

The Traffic Flow Control Algorithm Based on Graph Theory together with the Maximum Flow: A Case Study on Consecutive Road at Pattani Hospital and City Hall

Nifatamah Makaje, Asma Yafaad, Aniruth Phon-On, Areena Hazanee*

Department of Mathematics and Computer Science, Faculty of Science and Technology,
Prince of Songkla University Pattani Campus, Thailand

*Corresponding author e-mail: areena.h@psu.ac.th

Received : 4 March 2026 / Revised : 16 May 2026 / Accepted : 29 June 2026

Abstract

This study proposes a traffic signal control algorithm for consecutive intersections surrounding Pattani Hospital and City Hall based on graph theory and maximum flow analysis. The traffic system is formulated as a flow network in which arc weights represent road capacities, and the Ford–Fulkerson algorithm is employed to determine the maximum feasible traffic flow. Optimal green signal durations for inbound approaches are subsequently derived from the resulting flow distribution to improve traffic performance. Furthermore, the study investigates the relationship between green signal duration and the maximum traffic clearance capacity of an intersection during a signal phase. Signal timing optimization is conducted with the objective of reducing vehicle delay and enhancing overall traffic efficiency. The analytical framework integrates effective road length with estimated traffic flow capacity derived from vehicle registration statistics in Pattani Province, while intersection traffic volumes are computed using fundamental kinematic principles. Numerical results indicate that while the proposed model successfully discharges all queued vehicles within a single green phase at certain intersections, residual queues still remain at highly congested nodes. However, by actively accounting for the receiving capacity of downstream intersections and the available roadway storage capacity, the algorithm ensures that all segments can accommodate the remaining queued vehicles. Consequently, although temporary queue accumulation occurs, the system effectively prevents complete traffic blockage or cascading gridlock across the network. Ultimately, a comparative evaluation demonstrates that the proposed approach provides superior traffic clearance performance and more efficient signal utilization compared to the Averaged-Time (AT) model.

Keywords: Graph theory, Maximum flow, Ford-Fulkerson algorithm, Traffic signal management, Traffic light control algorithm, Consecutive intersections

1. Introduction

In contemporary urban areas, traffic congestion is continually exacerbated by a growing influx of vehicles. A conventional approach to alleviating this issue relies on fixed-time traffic signal strategies (Roess et al., 2011; Webster, 1958), which operate independently of real-time traffic conditions. To address these limitations, modern Intelligent Transportation Systems (ITS) have increasingly shifted towards dynamic and data-driven methods, particularly through smart traffic optimization powered by real-time data (Rahman et al., 2025). Furthermore, recent advancements have explored networked sensor-based adaptive controls to actively stabilize dynamic traffic flows (Wang & Shao, 2025). Parallel to these trends, numerous researchers have applied graph theory to optimize traffic light control systems and minimize vehicle waiting times at intersections (Baruah & Baruah, 2012; Darmaji et al., 2024; Mandanaka & Lekhadiya, 2024; Muhiuddin et al., 2020; Ngaosai & Chawachat, 2018; Setiawan & Budayasa, 2017; Xing et al., 2022).

In this paper, we propose an algorithm for traffic flow control by calculating traffic flow and determining the optimal schedule for activating green light signals at consecutive intersections using maximum flow theory for consecutive intersections introduced in Cormen et al. (2009). To determine the maximum flow for consecutive intersections, we adapt the technique introduced by Ngaosai and Chawachat (Ngaosai & Chawachat, 2018), which

uses vehicle density to model intersections as a flow network and applies the maximum flow algorithm to allocate the traffic signal time accordingly. However, our approach differs from theirs in that we apply this concept to the traffic management of four consecutive intersections in Pattani city, where data on vehicle density is currently unavailable. Moreover, this study presents analytical results derived from calculations that integrate road length with the actual vehicle flow capacity, applying basic mathematical principles to approximate the latter using vehicle registration data from Pattani Province. Additionally, once the maximum flow values are obtained, the volume of vehicles passing through these intersections is calculated by applying fundamental kinematic principles to determine travel distance based on initial and final velocities.

