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Time Based Traffic Signal Coordination (A Case Study of Gatthaghar and Naya Thimi Intersections)

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Abstract

The aim of coordinating traffic signals is to provide smooth flow of traffic along streets and highways in order to reduce travel time, stops and delay. This research was carried out to investigate the benefits of signal coordination by means of traffic microsimulation software, PTV Vissim. After calibrating Vissim, signal coordination was performed by executing simulation runs of the prepared model in Vissim. The output values of the performance measures, namely 'delay' and 'travel time' were compared to the corresponding values before coordination. Considerable reduction in the values of delay and travel time was observed after coordinating the signals with the optimized offset value.

It is expected that the methodology adopted in this research will prove useful for similar studies elsewhere, provided the site geometry and traffic flow pattern are somewhat similar.

Keywords

signal coordination – simulation – delay – travel time – offset – split

1. Introduction

The origin of traffic control signals can be traced back to the manually operated semaphores first used in London as early as 1868. These days, urban arterials are being called upon to carry more users than ever before. The users of these facilities are growing more complex (older drivers, more distractions, larger vehicles, etc.) and the demand for such use continues to outpace transportation supply. Traffic signals, once installed, are often not proactively managed. Outdated or poor traffic signal timing accounts for a significant portion of traffic delay on urban arterials [1].

One of the popular concepts in traffic signalization is signal coordination. Signal Coordination refers to the timing of the signals so that a platoon of cars traveling on a street arrives at a succession of green lights and proceeds through multiple intersections without stopping. The goal of signal coordination is to get the greatest number of vehicles through the system with the fewest stops in a comfortable manner.

Improvement of traffic signal timing and using traffic signal coordination are two of the most important strategies for reducing delay, travel time and queue length in urban area [2]. These measures avoid the need to expand the existing infrastructure or build new infrastructure to cope with the increased congestion level, saving a huge share of budget allocated in transportation sector. However, detailed study and accurate forecasting of future traffic scenario are essential for the longevity of the designed signal plan, more so in case of coordinated signals.

2. Literature Review

Drivers place their physical safety and that of their passengers confidently in the signal's ability to give them the right-of-way [3]. Traffic signal retiming is one of the most cost effective ways to improve traffic flow and is one of the most basic strategies to help mitigate congestion [1]. The benefits of up-to-date signal timing include shorter commute times, improved air quality, reduction in certain types and severity of crashes, and reduced driver frustration [1]. The ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system is called traffic signal coordination [1].

2.1 Principles of Coordinated Signal Operation

The decision to use coordination can be considered in a variety of ways. There are numerous factors used to determine whether coordination would be beneficial. Establishing coordination is easiest to justify when the intersections are in close proximity and there is a large amount of traffic on the coordinated street. The traffic signals within 800 meters (0.5 miles) of each other along a corridor should be coordinated unless operating on different cycle lengths [1].

An offset is defined as the time difference in the beginning of green between adjacent traffic control signals and is expressed in seconds. Traffic signal coordination is a method of establishing relationships between adjacent traffic control signals using offsets [3].

The "ideal offset" is defined as exactly the offset such that, as the first vehicle of a platoon just arrives at the downstream signal, the downstream signal turns green. It is usually assumed that the platoon was moving as it went through the upstream intersection. The general expression for the two offsets in a link on a two-way street can be written as [4]:

$$t_{1i} + t_{2i} = nC \quad (1)$$

where,

t_{1i} = offset in direction 1 (link i), sec

t_{2i} = offset in direction 2 (link i), sec

n = integer value

C = cycle length, sec

To have $n = 1$, $t_{1i} \leq C$; to have $n = 2$, $C < t_{1i} \leq 2C$

The benefit of traffic signal coordination is based on the relationship between the prevailing speed of vehicles on the main street, the spacing of/distance between traffic signals, the hourly traffic volume on a major street, hourly traffic volumes on the side streets, and number of non-signalized intersections along the roadway system [3].

The time-space diagram is a chart that plots ideal vehicle platoon trajectories through a series of signalized intersections. The locations of intersections are shown on the distance axis, and vehicles travel in both directions (in a two-way street). Signal timing sequence and splits for each signalized intersection are plotted along the time axis [1].

