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MINIMIZING THE NUMBER OF VEHICLES IDLING AT AN INTERSECTION

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The objective of this project is to find an optimal solution minimizing the number of vehicles idling at the Kapiolani-McCully intersection during the evening peak period (6 pm - 8 pm), by assigning appropriate traffic signal times for each direction. This duration would also take into account pedestrian safety constraints, set by the US Federal Highway Administration, i.e., that standard walking rates for pedestrians should be 4 feet per second for safe crosswalk countdown times. Signal times for four directions, i.e., McCully straight turn, McCully left turn, Kapiolani straight turn, and Kapiolani left turn, were determined using linear programming based on queue length, crosswalk countdown time, and vehicle arrival rates. Average vehicle arrival rates for each direction were measured to calculate the cumulative number of vehicles waiting. Since all vehicles in all directions can use the “right on red” rule for right turns without waiting for a green signal, the study focused on the number of vehicles waiting in the left-turn and straight-turn lanes. The study found that, in order to minimize the number of vehicles waiting under the constraints, a green-light time assigned for straight turns on McCully should be 23 seconds, a green-light time for straight turns on Kapiolani should be 20 seconds, and a green-light time of 9 seconds for all the left turns.

Keywords: Traffic Signal, Linear Programming, LINDO, Green-Light Time, Peak Period, Vehicle, Queue Length.

1 INTRODUCTION

The primary purpose of traffic lights at intersections is to provide safety for vehicles moving in perpendicular directions by establishing traffic signals for vehicles to make turns and stop, in addition to providing crosswalk safety for pedestrians. However, traffic at intersections is unavoidable, and the red light is always assigned to vehicles from all directions; therefore, signal time needs to be well-managed in order to improve traffic flow under safety constraints, which is the first priority of intersections. Given that transportation demand for each direction at an intersection during a specific period may vary, and the width of each crosswalk might be different, it is possible for the traffic flow at the intersection to be improved by having non-standard durations for traffic light activity.

In this study, the Kapiolani Boulevard and McCully Street intersection in Honolulu was adopted as a case study to see if the traffic flow during the 6 pm - 8 pm peak period can be improved, using the number of vehicles waiting at the intersection as indicator. Since the study opted to apply linear programming as a tool to handle the problem, the fluctuations in vehicle arrival rates for all directions during the period are inevitably neglected. Instead, the average vehicle arrival rate was applied to calculate the cumulative number of vehicles waiting at the intersection. At the Kapiolani-McCully intersection, driving directions can be categorized into four directions based on arrival: eastbound Kapiolani, westbound Kapiolani, northbound McCully, and southbound McCully. Moreover, each direction can be classified into three turns: left turn, straight "turn", and right turn. Since right turn is free to make in every direction, the study focuses on eight turns –the left turn and straight turn of each direction. Vehicle arrival rate variables used in this study are denoted by three-letter abbreviations and their corresponding green-light times are denoted by T1 - T4, as illustrated in Figure 1.

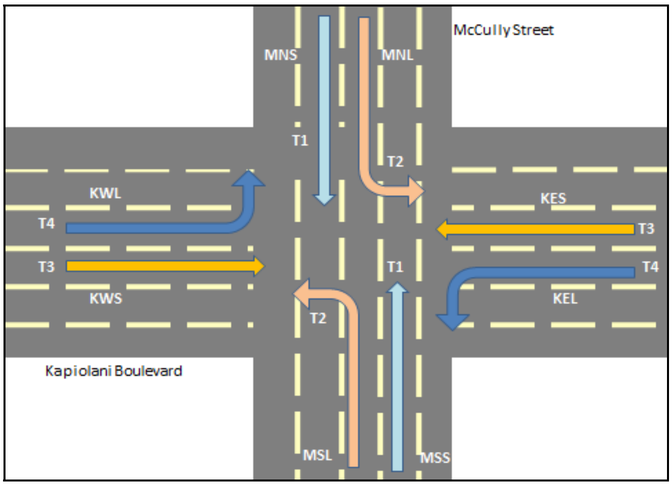

Figure 1. Layout of the Kapiolani – McCully intersection.

2 LINEAR PROGRAMMING CONSTRUCT

2.1 Objective Function

The objective function is that to minimize the number of vehicles waiting at the intersection based on the average arrival rate and signal times of each turn. As a result, the average arrival rate for each turn was collected to estimate the number of vehicles waiting in that line by multiplying the arrival rate by the red-light duration of that direction. In other words, average queue length for any direction can be estimated to be a multiplication between the arrival rate and waiting time. For example, MSL is an average arrival rate of the south McCully left-turn lane and its green light signal time is T2, as shown in Figure 1. Because the duration of a cycle is known to be T2 + T1 + T4 + T3, in that order, the average queue length is MSL x (T1 + T4 + T3). Consequently, the objective function can be written as:

$$\text{MIN} \quad KWL\,(T1 + T2 + T3) + KWS\,(T1 + T2 + T4) + MNS\,(T2 + T3 + T4) + MNL\,(T1 + T3 + T4) + KES\,(T1 + T2 + T4) + KEL\,(T1 + T2 + T3) + MSL\,(T1 + T3 + T4) + MSS\,(T2 + T3 + T4)$$

Figure 2. The objective function to minimize the number of vehicles idling at the intersection.