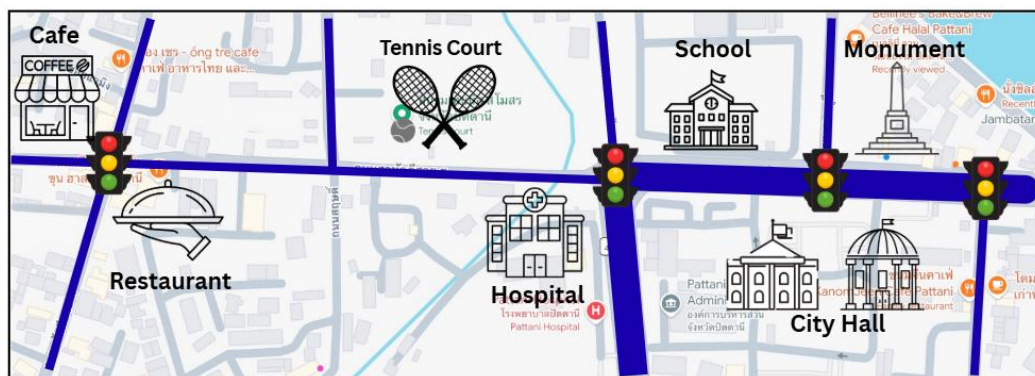
2. Materials and Methods

2.1 Scope of research

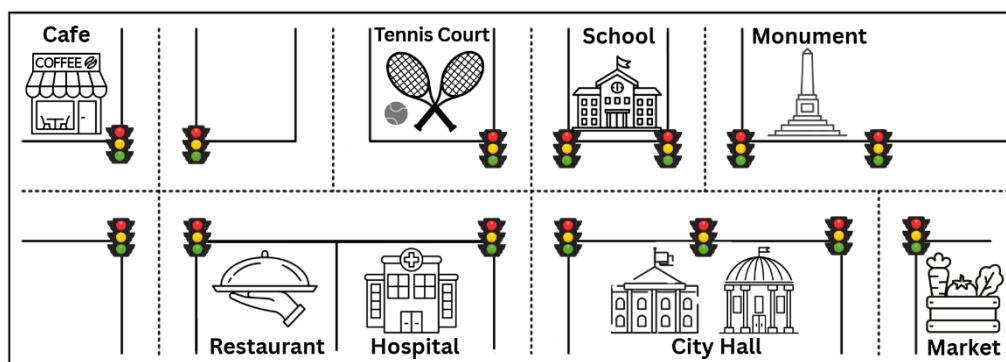
The scope of the study is defined as follows:

Study Area Scope:

The traffic on Samakkhi Sai Kor road near Pattani hospital and Phiphit road near the Pattani principal hall. The study area includes five interconnected intersections and four traffic signals, as illustrated in Figure 1, and hereafter referred to as *PN Hospital – City Hall*.



(a) Map for the research area captured from Google Map



(b) Map for the research area by illustrating

Figure 1. Map and traffic lanes of the research area.

Input Data Scope:

The number of vehicles used as input for the algorithm represents preliminary data employed to test the algorithm's performance. Due to limitations in data collection across multiple intersections, human errors may have occurred during the observation process. In this study, traffic data were collected from roads with vehicles waiting at red traffic lights during peak hours, i.e. 07:00–09:00 and 16:00–18:00 on Mondays during school term time which is the busiest traffic period.

Variable Scope and conditions:

- Road distances were collected via Google Maps and were measured from the starting point at the traffic signal intersection to the end of the intersection with traffic signals or where there is another intersection or roundabout.
- The road width parameter was excluded from the analysis since the study area is in a city zone where each lane accommodates a single vehicle queue, i.e., no lane overlaps or double parking were observed.
- The percentage of cumulative number of registered vehicles was recorded by the Pattani Provincial Transport Office between 2016 and 2020 categorized by vehicle type. There are 18 types of vehicles in Pattani Province, however, we are considering the area around the Pattani Hospital intersection which mainly sees three types of vehicles frequently that are: *Type 1* passenger cars with up to 7 seats, *Type 2* passenger cars with more than 7 seats, and *Type 3* private goods-carrying vehicles (pick-up trucks, pick-up passenger or van type).
- The lengths of vehicle Types 1, 2, and 3 are approximated as 4.3, 5.5, and 5.0 meters, respectively.
- Motorcycles are not directly considered in the capacity calculation because there are designated areas for them to wait at traffic signals. In this study, an additional 10 seconds is incorporated to account for the start-up delay of both passenger cars and motorcycles when the signal turns green.
- Turning lanes are considered without including vehicles making U-turns.