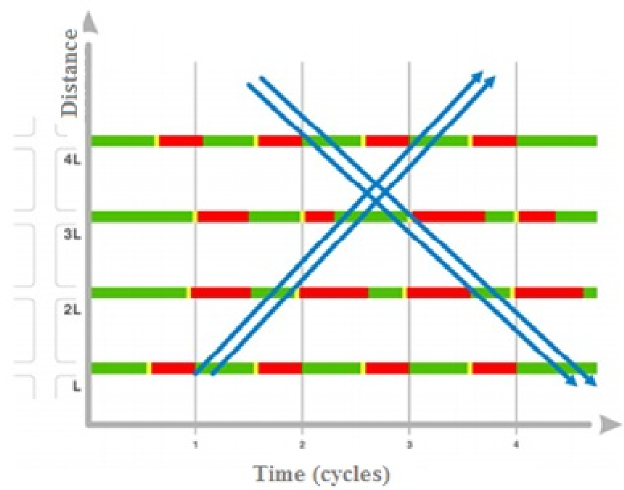

Figure 1: Time-Space Diagram of a Coordinated Timing Plan

Speed is self-regulated in coordinated signal systems; drivers travelling too fast will arrive on a red indication and end up stopping, drivers travelling too slowly will not arrive at the next signal in time to utilize the green indication [5].

Traffic signal coordination can be done in several ways [3]:

- Time Based Coordinated (TBC) System
- Interconnected Pre-timed System
- Traffic Responsive System
- Interconnected Actuated Systems
- Traffic Adaptive System

Time Based Coordination [3]**:** This form of coordination utilizes non-interconnected controllers with auxiliary devices called time based coordinators. These devices use the power company supplied frequency to keep time very accurately. Since all intersections use the same power source, the time-based coordinators provide coordination without physical interconnection.

2.2 Benefits of Signal Coordination

We coordinate traffic signals to ensure optimum travel speeds, reduced delays, and minimal stops. The major benefits of properly coordinated signals [6] are listed below:

- Improved mobility and access
- Bolstered local economies
- Reduced vehicular accidents
- Reduced energy and fuel consumption
- Eliminated or delayed street widening needs
- Improved emergency response
- Reduced motorist frustration and road rage
- Reduced vehicle wear
- Increased control of travel speeds
- Reduced diversionary flows in neighborhoods
- Reduced vehicle emissions

2.3 Limitations of Signal Coordination

The limitations of signal coordination [2] are mentioned below:

- Increase in travel speeds may have a negative impact in the community
- May attract additional traffic through the corridor
- Maintenance and equipment costs may be high based on the type of hardware and software used
- Requires qualified staff for maintenance and monitoring of daily operations

2.4 Benefits of Using Microsimulation Software in Signal Coordination Design

Microsimulation softwares (such as Vissim) can be used to develop a simulation model that represents system behaviour closely enough to allow the model to be used as a substitute for the actual system [7]. Furthermore, the interactive nature of microsimulation means that it is ideal for quick scenario testing and decision making, enabling the impacts of proposed design changes to be tested and visualised so that informed decisions can be made [8]. It also assists in conveying the results of investigations to persons not familiar with traffic engineering terminology and concepts [7].

Before implementing signal coordination in the field, its benefits have to be justified in a robust way. Through microsimulation modeling, the feasibility and the expected benefits of signal coordination in the concerned road section can be evaluated beforehand. In his study, Jun Zhou used Vissim to see the changes in average speed, average delay and average parking delay after coordinating the signals on Huai'an south road in China, and got the following results [9]:

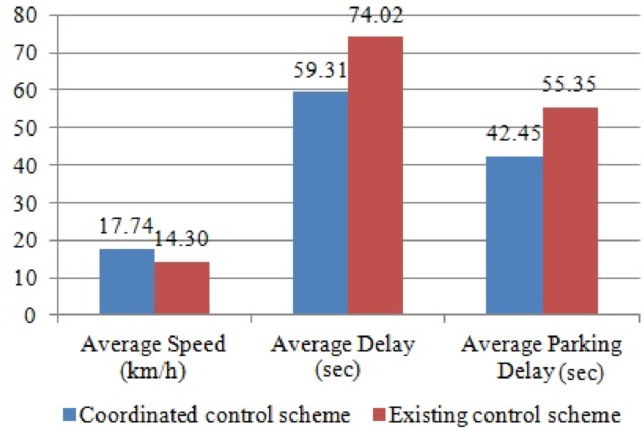

Figure 2: Comparison of Coordinated Scheme against Existing Scheme [9]

3. The Need and the Objective of the Study

3.1 The Need of the Study

Tinkune-Suryabinayak road section falls under "High Strategic Importance" category as per the Department of Roads (DOR), Nepal. The recent years' data (refer Table 1) reveal significant growth in traffic volume since 2011. This growth is mainly attributed to the expansion of the road section to six lanes in 2011. Presently, one can experience a fairly pleasant traffic flow condition at the site during off peak hours. However, during peak hours, the vehicular queues at the signalized intersections are increasing notably day by day. Also, at present, there is a high possibility that the same driver may encounter red signal at consecutive intersections, thereby causing further delay and frustration. Such scenario indicates that the currently functioning signals may need some modifications (retiming/coordination) to cope with the increasing traffic demand.

