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Adaptive Signal Control to Enhance Effective Green Times for Pedestrians: A Case Study

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Abstract

In this paper, an adaptation of Split, Cycle, and Offset Optimization Technique (SCOOT) is sought in order to manage the pedestrian and vehicular traffic in Kadıköy, Istanbul. In Kadıköy, there has been an immense crowd at the coastline in either peak or off-peak hours because of the marine transit terminal. When the M4 metro line is added to the rail network at the Anatolian side of Istanbul, it has become an intolerable mess for both the vehicular and the pedestrian traffic. In the case area, there is also a tram line conflicting at the intersection to our interest. The problem observed in the case area is two-fold: if the pedestrians seize a chance to cross the street, most of them choose to cross even if the signal phase is red for them; and, there is a possibility for waiting pedestrians that they cannot complete the crossing action because of the limited green time. After the completion of data processing, simulations are done with microsimulation environment, PTV - VISSIM. In order to evaluate the proposed solution, two parameters are chosen, i.e. pedestrian travel time and vehicle delays at the intersections. The comparison between real-time measurements and simulation results illustrates the need for a trade-off between pedestrian travel time and vehicle delay.

Keywords: Smart Mobility; Pedestrian Traffic; Adaptive Traffic Control.

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1. Introduction

In this study, we present an adaptive approach to optimize traffic lights in the Kadıköy area, in Istanbul that is used by an excessive amount of pedestrians. With the implementation of the M4 subway in 2012, pedestrians' accessibility to the studied area has become easier. Since there is no crowd analysis made by authorities, problematic issues have risen for both vehicles and pedestrians. When the high pedestrian demand is present to use urban intersections and the demand is not investigated carefully, various issues are likely to occur. Increase in pedestrian and vehicle delay is one of the most important problems in this manner. To address these problems, an adaptive traffic control system, SCOOT, is proposed with considering the multi-modal property of the case area, i.e., private vehicles, public transport (ferry, subway, tram, and etc.), and pedestrians.

Rest of the paper is organized as follows: in Section 2, relevant literature with our case study is given. Section 3 presents the methodology we adopted in our study including: the entire modeling frame, signal control design steps, case area description, and simulation environment. In Section 4, a comparison between the current control and the proposed control is made. Finally, the main conclusions and possible future research are summarized in Section 5.

2. Literature Review

As in conjunction with the presented literature, we focus on pedestrian behaviors at signalized intersections and traffic control strategies proposed for handling the high variability of pedestrian demand. The literature presented in the following is divided into two parts in order to clarify the related works considering pedestrian dominated and adaptive signal control dominated studies.

Pedestrian activity at the signalized intersections has been being studied including the past four decades. Most of the studies are conducted for regulating vehicular traffic and generally, the pedestrian delay and the safety are considered as performance criteria in such works. Fruin (1971) presents extensive research for designing pedestrian facilities. Highway Capacity Manual (2010) explains how to design and implement such facilities with some assumptions. Pedestrian delay and effects of bi-directional flow are not discussed within the Highway Capacity Manual. Lam et al. (2002) investigated the relationship between pedestrians' speed and flow under different circumstances and examined the effects of bi-directional flow at signalized crosswalks in Hong Kong. In order to be efficient when designing pedestrian facilities, authors claim that mean walking speeds and pedestrian demand should be carefully analyzed and crosswalks must ensure adequate safety because of the conflict with vehicular traffic.