Remark:

This study does not cover external factors such as weather conditions, driver behavior, or unexpected events such as accidents or road construction. The focus is on calculating appropriate traffic signal timings under normal conditions during peak traffic hours.

Additionally, the traffic composition is approximated using cumulative provincial vehicle registration statistics from 2016 to 2020. While this provides a necessary mathematical baseline for data-scarce regions, it may not fully capture real-time fleet fluctuations during peak hours in the specific hospital zone. This data constraint is acknowledged as a design limitation.

2.2 Definitions in graph theory

The following definitions are due to Chatrakijvarun (1991), Rosen (2000) and Bondy & Murty (2008).

Definition 2.2.1

A **directed graph** $D := (V(D), A(D))$ consists of a set of vertices and a set $A := A(D)$ disjoint from $V(D)$, of arcs, together with an incidence function ψ_D that associates with each arc of D an ordered pair of vertices of D .

Definition 2.2.2

A **network** $N := N(X, Y)$ is a digraph D with two distinguished vertices, a **source** x and a **sink** y , together with a nonnegative real-valued function c defined on its arc set A . The remaining vertices are called **intermediate vertices**, and the set of these vertices is denoted by I . The function c is the **capacity function** of N and its value on an arc a is the **capacity** of a .

Definition 2.2.3

Given N is a network with a source x and a capacity c . Let $I(v) = \{a \in A | v \text{ is the terminal vertex of arc } a\}$ and $O(v) = \{a \in A | v \text{ is initial vertex of arc } a\}$. If $f: A \rightarrow \mathbb{Z}$ such that $0 \leq f(a) \leq c(a)$ for all $a \in A$ and $\sum_{a \in I(v)} f(a) = \sum_{a \in O(v)} f(a)$ for all $v \in I$ then f is called a **flow** and called $|f| = \sum_{e \in O(x)} f(e)$ **value of flow** in a network N .

Definition 2.2.4

Let f^* be a flow in a network N . If $|f| \leq |f^*|$ for all f in N then f^* is a **maximum flow**.

2.3 Defining the network

To study the traffic signal management, we first use a network representation for PN Hospital – City Hall consecutive intersections. To form a network, several pieces of data are needed, such as the number of lanes in each intersection, their directions, and the capacity of the routes within the selected scopes. Each node represents the traffic stream at each intersection, and each edge, with its direction (referred to as an arc), represents the route

through which vehicles are transported between these locations. In this study, the arc weights are real positive numbers associated with each arc, representing the capacity of the route, i.e., the maximum amount of flow possible per unit of time.

The definitions of roads based on the directions of vehicle movements are stated as follows:

- The inbound road refers to the road where vehicles enter the intersection.
- The outbound road refers to the road where vehicles exit the intersection.

To determine the maximum traffic flow at the intersection, the problem is modeled using a network, consisting of source nodes, sink nodes, and intermediate nodes as follows:

- Source (S): The node S is designated as a hypothetical source that represents the origin point of vehicle movement.
- Sink (T): The node T is designated as a hypothetical sink that represents the destination point of vehicle movement.
- Intermediate nodes: The intermediate nodes represent the pathways of all roads that are neither source nor sink nodes. These intermediate nodes are divided into three subsets: Subset I represents the set of vertices that are pathways of inbound roads, Subset O represents the set of vertices that are pathways of outbound roads and Subset C represents the set of vertices that connect two intersections.

The process of assigning arcs and establishing a network can be outlined as follows:

- Add arcs from the source node S to various nodes in the set I and represent the set of these arcs as E_1 .
- Add arcs from various nodes in the set I to the sink node T and represent the set of these arcs as E_2 .
- Add arcs from nodes representing inbound roadways to outbound roadways according to the actual traffic flow and represent the set of these arcs as E_3 .

2.4 Defining arc capacity

There are three possible cases of arc capacity:

- The capacity of arcs in set E_1 is determined by the density of vehicles on the street. Density refers to the total number of vehicles waiting at a red traffic light at any given time, measured in vehicles.
- The capacity of arcs in set E_2 is determined by the difference between the capacity to accommodate vehicle volume and the density of vehicles at the intersection, measured in vehicles.
- The capacity of arcs in set E_3 is considered infinite.

