*t_4 \le -15$
$0*t_1 + 0*t_2 + 0*t_3 - t_4 \le -20$
$t_1 + 0*t_2 + 0*t_3 + 0*t_4 \le 115$
$0*t_1 + t_2 + 0*t_3 + 0*t_4 \le 105$
$0*t_1 + 0*t_2 + t_3 + 0*t_4 \le 80$
$0*t_1 + 0*t_2 + 0*t_3 + t_4 \le 85$

By this, we get t_1 = 115, t_2 = 105, t_3 = 36.67, t_4 = 52.5.
Therefore, approximately 762 cars will be still waiting.

This above model have been solved using MATLAB, codes of which are attached with the project.

MODEL 1.2 FOR NON - OFFICE HOURS (8 P.M. to 8 A.M.)

Following are the value assumed:

- $X_1 = 150$
- $X_2 = 130$
- $X_3 = 85$
- $X_4 = 50$
- $Y_1 = 3$
- $Y_2 = 3$
- $Y_3 = 2$
- $Y_4 = 2$

Objective function:

$$\text{Min}(Z) = (150 - 3t_1) + (130 - 3t_2) + (85 - 2t_3) + (50 - 2t_4)$$
$$= -3t_1 - 3t_2 - 2t_3 - 2t_4 + 415$$

Sub to:

$t_1 \geq (3/2)*t_3 + 5$
$t_2 \geq (2/3)*t_4$
$t_1 + t_2 \geq 14$
$t_1 \geq 10$
$t_2 \geq 10$
$t_3 \geq 5$
$t_4 \geq 5$
$t_1 \leq 45$
$t_2 \leq 35$
$t_3 \leq 30$
$t_4 \leq 25$

Writing the equation in standard form

$\text{Min}(Z) = -3t_1 - 3t_2 - 2t_3 - 2t_4 + 415$

Sub to:

$-t_1 + 0*t_2 + (3/2)*t_3 + 0*t_4 \leq -5$
$0*t_1 - t_2 + 0*t_3 + (2/3)*t_4 \leq 0$
$-t_1 - t_2 + 0*t_3 + 0*t_4 \leq -14$
$-t_1 + 0*t_2 + 0*t_3 + 0*t_4 \leq -10$
$0*t_1 - t_2 + 0*t_3 + 0*t_4 \leq -10$
$0*t_1 + 0*t_2 - t_3 + 0*t_4 \leq -5$
$0*t_1 + 0*t_2 + 0*t_3 - t_4 \leq -5$
$t_1 + 0*t_2 + 0*t_3 + 0*t_4 \leq 45$
$0*t_1 + t_2 + 0*t_3 + 0*t_4 \leq 35$
$0*t_1 + 0*t_2 + t_3 + 0*t_4 \leq 30$
$0*t_1 + 0*t_2 + 0*t_3 + t_4 \leq 25$

By this, we get $t_1 = 45$, $t_2 = 35$, $t_3 = 26.67$, $t_4 = 25$.
Therefore, approximately 72 cars will be still waiting.