Optimization for signal controls in an adaptive fashion is practical because of the stochastic structure of traffic demand. Carsten et al. (1998) evaluate different pedestrian facilities in Europe in terms of investigating the shortcomings of fixed time signalization, i.e. insufficient split times for pedestrians, varying pedestrian demand and lack of adaptation, and proposed an adaptive control strategy based on the real-time pedestrian volume measurements with microwave detectors. The results are gathered under safety, comfort, and effects on vehicle traffic. Xiao et al. (2013) propose an adaptive pedestrian signal controller system using image acquisition. A video camera is mounted for detecting pedestrians in the waiting zone. If the waiting pedestrians pass a predetermined threshold value or waiting time exceeds a certain amount of time, the control unit terminates the current vehicle green phase and sets green light for pedestrians. An integrated optimization model for selecting pedestrian phase patterns is proposed in Ma et al. (2015) in order to improve both efficiency and safety at intersections. An economic evaluation framework is created for converting safety issues and delays to monetary values, which are sought to be minimized by an objective function using pedestrian phase pattern and signal timings. Li et al. (2010) proposed a new signal control system to manage high pedestrian demand. As a novel approach, an objective function, which uses vehicular and pedestrian flows as input parameters in order to minimize pedestrian and vehicular delay, is proposed. Pedestrian delay is taken into account with two different delay types: waiting delay and crossing delay. Waiting delay is the lost time of pedestrians due to stoplight, and crossing delay is a result of interaction between opposing pedestrian flows and this type of delay is more significant when the pedestrian demand is high. Another optimization model considering both the vehicles and pedestrians using a convex program for the intersections with one- and two-stage crosswalks is proposed in Yu et al. (2017). Ma et al. (2008) proposed a fuzzy logic control for pedestrian crossings. Four different pedestrian volumes range from 50 pedestrians per hour to 500 pedestrians per hour are tested in the VISSIM environment. Model proposed by Ma et al. (2008) has shown that the fuzzy control system provides higher improvements in vehicle delay and pedestrian delay compared to actuated and fixed control systems. Coordination of signal controllers is formulated with mixed-integer linear programming (MILP) in Ma and Yang (2009). Cycle time and the corresponding splits are calculated with the Webster method and compared with the proposed model. For the comparison, delay times for pedestrians and vehicles are used. Vehicle delays are significantly reduced while pedestrian delay is slightly increased with the proposed model of Ma and Yang (2009). A hybrid system is proposed in He et al. (2014) considering both the coordination of the signal control system and the signal priority. Conflicts between the actuated-coordination and multi-modal signal priority are addressed and formulated with request-based MILP. For providing priority to different modes, the weighting of the parameters can be set for modes that have maximum priority such as emergency vehicles and railway vehicles. Several scenarios tested with high traffic volume, proposed in He et al. (2014), achieved reductions in both bus and pedestrian delays.

The novel approach in this study is that we consider both vehicular and pedestrian traffic with an adaptive optimization technique named SCOOT. Using this method, we provide safe and efficient control on pedestrian flow regarding the reduced delay time at intersections while providing sufficient split times for vehicle demand.

3. Methodology and Case Study

For the adaptive control purposes of the signalized intersection to our interest, we use an integrated process that is composed of a traffic signal optimization tool and microscopic traffic simulators for vehicular and pedestrian traffic that are explained in the following sub-sections. The flowchart given by Figure 1 shows the integrated modeling frame, which starts by reading inputs for both vehicles and pedestrians, i.e., flows, routes, and speed distributions. Initiated with the data that is input, SCOOT algorithm calculates the cycle lengths, splits, and offsets in an adaptive manner for given time periods. In the next step, the applicability of the calculated pedestrian split is checked for the minimum green time for pedestrians as given in Equation 1. The algorithm of SCOOT recalculates the cycle lengths, splits, and offsets until the constraint of minimum green time for pedestrian split is ensured.

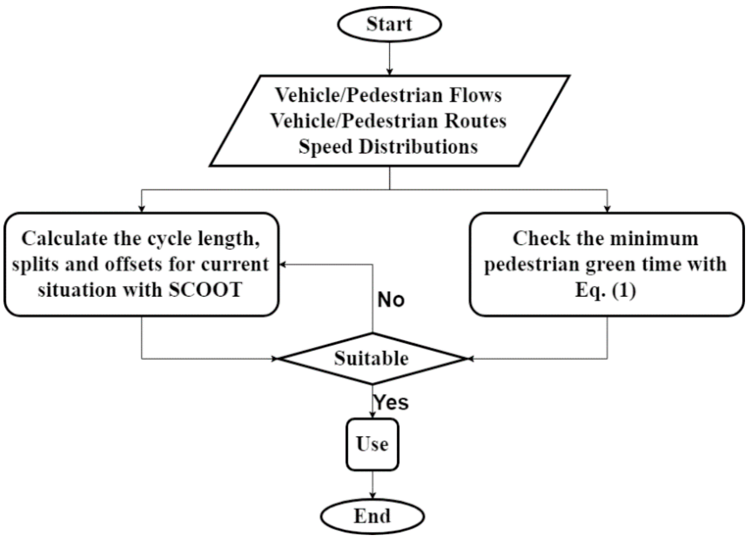


Fig. 1. Flowchart of entire modeling frame.

$$g_p = 3.2 + \frac{l}{v_p} + \left(0.81\frac{n_p}{w_e}\right) \quad (1)$$

In order to obtain the minimum for pedestrian green time, the Equation 1 (Mannering and Washburn, 2013) is used, where g_p, l, v_p, n_p, and w_e denotes respectively the minimum green time for pedestrians, the length of the cross-walk, the speed of pedestrians, the number of pedestrians traversing the crosswalk during a green phase, and the effective width for the cross-walk.