2.5 Ford-Fulkerson method

Given a flow network $D := (V(D), A(D))$, where each edge $(x, y) \in A$ has a non-negative capacity $c(x, y)$, the algorithm proceeds as follows (Ford & Fulkerson, 1956):

- **Step 1 Initialize Flow** : Set the flow $f(x, y) = 0$ for all $(x, y) \in A$ and $|f| = \sum_{e \in O(x)} f(e) = 0$.
- **Step 2 Construct Residual Graph** : Build the residual graph N_f based on the current flow. For each edge $(x, y) \in A$, the residual capacity is $C_f(x, y) = c(x, y) - f(x, y)$.
- **Step 3 Find Augmenting Path** : While there exists a path P from the source S to the sink T in N_f where every edge in P has positive residual capacity :
 - Determine Bottleneck Capacity: Let $C_f(P) = \min\{C_f(x, y) | (x, y) \in P\}$, the minimum residual capacity along the path.
 - Augment Flow: For each edge $(x, y) \in P$:
 - $F(x, y) := f(x, y) + C_f(P)$
 - $F(y, x) := f(y, x) - C_f(P)$ (add reverse flow)
- **Step 4 Repeat** : Repeat Steps 2–3 until no augmenting path exists.
- **Step 5 Output** : The flow F is the maximum flow from source S to sink T .

3. Research Process

In our study, the traffic flow refers to the count of vehicles entering or exiting the intersection. The maximum flow represents the peak number of vehicles on the road. One important consideration is to ensure that vehicle

movement stays within the network's flow capacity. The main goal of our study is to calculate the green light duration (in seconds) to achieve the maximum flow of the network.

3.1 Traffic network

In the research area PN Hospital - City Hall as shown in Figure 1, there are 34 roadways, i.e. lanes 1,2,3,...,34, representing 34 vertices with each vertex numbered according to its corresponding lane on the road as illustrated in Figures 2 and 3. Although no obvious origin point and no exit point are depicted, they are assumed to fulfill the requirements of the network flow graph and are set as nodes S and T .

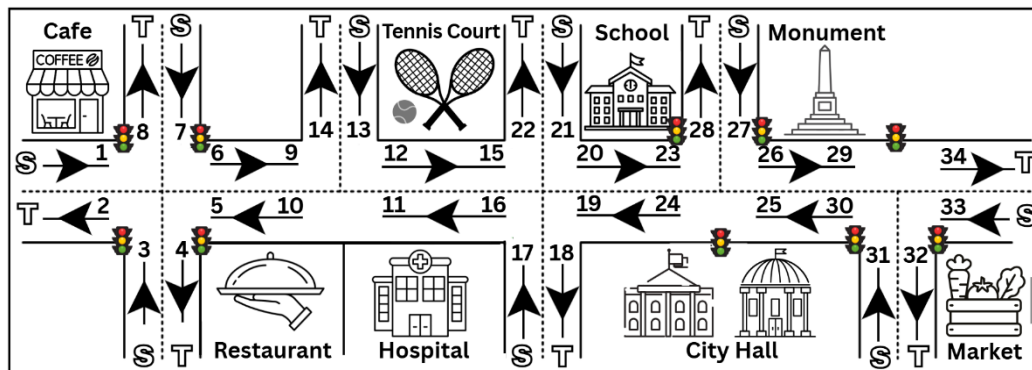


Figure 2. The traffic lanes of the observed area, with 34 vertices 1,2,3,...,34, including origin and exit vertices S and T .

The set of vertices corresponding to the observed area, as shown in Figure 2, is categorized as follows:

- Set of inbound lanes: these vertices correspond to lanes that direct traffic towards intersections ;
 $I = \{1, 3, 7, 13, 17, 21, 27, 31, 33\}$.
- Set of outbound lanes: these vertices represent the lanes that guide traffic away from the intersections;
 $O = \{2, 4, 8, 14, 18, 22, 28, 32, 34\}$.
- Connecting lanes: these vertices represent the road segments linking two consecutive intersections :
 $C = \{5, 6, 9, 10, 11, 12, 15, 16, 19, 20, 23, 24, 25, 26, 29, 30\}$.

Next, the arcs of the graph are defined to represent possible traffic flows between the vertices. The arcs are established as follows:

- From Source (S) to Inbound Lanes (I): An arc is added from the source vertex to each vertex in the set of inbound lanes, representing the traffic entering the system :

$(S, 1), (S, 3), (S, 7), (S, 13), (S, 17), (S, 21), (S, 27), (S, 31), (S, 33)$.