Table 1: Traffic Growth Rate in Recent Years *(Data Source: DOR)*

Year	AADT (vpd)	Traffic Growth Rate (percent)
2009	24780	37
2010	21060	-15
2011	48105	128
2012	49192	2

3.2 The Objective of the Study

The main objective of this study is to justify the need to re-time and coordinate the traffic signals at the study zone by comparing the 'before' and 'after' scenarios through the use of simulation model prepared using Vissim.

4. Methodology, Data Analysis and Results

4.1 Data Collection

Video cameras were used as a data collection tool to record the footage of traffic flow at the intersections. Following data were collected in the field:

- Intersection geometry, including lane usage and link distances
- Existing intersection turning movement counts
- PM peak period observation (16:30 to 18:30) (4 days, 15 minute periods per day)
- Posted speed on each approach
- Classified count of vehicles
- Field studies including travel time runs, queue lengths and approach delay studies. These data were useful for the calibration of the computer model and for comparison to corresponding data in the "after" condition
- Currently functioning signal timing and phasing data
- Additional data (as required)

4.2 Data Analysis and Results

The basic timing parameters of coordination are cycle length, splits, coordinated phases, and offsets [1]. The collected data were analyzed by undertaking the steps mentioned hereafter.

4.2.1 Calibration, Validation and Recalibration of the Model

The field data of Day 1, Day 2 and Day 3 were fed to Vissim as inputs. Simulation runs were performed for those inputs. Observations were made to see if the simulation matches the corresponding field values of delay and travel time. The model was validated by using the data of Day 4 collected at the same site under similar conditions. The validated model was then recalibrated by using the data of all four days.

Calibration for Delay Values:

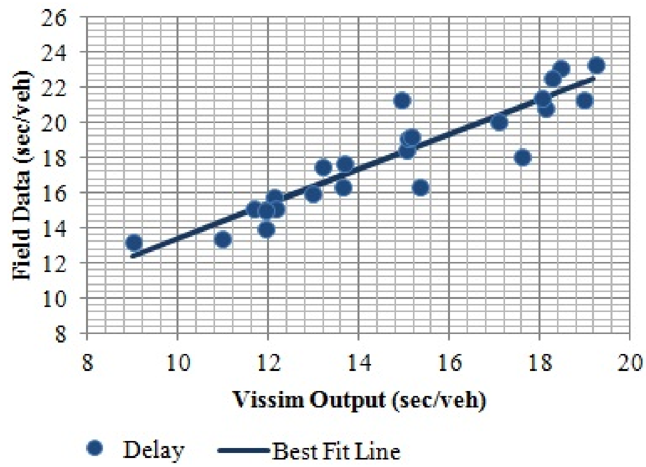

Figure 3: Calibration for Delay Values

R squared = 0.8476 (i.e. 84.76 percent of variance of field data is explained by the variance of Vissim output)

Significance F = 1.86E-10 (i.e. there is only 1.86E-08 percent possibility that the regression output was merely a chance occurrence)

Regression equation: y = 0.9883x + 3.5131 (i.e. Field value = 0.9883*(Vissim output value) + 3.5131)

Validation for Delay Values:

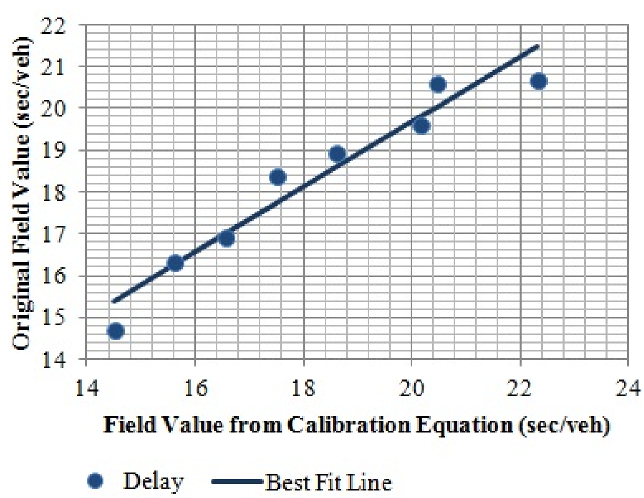

Figure 4: Validation for Delay Values

R squared = 0.9352 (i.e. 93.52 percent of variance of original field data is explained by the variance of field data obtained from calibration equation)

Significance F = 8.69E-05 (i.e. there is only 0.00869 percent possibility that the regression output was merely a chance occurrence)

The results of regression analysis confirmed the validity of the calibrated model.