2.2 Constraints

Maximizing the green-light times for those turns that contain greatest arrival rates could minimize the number of idling vehicles; however, pedestrian safety and vehicle flow rate, along with queue lengths, need to be considered as essential constraints for the traffic signal time at the intersection.

2.2.1 *Pedestrian constraints*

According to the US Federal Highway Administration, the standard walking speed for pedestrians should be 4 feet per second for safe crosswalk countdown time at the intersection (FWHA 2004). The lengths of two crosswalks on Kapiolani Boulevard at the Kapiolani – McCully intersection, measured by the distance from two curbs, is approximately 90 feet. On the other hand, the length of the north crosswalk on McCully Street is 60 feet, while the length of the south crosswalk on McCully Street is 80 feet. Owing to safety concerns, the longer crosswalk on each street needs to be chosen to account for the safe countdown time. Moreover, the green-light time for the street parallel to a crosswalk corresponds to the maximum countdown times of the two parallel crosswalks; consequently, the 90-foot length and 80-foot length are chosen to make constraints for the green-light time for straight turns on Kapiolani Boulevard and McCully Street, respectively.

2.2.2 *Queue-length constraints*

Queue-length constraints for all the considered eight turns were set in this study in order to set the boundary of the maximum number of vehicles waiting to make turns for each direction. The queue length of 10 vehicles per lane was set as the maximum queue length in this study to optimize performance; thus, the maximum number of vehicles waiting on each driving turn = 10 x number of lanes for that turn. As a result, the constraint that the queue lengths for all driving turns must not contain, on average, more than 10 vehicles per lane could be established based on this idea.

2.2.3 *Vehicle-flow constraints*

The green-light signal durations for all the left turns at the intersection were not restricted by the crosswalk constraint, since all the crosswalks were unavailable for pedestrians when the left turns were signaled by the green light. Therefore, vehicle flow constraints were established in this study in order to improve traffic flows at the intersection for left turns and straight turns.

For the straight turns, the total distance for the last car to travel across the intersection was the width of the perpendicular road plus length of 10 vehicles. Besides, the average vehicle length ranged from 16.4 feet for basic sedans to 17.6 feet for luxury cars; thus, the vehicle length of 17 feet was estimated to calculate the constraints in this study (Wikipedia 2013). Therefore, the straight-turn travel distance for the 10th vehicle on McCully Street was estimated to be (90 + (17x10)) feet = 260 feet, while the straight-turn travel distance for the 10th vehicle on Kapiolani Boulevard was estimated to be (80 + (17x10)) feet = 250 feet.

For the left turns, although the displacement between two crosswalks of the perpendicular street was shorter than the distance for making straight turn, vehicles experienced a curve when making a left turn, so that turning radius should be taken into account. However, for convenience in this study, all the curve distances at the intersection were estimated to be 240 feet in linear programming due to safety factors. According to an ordinance enacted by the City and County of Honolulu (1999), the speed limit is restricted to 25 mph on any street or highway where a speed limit has not been otherwise been posted; however, the vehicles start from zero speed when the light turns green. Moreover, the speed could be less for vehicles making left turns. Consequently, a speed of 15 mph (22 fps) was chosen to apply to vehicles in this study in order to account for realistic vehicle speeds at the intersection.

2.3 Collected Data

In order to determine the vehicle arrival rate for each driving turn, raw data was collected by randomly sampling the number of vehicle arrivals during 6 pm - 8 pm on various days. The number of vehicles arriving over a two-minute period, which is a cycle of the existing T1 + T2 + T3 + T4, was collected as raw data for each turn. Next, the vehicle arrival rates can be determined by dividing the number of vehicles arrived by the duration of two minutes. This study applied the central limit theorem that a sample size is considered large enough when at least 30 observations are collected. The raw data of the number of vehicles arrived during a 120-second duration is shown in Table 1.

Table 1. Average vehicle arrival rates during two-minute cycle the intersection.