- From Outbound Lanes (O) to Sink (T): An arc is added from each vertex in the set of outbound lanes to the sink vertex, representing the exiting traffic system :

$(2, T), (4, T), (8, T), (14, T), (18, T), (22, T), (28, T), (32, T), (34, T)$.

- Between Inbound and Outbound Lanes: Arcs are added to connect the inbound lanes to the outbound lanes including street between intersections, simulating the possible traffic routes between intersections based on actual traffic patterns. There are 50 arcs in total for connecting lanes as follows and are displayed in Figure 3 :

$(1,4), (1,6), (1,8), (3,2), (3,6), (3,8), (5,2), (5,4), (5,8), (6,9), (7,2), (7,4), (7,6), (9,12), (9,14), (10,5), (11,10), (11,14), (12,15), (13,10), (13,12), (15,18), (15,20), (15,22), (16,11), (17,16), (17,20), (17,22), (19,16), (19,18), (19,22), (20,23), (21,16), (21,18), (21,20), (23,26), (23,28), (24,19), (25,24), (25,28), (26,29), (27,24), (27,26), (29,32), (29,32), (29,34), (30,25), (31,30), (31,30), (31,34), (33,30), (33,32)$.

These arcs form the flow network that represents the traffic movements within and between the intersections.

To optimize traffic signal management based on the constructed network graph and the concept of maximum flow, a traffic flow algorithm must be established. This algorithm utilizes both the structural data of the traffic network and real-time traffic conditions to enable effective signal timing control and to optimize vehicle flow through each junction.

3.2 The traffic flow algorithm

This study proposes a traffic flow control algorithm consisting of three sequential steps: vehicle data preparation, calculation of the maximum flow for each lane, and integration of these components to determine the optimal traffic signal timing, as illustrated in the flowchart in Figure 4. The details of each step are described below.

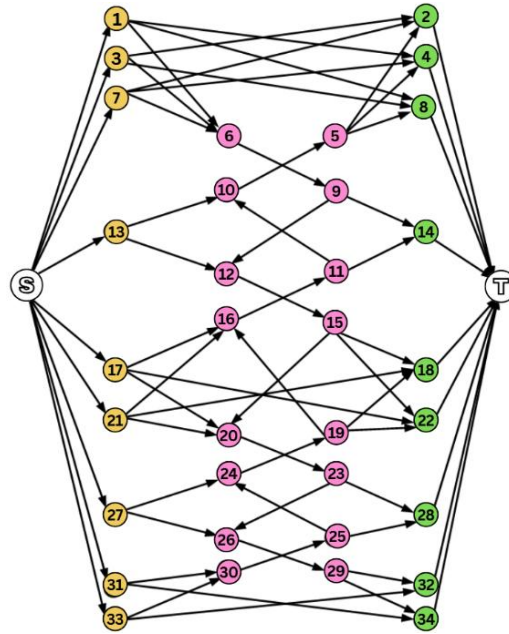


Figure 3. The network graph of the observed area, with 36 nodes and 68 arcs.

Step 1 Prepare Vehicle Volume Data :

The preparation of vehicle volume data for the system can be performed in two distinct approaches, depending on the method used to collect the number of vehicles waiting at each traffic junction.

- Collecting vehicle counting without classification, in which all vehicles are recorded collectively without distinguishing between vehicle types. Nevertheless, information regarding the total number of vehicle types and their proportional distribution is required to ensure comprehensive data representation.
- Collecting vehicle counting with classification, which categorizes vehicles according to their types, after which the total traffic volume is calculated in terms of Passenger Car Units (PCU) to ensure standardized and comparable measurements across heterogeneous traffic conditions.

Step 2 Determining Maximum Flow Volume

Calculate the maximum flow by applying the Ford-Fulkerson algorithm together with vehicle volume data from Step 1.

Step 3 Calculating Traffic Signal Timing

The determination of traffic signal durations, including green, yellow, and red intervals, is based on the analysis of the traffic signal duration for one cycle (C_0) at the junction, defined as J_i when n represents the number of intersections, $i = 1, 2, 3, \dots, n$, and the computation of the effective green time (T_G). Subsequently, the duration of the yellow signal (T_Y) is deducted from the total cycle time, resulting in the calculation of the red signal duration (T_R). The green light duration (in seconds), i.e. T_G , can be calculated as follows:

$$T_G = \frac{\sum_{w \in O(v)} S_f(w)}{\sum_{v \in J_i} S_n(v)} \times C_0, \quad (1)$$

when $S_f(w)$ represents the flow of the outbound road v at node w , whereas $S_n(v)$ represents the number of vehicles moving from the inbound road v to outbound road w at the intersection J_i .