Recalibration for Delay Values:

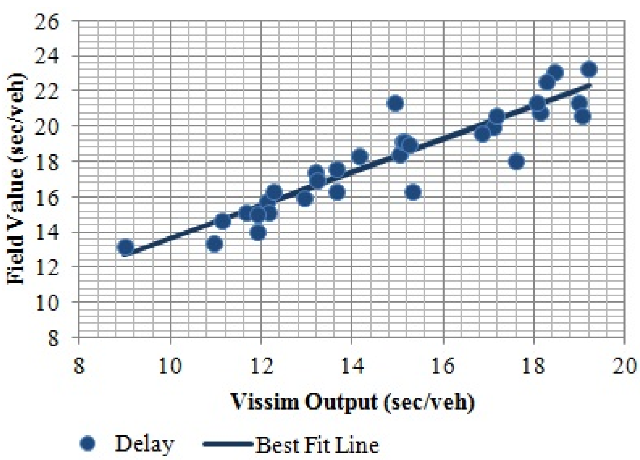

Figure 5: Recalibration for Delay Values

R squared = 0.8510 (i.e. 85.10 percent of variance of field data is explained by the variance of Vissim output)

Significance F = 6.18E-14 (i.e. there is only 6.18E-12 percent possibility that the regression output was merely a chance occurrence)

Regression equation: y = 0.9431x + 4.1992 (i.e. Field value = 0.9431*(Vissim output value) + 4.1992)

In a similar way, the model was calibrated, validated and recalibrated for the values of travel time.

4.2.2 Cycle Length Determination

For coordinated signals, the cycle length (C) should be the same at each intersection to maintain a consistent time based relationship ('double cycle' being an exception). In this study, the greater of the two existing cycle lengths of Gatthaghar (C=108 sec) and Naya Thimi (C=98 sec) intersections was used as the cycle length of the coordinated signals. So, C=108 sec was taken for the coordinated signals.

4.2.3 Split Distribution

Once a cycle length is determined, split distribution is the process of determining how much of the cycle should be provided to each of the phases [1]. Here, split values were kept unchanged for Gatthaghar intersection, i.e. the split values used for coordination were same as the split values of the existing isolated signal. For Naya Thimi intersection, the 'green time' of the major roads (EB and WB) was increased by ten seconds, leading to the design value of cycle length of 108 seconds.

4.2.4 Offset Optimization

Offsets should consider the actual or desired travel speed between intersections, distance between signalized intersections, and traffic volumes. In an ideal coordinated system, platoons leaving an upstream intersection at the start of green should arrive at the downstream intersection near the start of the green indication [3].

Successive trials were performed in Vissim to find the optimum offset value, keeping other parameters unchanged.

Two different scenarios of signal coordination were evaluated:

1. Signal coordination was performed with an offset optimized for the heaviest traffic flow direction (Eastbound) (i.e. higher priority given to the critical direction; such strategy can be applied to coordinate the Westbound traffic at AM peak hours and Eastbound traffic at PM peak hours).
2. Signal coordination was performed with an equal value of offset for both the directions (Eastbound and Westbound) of the major road (i.e. equal importance given to both the directions).

4.2.5 Comparison of Values of Performance Measures Before and After Coordination

The changes in the values of the performance measures (delay and travel time) observed in Vissim after coordination were compared against the 'before coordination' conditions to find out the effectiveness of signal coordination at the study site.

Comparison of Values of Delay Before and After Coordination:

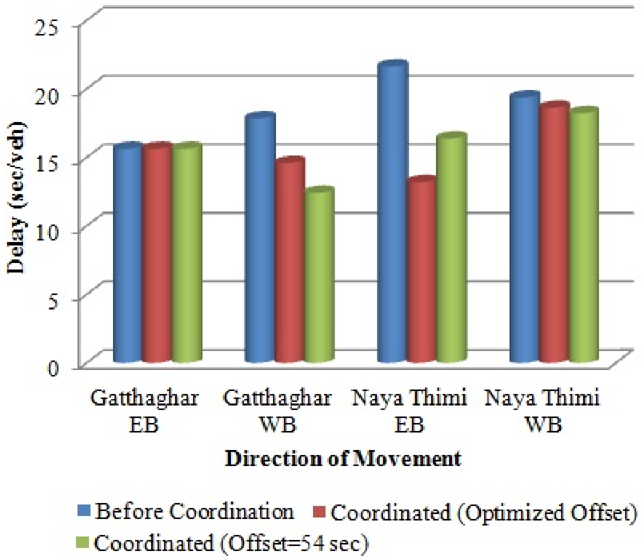

Figure 6: Comparison of Delay Before and After Coordination

Table 2: Delay Comparison for Optimum Offset

Movement	Change in Delay	Remarks
Major (EB and WB)	6.31 veh-hrs/hr	Decrease
Minor (NB and SB)	0.18 veh-hrs/hr	Increase