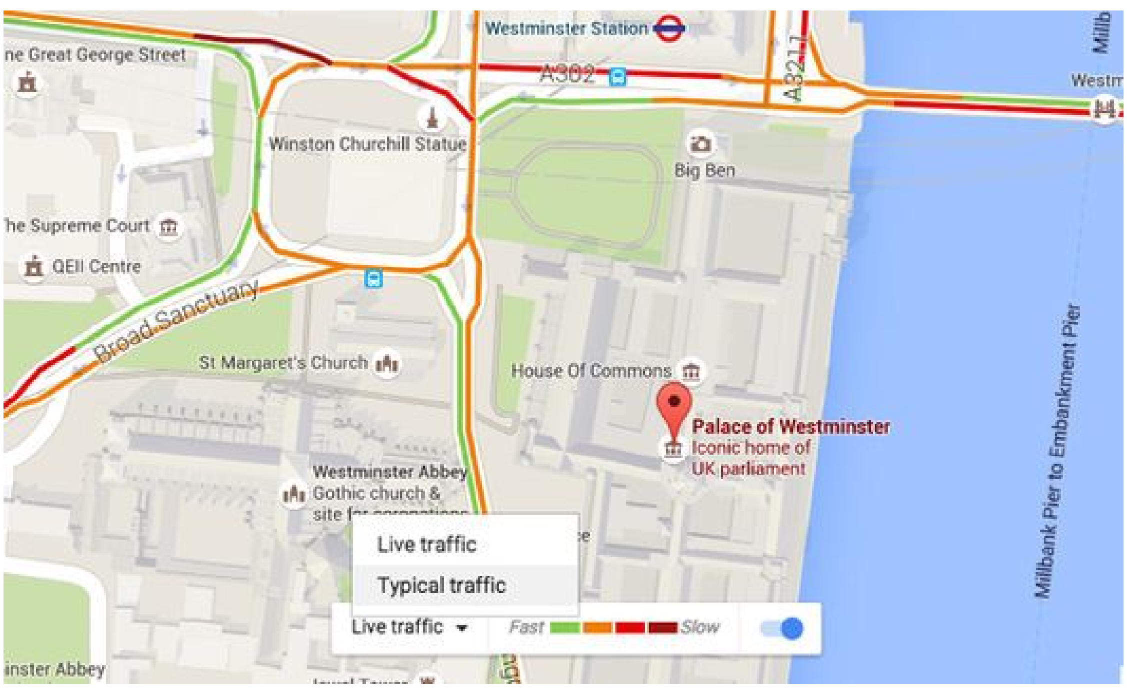
This above model have been solved using MATLAB, codes of which are attached with the project.

Model - II

After we have optimised Traffic Signal setting at each traffic signal square or so called the intersection of roads, now for minimizing the average driving time we need to optimise the overall travel time of vehicles, that means considering the journey of vehicle/driver as a whole.

> *According to report by Boston Consulting Group (BCG), "The peak hours for this survey were 7-9 am and 6-8 pm during which commuters spent one-and-a-half times longer to travel a given distance as compared to non-peak hours." This is a serious issue and needs to be optimised very smartly. We propose a solution to this that can be solved using optimisation techniques.*

We consider the source and destination of a particular vehicle and then look at the number of Traffic Signals that it has to come across in its journey. After we get this data of number of traffic lights in its way, we figure out all the constraints, problems and delays based on real time traffic conditions at those particular intersection of roads. We then estimate the average time to be spent by vehicle at each traffic signal. The summation of this time for all the number of traffic signals in its journey gives the actual time spent by vehicle and this is what needs to be minimized for improving drivers actual travel time.



We consider a case where say the driver in its journey have 4 different traffic signals. The time taken at each traffic signal be X_1 at traffic signal T1, X_2 at Traffic Signal T2, X_3 at Traffic Signal T3 and X_4 at Traffic Signal T4.

In practical application we will have different constraint in each traffic signal. Say, traffic signal T1 consumes at least thrice as much as time consumed at Traffic Signal T3. Also, say Traffic Signal T4 takes at least 5 minutes more than time consumed at Traffic Signal T2. Since vehicle must has to wait at each traffic signals we know that time consumed at each signal will be greater than or equal to 0. Also, the traffic that is at traffic signal T3 gets diverged, half towards T4 and half towards some other direction. Thus, Time taken at T4 is half of T3. Considering the average data, we can have got the data that at traffic signal T3, it takes at least 3 units of time and at traffic signal T2, it takes at least 2 units of time.