3.1. Simulation Environment

Having experienced the its user-friendly feature in a number of our previous studies on freeway traffic modeling, e.g., state modeling (Silgu and Celikoglu, 2015), the control problem of freeway ramps (Demiral and Celikoglu, 2011; Abuamer et al., 2016; Abuamer et al., 2017), and the variable speed limiting of freeway mainstreams (Sadat and Celikoglu, 2017), and urban road flow modeling (Silgu et al., 2018), we have used VISSIM, a microscopic traffic simulation software (PTV, 2018), for modeling the multimodal case study area we are interested in. As the roads serving to the case area is a part of an urban road network, we have adopted Wiedemann's car-following model for urban areas (Wiedemann, 1974). However, since pedestrian considerations in VISSIM are not sufficient to model our case, VISWALK, which is an integrated module for pedestrian flow modeling in VISSIM. Using VISWALK, one can analyze explicitly the motion of pedestrians, based on the Social Force Model (Helbing and Molnár, 1995). It is important to note that VISWALK pedestrians differ from default VISSIM pedestrians that are modeled as a vehicle type, in terms of motion models. In VISWALK, pedestrians are simulated to walk at a two-dimensional space freely, wherein VISSIM pedestrians are simulated to move along user-defined links. Thus, using the Social Force Model in simulation gives more detailed and realistic results compared to VISSIM pedestrians (PTV, 2018).

3.2. Signal Control Design

In order to manage the conflicting movements of vehicular and pedestrian traffic at the two adjacent intersections, and, hence, to optimize the signalization system in our case study area, the SCOOT method is utilized. SCOOT is an adaptive signal control algorithm, which is developed by Transportation Research Laboratory (TRL) and applied in more than 250 cities and towns all around the World (Bretherton et al., 2008; TRL, 2019). Real-world applications of the SCOOT (Bretherton et al., 2008; TRL, 2019) verify its applicability and for further investigations provide us having a comparison with other real-world case studies and our case study.

Using SCOOT, one can aggregate the data from both pedestrians and vehicles approaching to an intersection and process the data for optimizing the cycle, split and offset times of adjacent intersections (Hunt et al., 1981). Principles adhered while using SCOOT can be explained in three parts: cyclic flow profiles, queue estimation, and incremental optimization. The system creates flow profiles for every link in the area within 4 seconds interval. These profiles are generated by data coming from loop detectors in an aggregated way and a profile is created for a platoon of vehicles successively within a cycle time for one-way flow. For estimating the number of vehicles and pedestrians which approach the downstream of the intersection during the red phase, a personalized computer is programmed. After estimating the queue length, the time needed for discharging the queue is calculated by knowing that vehicles and pedestrians discharge at a saturation rate. After the queue discharge estimation, the algorithm is checking for whether the coordination plan is sufficient for new traffic situations or not. This measurement can be done in a series of frequent but small increments.

There are three optimizers within the SCOOT for controlling the traffic: split, offset and cycle time. Split optimizer makes the decision of advance, retard or stay the same for every stage change. Stage is defined in SCOOT User Guide (Siemens Traffic Controls Ltd, 2003) as an Urban Traffic Control stage that the right-of-way, yellow change, and red clearance intervals in a cycle that is assigned to an independent traffic movement. Temporary changes are set to ± 4 seconds while permanent changes are restricted to ± 1 second. Offset optimizer works for every cycle within a predetermined stage to decide the time between the nodes for minimizing stops and delays. This minimizing process is done by comparing the sum of Performance Indexes for each optimization option. Node is defined in SCOOT User Guide (Siemens Traffic Controls Ltd, 2003) as a junction or pelican under control in the SCOOT network. Cycle time optimizer sets the intersections' capacity: the longer the cycle time is, the more traffic is served by the intersection. Optimizer can seek a solution with "double-cycling" if it sees an advantage for it adhering the minimum green times for both vehicles and pedestrians.

In the present study, our algorithm actuates the related signal controller to adjust the pedestrian green time considering as well the vehicular traffic's volume information from the successive traffic lights to prevent vehicular congestion in cases with low demands of pedestrian traffic when the approaching pedestrians' flow reaches to a critical volume.

3.3. Case Study Area

Kadıköy is one of the most visited districts due to its numerous cultural and shopping centers, as it is located on the Anatolian side of Istanbul. Citizens and tourists can access the studied area with different modes of transport. A tram line that serves as a ring between from the shore area to the central area of Kadıköy exists as well. As a result, high pedestrian demand occurs at the intersections we consider most of the time.