Overall change in delay for optimum offset = 6.13 veh-hrs/hr (decrease)

Table 3: Delay Comparison for Equally Distributed Offset

Movement	Change in Delay	Remarks
Major (EB and WB)	5.57 veh-hrs/hr	Decrease
Minor (NB and SB)	0.16 veh-hrs/hr	Increase

Overall change in delay for equally distributed offset = 5.41 veh-hrs/hr (decrease)

Comparison of Values of Travel Time Before and After Coordination:

For optimum offset:

Travel time before coordination = 139.78 sec/veh

Travel time after coordination = 124.90 sec/veh

Reduction in travel time = 14.88 sec/veh

For equally distributed offset:

Travel Time before coordination = 139.78 sec/veh

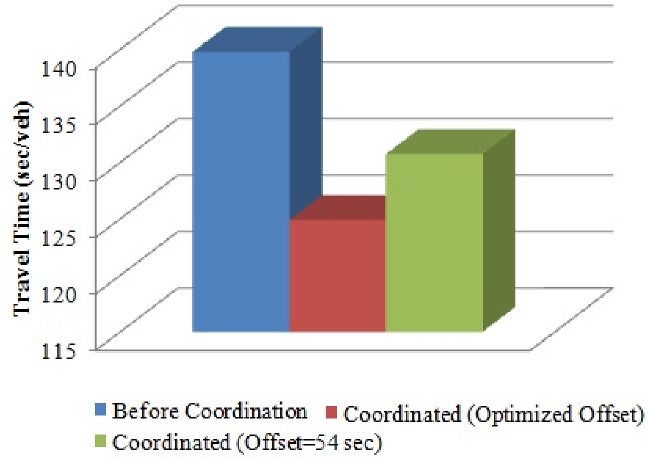

Figure 7: Comparison of Travel Time Before and After Coordination

Travel Time after coordination = 130.73 sec/veh

Reduction in Travel Time = 9.05 sec/veh

5. Conclusion

The results obtained after coordination showed an average reduction of 6.13 veh-hrs/hr of delay in the system (4.71 and 1.61 veh-hrs/hr respectively in critical [Eastbound] and non-critical [Westbound] directions) when using the offset optimized for the critical direction; and an average reduction of 5.41 veh-hrs/hr of delay in the system (2.95 and 2.63 veh-hrs/hr respectively in Eastbound and Westbound directions) when using the equally distributed value of offset (54 seconds). The corresponding reductions in the travel time values for a 1500 m segment along the critical direction were 14.88 sec/veh and 9.05 sec/veh respectively. These values are quite significant considering the fact that the reductions are primarily caused by coordination of signals, without applying many changes to other signal timing and phasing parameters. Also, the fact that no new accessory or infrastructure is needed for time based signal coordination further glorifies its benefits. This leads to a conclusion that the traffic signals at Gatthaghar and Naya Thimi intersections would serve better if coordinated.

6. Recommendations for Further Research

It is an extremely difficult task to cover all aspects of a topic in a limited time frame. Following tasks are recommended for future studies in a similar topic:

- Conducting the same research and comparing the results by using other traffic flow simulation softwares such as SimTraffic, Sidra Intersection and CORSIM is suggested.
- The traffic flow at a road section may exhibit different patterns in morning and evening peak periods. So, for better accuracy of the results, it is suggested that the morning peak period movements are also studied.
- For more reliable results, it is recommended to take pedestrian movements into account while conducting similar research.
- The area of study should be broadened, i.e. other intersections along Tinkune-Suryabinayak section should also be studied and possibility of coordinating all the signals should be checked. It would be even better to conduct similar research at other locations in the country.
- The vehicular volumes considered in this study were based on the present data collected on field. It is suggested to accurately forecast the future traffic volumes and attempt coordination of signals for those volumes. It would enable timely updating of the coordination scheme.
- There is another approach to updating traffic signals, namely signal actuation. Actuated signals can immediately adjust green and red times based on the relative traffic demands on different directions at that instant. Conducting research on signal actuation at Tinkune-Suryabinayak road section is suggested.

Acknowledgments

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