	KEL	KES	MSL	MSS	KWS	KWL	MNS	MNL
Average	7.13	26.47	4.33	11.57	32.2	3.6	9.93	1.67
S.D.	1.94	4.14	1.95	2.96	5.62	1.3	3	1.18
Arrival Rate (veh/s)	0.05944	0.22056	0.03611	0.09639	0.26833	0.03	0.08278	0.01389
Queue length (veh)	5.47	13.67	3.68	7.13	16.64	2.76	6.13	1.42

3 LINDO CODE

The study solves the problem by simplifying the traffic system at the Kapiolani-McCully intersection. Although the problem could be more accurately resolved via stochastic and simulation processes, linear programming was adopted using LINDO as a tool. The program code from LINDO is presented in Figure 3.

```
MIN   0.030 T1 + 0.030 T2 + 0.030 T3 + 0.268 T1 + 0.268 T2 + 0.268 T4
      + 0.083 T2 + 0.083 T3 + 0.083 T4 + 0.014 T1 + 0.014 T3 + 0.014 T4
      + 0.221 T1 + 0.221 T2 + 0.221 T4 + 0.059 T1 + 0.059 T2 + 0.059 T3
      + 0.036 T1 + 0.036 T3 + 0.036 T4 + 0.096 T2 + 0.096 T3 + 0.096 T4
ST
! Pedestrian Constraints
T1 > 22.5
T3 > 20
! Queue Length Constraints
0.268 T1 + 0.268 T2 + 0.268 T4 < 40     ! KWS = 0.268
0.221 T1 + 0.221 T2 + 0.221 T4 < 40     ! KES = 0.221
0.083 T2 + 0.083 T3 + 0.083 T4 < 20     ! MNS = 0.083
0.096 T2 + 0.096 T3 + 0.096 T4 < 20     ! MSS = 0.096
0.030 T1 + 0.030 T2 + 0.030 T3 < 10     ! KWL = 0.030
0.059 T1 + 0.059 T2 + 0.059 T3 < 10     ! KEL = 0.059
0.014 T1 + 0.014 T3 + 0.014 T4 < 10     ! MNL = 0.014
0.036 T1 + 0.036 T3 + 0.036 T4 < 10     ! MSL = 0.036
! Vehicle Flow Constraints
T3 > 11.36
T1 > 11.82
T4 > 10.91
T2 > 10.91
END
GIN 4
```

Figure 3. The LINDO code to minimize the number of vehicles idling at the intersection.

4 RESULTS AND CONCLUSIONS

In order to minimize the number of vehicles waiting at the Kapiolani-McCully intersection, under pedestrian safety, queue length, and vehicle flow constraints, the green-light time assigned for straight turns on McCully should be 23 seconds (T1 = 23 s); the green-light time of 20 seconds (T3 = 20 s) was required for straight turns on Kapiolani Boulevard; and the green-light time of 11 seconds needed to be assigned for all the left turns (T2 = 11 s and T4 = 11 s). Compared to the existing traffic light system, the suggested green-light times from the model were shorter, except T2, which was only 3 seconds greater than the existing duration, as seen in Table 2. The existing green-light time for straight turns on McCully (T1) was 36 seconds, while the suggested duration was 13 seconds less. Similarly, the existing green-light time for straight turns on Kapiolani Boulevard (T3) was 48 seconds, while the suggested duration is 28 seconds less. In addition, the existing green-light time for vehicles turning left from Kapiolani Boulevard to McCully Street (T4) was 18 seconds, but the suggested green-light time was only 61% of the existing duration. However, the existing green-light time for vehicles turning left from McCully Street to Kapiolani Boulevard (T2) was 8 seconds, while the suggested duration was nearly 37.5% more. According to the results run on LINDO, the expected average number of vehicles idling at the intersection was 37.0 vehicles at a time, compared to the average number of 56.9 vehicles waiting at the intersection during 6 pm to 8 pm in the existing system.

If the suggested traffic light system is applied to the intersection, the number of vehicles waiting could be reduced by 19.9 vehicles, or 35%. The average queue lengths of the existing system and the system operating under the suggested green lights are illustrated in Figure 4 (left) and Figure 4 (right), respectively.

Table 2. Comparison between parameters of the existing and suggested traffic light systems.

Parameter	Existing System	Suggested System
T1	36 sec	23 sec
T2	8 sec	11 sec
T3	48 sec	20 sec
T4	18 sec	11 sec
Average Number of Vehicles Waiting	56.9 vehicles	37.0 vehicles

Figure 4. The existing average queue lengths at the intersection (left) and the expected average queue lengths at the intersection when the suggested green lights are applied (right).

References

City and County of Honolulu, Chapter 15: Traffic Code Article, Revised Ordinances of Honolulu 1990.

FWHA, *Manual on Uniform Traffic Control Devices*, 2009.

US Department of Energy, How are vehicle size classes defined?, 2013. Retrieved from www.fueleconomy.gov/feg/info.shtml#sizeclasses. Accessed in December, 2013.

Wikipedia, Full-Size Car, 2013. Retrieved from en.wikipedia.org/wiki/Full-size_car. Accessed in December, 2013.