Data to calibrate simulation models are collected using video cameras. The calibration of the simulation model, which is created using VISSIM in an integrated manner with VISWALK, is done aggregating the data collected. As it is indicated earlier, Wiedemann (1974) is adopted as the car-following model, which has 3 parameters (2 parameters for safety distance and 1 parameter for standstill distance), is calibrated using field data acquired from video recordings.

The case area is shown in Figure 2. Areas that are surrounded by blue polygons are the pedestrians' free walking spaces. Yellow arrows show the two consecutive traffic lights. Ferry stations are located at the points as pointed by red arrows. Subway entry and exit points are shown by green arrows. Tram line is represented by the black poly-line.

Fig. 2. Case area.

The crosswalk closer to the ferry terminal is located at the northern bound of the yellow arrow in Figure 2, while the crosswalk linking the pedestrian flow to the central area is located at the southern bound of the yellow arrow. Both intersections are one-way for vehicular traffic. Vehicles using the ferry intersection comes from either state road D-100 freeway -one of the most densely used urban freeways connecting Europe and Asia- or the arterial roads. City center intersection enables vehicles to access to D-100 freeway or residential areas within the Asian side of the city.

3.4. Simulation of Case Area Traffic

Vehicle and pedestrian conflict areas, consisting of 48 sub-areas for pedestrians and 36 links for vehicles, are resembled using VISSIM links as pedestrian areas. Normally, areas defined in VISSIM give pedestrians a free walking space and any interaction with vehicles is prohibited. Trip generation and distribution are determined from video recordings considering the modal split for four different vehicle types at the intersections. A total of 6000 vehicles that enter the case area in 3600 seconds from three origin points.

Data for pedestrian motion is divided into three parts. Firstly, city-line ferry passengers that arrive to and depart from stations are loaded with 15 minutes of cyclic inputs. Secondly, subway passengers traveling in the case area are loaded to the simulation environment with 6 minutes of cyclic inputs. Lastly, pedestrians that are counted using video recordings are modeled in the system. 19500 VISWALK pedestrians enter the system from 48 sub-areas. Therefore, there exist 2256 (48*47) routes in the VISSIM model for pedestrians.

Simulation environment in VISSIM is shown in Figure 3. Black polygons that labeled with ferry and city center indicate the nodes for evaluation. Yellow and red filled dots represent pedestrian travel time measurement points. Data collection points are labeled with green and placed at each lane for vehicles. Data collection points are VISSIM network objects that enable lane-based evaluation.

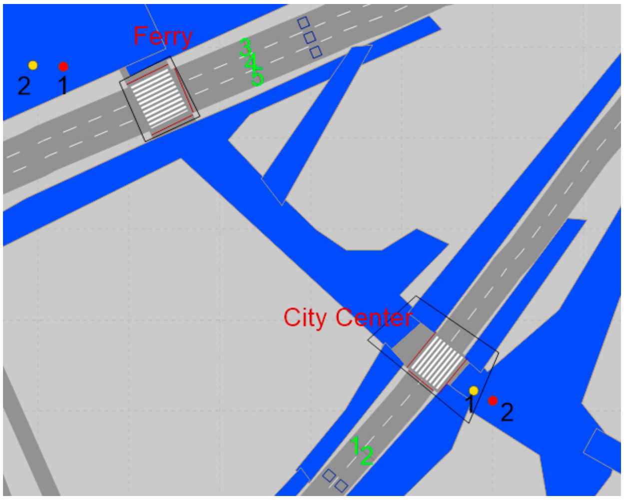


Fig. 3. Intersections considered in case area at VISSIM environment.

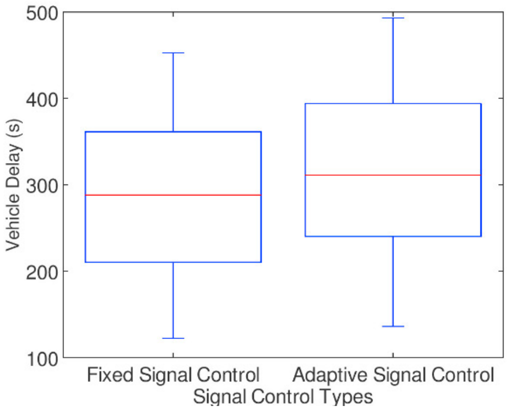
While modeling via simulation environment, each of the pedestrian detectors is designed to occupy an area of 1.5 m long and 10 m wide to include all the pedestrians that wait to cross. Successive loop detectors are mounted along the road to measure pedestrian occupancy and derive aggregated data. For sake of simplicity in the computational process of the traffic signal optimization tool, the spacing between adjacent loop detectors is set to 14 m.