Once the duration of the green signal has been determined, the duration of the red signal can be calculated by subtracting the green and yellow intervals from the total cycle length, as follows:

$$T_R = C_0 - T_G - T_Y. \quad (2)$$

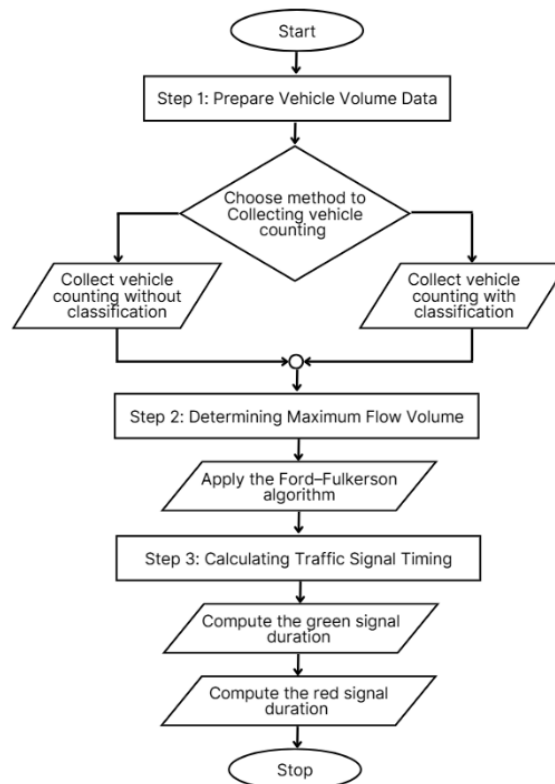


Figure 4. The traffic flow algorithm.

3.3 Assessment of signal timing effectiveness

The effectiveness of the designed signal timing can be evaluated by examining how well the calculated green time matches the actual traffic demand. This assessment involves estimating the number of vehicles that can pass through the intersection within one complete signal cycle and comparing it with the roadway capacity. This evaluation provides a quantitative measure of how efficiently the designed timing plan supports smooth traffic flow and reduces possible delays.

The maximum traffic demand for each roadway approach, represented by N_{max} (vehicles), is determined as a function of the green signal duration and the corresponding effective travel distance during the green light, represented by D_G (in meters). The formulation is expressed as:

$$D_G = \left(\frac{u+v}{2} \right) T_G, \quad (3)$$

$$N_{max} = \sum_{i=1}^3 n_i = \frac{cD_G}{\sum_{i=1}^3 (\alpha_i + 0.5)k_i}, \quad (4)$$

where u is the initial speed, v is the final speed, T_G is the green light duration, c is the number of lanes, n_i is the number of vehicles of type i , α_i is the length of vehicles of type i , and k_i is the percentage of vehicles of type i . It is worth noting that the kinematic formula used in Equation (3) used to estimate clearing distances assumes uniform acceleration. While this deterministic approach is suitable for macro-level signal assessment under data-scarce environments, it serves as a simplified representation that omits real-world acceleration delays and congestion-induced speed fluctuations. This boundary condition is acknowledged as a limitation of the current model.

4. Results and Discussions

The flow network graph constructed in this study as shown in Figure 5 provides a comprehensive simulation of the traffic system. It can be utilized to analyze traffic congestion, optimize traffic flow, and assess the impact of traffic signals on overall traffic conditions. To manage the traffic signal optimization, the following step-by-step traffic flow algorithm is applied:

Step 1: Prepare Vehicle Volume Data

This step involves collecting input data for each road, including the density of vehicles on the road, and the road's vehicle-carrying capacity.

i) Vehicle Density

As mentioned in Subsection 3.1, vehicle counts were collected using manual observation without vehicle-type classification. The collected data for each numbered node, as illustrated in Figure 2, are presented in Table 1. Although human error was acknowledged, the primary objective is to develop a traffic control algorithm adaptable to any system capable of recording vehicle volumes.

Table 1. The number of vehicle and vehicle carrying capacity of each node.