The total time taken by the driver to cover a distance of 100 Km = 100 km / 50 km/hr
= 2 hrs
= 2*60 mins
= 120 mins

Therefore, the total time taken by the drive to reach from source to destination
$= X_1 + X_2 + X_3 + X_4 + 120$ mins

Sub to:

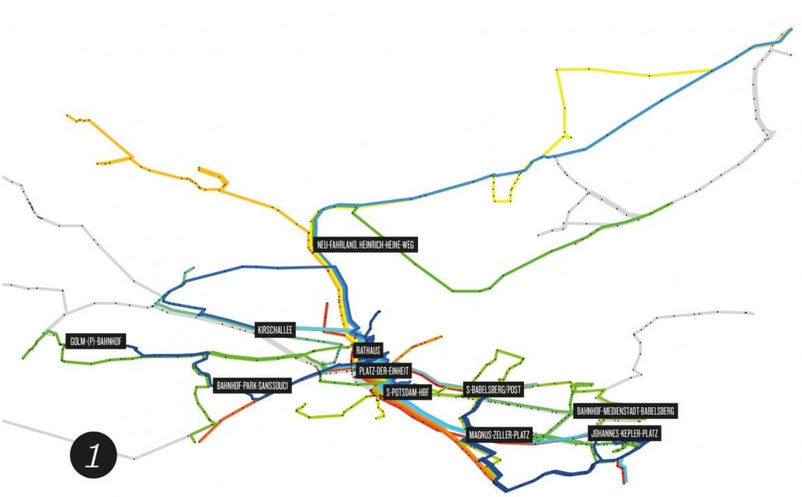
$X_1 \geq 3*X_3$

$X_4 \geq X_2 + 5$

$X_4 \leq X_3 / 2$

$X_3 \geq 3$

$X_2 \geq 2$



Writing the above equation in standard form :-

Min(Z) = $X_1 + X_2 + X_3 + X_4 + 120$

Sub to:

$-X_1 + 0*X_2 + 3*X_3 + 0*X_4 \leq 0$

$0*X_1 + X_2 + 0*X_3 - X_4 \leq -5$

$0*X_1 + 0*X_2 - X_3 / 2 + X_4 \leq 0$

$0*X_1 + 0*X_2 - X_3 + 0*X_4 \leq -3$

$0*X_1 - X_2 + 0*X_3 + 0*X_4 \leq -2$

$X_1 \geq 0$

$X_2 \geq 0$

$X_3 \geq 0$

$X_4 \geq 0$

By this we get $X_1 = 42$, $X_2 = 2$, $X_3 = 14$, $X_4 = 7$ as the answer.

Therefore the minimum time required is = 42 + 2 + 14 + 7 + 120 = 185 mins
= 3 hrs 5 mins

The above problem was solved using MATLAB and code file is attached along with the project.

Project Completion Details

Project Design and Content

Honey Agrawal

Problem Description

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Model-I (A and B) Formulation

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Model-II Formulation

Anshu Musaddi

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MATLAB Codes

Anshu Musaddi

Acknowledgement

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My thanks and appreciations also go to my colleague in developing the project and people who have willingly helped me out with their abilities.

References

- Matlab Reference : https://mathworks.com/
- IEEE Papers Like : https://ieeexplore.ieee.org/document/7743821
- Wikipedia (Ex: https://en.wikipedia.org/wiki/Traffic_congestion)
- Reports Made by Mapon https://www.mapon.com/en
- Surveys Made by Times of India : https://timesofindia.indiatimes.com/topic/traffic-congestion
- Lecture Notes by Dr. Jayaprakash Kar

Certificate

Date :

This is to certify that this project submitted by **Group-1 of A1/A2** batch in lieu of **Optimization Techniques and Applications** course of Computer Science Engineering 2018-19, is a bona fide record of the work carried out by the group at the Department of Computer Science Engineering, **The LNM Institute of Information Technology, Jaipur**, (Rajasthan) India, during their 3rd semester under my supervision and guidance and the same has not been submitted elsewhere.

Remarks :

(Dr. Jayaprakash Kar)