Vehicle detectors are placed at 30 m upstream from the intersections for creating cyclic flow profiles that are processed by SCOOT. VISSIM detectors for vehicles are transmitting an impulse message to the signal controller group as soon as the front of the vehicle arrives the detector. In our case, 2 signal controller groups are created for each intersection. Maximum cycle length has a constraint of 120 seconds. Minimum green time for pedestrians is set to 40 seconds. Minimum green time for vehicles is set to 50 seconds. Inter-phase lengths are 10 seconds for each phase switch.

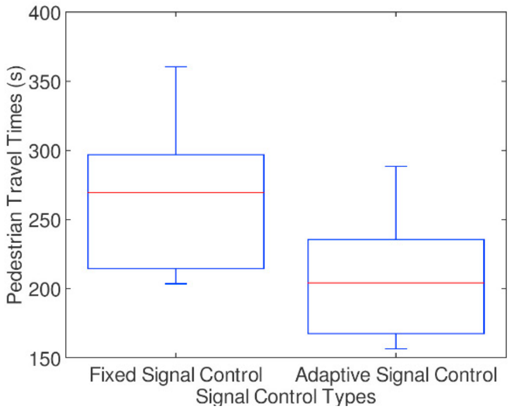
We have carried out the simulations using 10 different random seed values to reflect the stochasticity. Each simulation has been conducted in a real-time fashion, 1 simulation second to correspond 1 second in real time, as the SCOOT system necessitated.

4. Results and Discussion

Improvement of 30% in average for pedestrian travel times is obtained with an 11% increase in total delay for the vehicular traffic. The existing signal plans that are currently in use for controling the successive intersections analyzed use a cycle time of 105 seconds. In the signal control frame we propose, the cycle time varies dependent on the variation of the traffic demand. Increase on vehicle delays is inevitable with the current signal timing settings since 75 of the 105 seconds of cycle time is green for vehicular traffic. Contrary, with the method we propose, simulated pedestrian travel times in the network are considerably lower than the conditions with the current signal control in use. It is straightforward to conclude that the consequent trade-off is logic since the case area is in the heart of a central business district. Results for both vehicular and pedestrian traffic are presented in Figure 4.



a) Vehicle delay



b) Pedestrian travel times

Fig. 4. Delay and travel time performances by proposed method and current control: a) vehicle delays, and b) pedestrian travel times.

Vehicular delays from the system obtained by both the proposed and current control are compared, as the Performance Index defined by the SCOOT system aims to minimize the delays and number of stops. Mean vehicle delay time (red line at the box plot) for the current situation (fixed time control) is 288.45 seconds while mean vehicle delay time is calculated to be 311.53 seconds with the proposed method. Standard deviation for measured vehicle delays in the current control strategy and with the proposed method are calculated respectively as 102.54 seconds and 123.05 seconds. Minimum and maximum values for vehicle delays for fixed time control type are calculated as 122.48 seconds and 452.41 seconds, respectively. With the proposed method, minimum and maximum values for vehicle delays are calculated as 135.95 seconds and 493.13 seconds, respectively. For pedestrians, average travel times with two different control methods are evaluated. Pedestrian travel times shown by Figure 4b are calculated for the two densely used areas -which are used to retrieve pedestrian travel time measurements in Figure 3- with before and after measures. Mean pedestrian travel time in fixed time control is calculated as 269.56 seconds, while mean pedestrian travel time with the proposed method is calculated as 204.21 seconds. Standard deviation for pedestrian travel time is calculated as 35.16 seconds with the proposed method. With fixed time signal control, standard deviation is calculated as 47.37 seconds. In the current situation, minimum and maximum travel times for individual pedestrians are 203.54 and 360.35 seconds, respectively. With the proposed method, minimum and maximum travel times for individual pedestrians are 156.57 and 288.28 seconds, respectively.

It is further seen that dividing the case area into the 48 sub-areas has compensated the limitation of SCOOT by making the system responsive for short-term random fluctuations. One of the shortcomings of the system can be associated with its strictly centralized structure. Implementation of such systems generally requires an extensive and consequently expensive communication infrastructure that is potentially vulnerable to failures.

5. Conclusions and Future Research

In the present paper, we have studied employing SCOOT in a high populated area with pedestrian traffic concerns in Istanbul. Simulations we have performed show that, by using the SCOOT method for high pedestrian demand, a 30% of decrease in pedestrian travel time can be achieved. A disadvantage of using the system we propose in the case area is that delays vehicles experience increase by 11% with optimization using SCOOT.

As future research, we focus on pedestrians' behavior at two crossings can be analyzed with different parameters such as speed, jaywalking behavior, and bi-directional flow effects.

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