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Vehicle	50	0	10	0	20	20	5	0	20	20	24	15	5	0	15	24	99
Capacity	222	222	265	265	35	35	31	31	35	35	87	87	30	30	87	87	250
Node	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Vehicle	0	10	24	5	0	24	10	15	20	10	0	20	15	5	0	15	0
Capacity	250	61	61	29	32	61	61	49	49	31	31	49	49	124	124	36	36

ii) Vehicle-Carrying Capacity

As introduced in Subsection 2.1, the statistical data on new vehicle registrations in Pattani Province from 2016 to 2020 are used to estimate traffic composition. Since the data represent the entire province rather than only the study area, the analysis focuses on three principal vehicle types. Consequently, the estimated number of vehicles and roadway capacity may not be fully precise. The percentages of each vehicle type, as recorded in the vehicle registration, were 48% for Type 1, 3% for Type 2, and 49% for Type 3. To estimate roadway occupancy, the following model is applied :

$$4.8n_1 + 6.0n_2 + 5.5n_3 \leq cL, \quad (5)$$

where $n_1 = 48k$, $n_2 = 3k$, $n_3 = 49k$ represent the number of vehicles types 1, 2, 3, respectively, and k is a proportionality constant based on the observed percentages. The coefficients 4.8, 6.0, and 5.5 represent the effective space required per vehicle, calculated from average vehicle lengths combined with an assumed inter-vehicle spacing of 0.5 meters. Here, c denotes the number of lanes and L denotes the road length (meters). The left-hand side represents the total occupied space, which must not exceed the available lane-meters cL , indicating the maximum carrying capacity. Capacities for each observed node are summarized in Table 1.

Step 2 Determining Maximum Flow Volume

This step involves using the accommodation capacity calculated in Step 1 along with density data to define the capacities of the connecting roads represented in the flow network graph.

i) Setting Capacity for Connecting Roads

The capacity for each road was calculated based on the accommodation volume and vehicle density, divided into three cases as follows with the corresponding data shown in Table 2:

Case 1: Capacity from Source (S) to Inbound Lanes (I) was determined by the density of the road at the intersection.

Case 2: Capacity from Outbound Lanes (O) to Sink (T) including streets between intersections was calculated as the difference between accommodation capacity and vehicle density on outgoing roads.

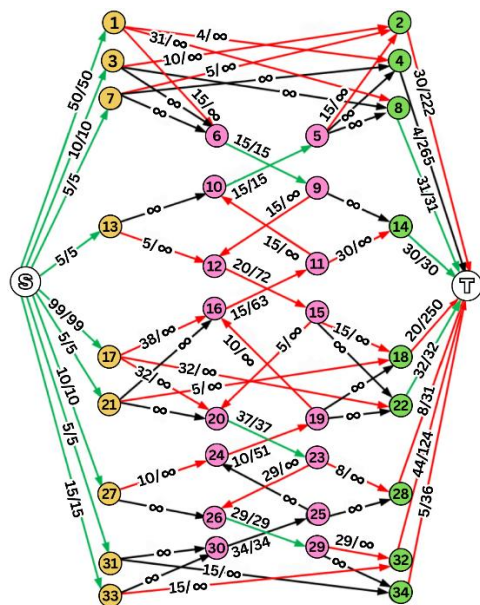
Case 3: The capacity of the remaining arcs those not included in Cases 1 and 2, was defined as infinity.

Table 2. Capacity data of inflow road, outflow road, and connecting road.

Case 1	Arc	(S,1)	(S,3)	(S,7)	(S,13)	(S,17)	(S,21)	(S,27)	(S,31)	(S,33)
Capacity of inflow road	Capacity	50	10	5	5	99	5	10	5	15
Case 2	Arc	(2,T)	(4,T)	(8,T)	(14,T)	(18,T)	(22,T)	(28,T)	(32,T)	(34,T)
Capacity of outflow road	Capacity	222	265	31	30	250	32	31	124	36
	Arc	(6,9)	(10,5)	(12,15)	(16,11)	(20,23)	(24,19)	(26,29)	(30,25)	
	Capacity	15	15	72	63	37	51	29	34	

ii) Calculating Flow Volume

The flow network is illustrated in Figure 5. Figure 5(a) presents the network graph in which each arc is labeled with two values: the first denotes the flow obtained from the Ford–Fulkerson method, and the second indicates the corresponding capacity derived from Table 2, expressed as (flow/capacity). Green arcs represent saturated links where flow equals capacity, implying that no additional vehicles can be accommodated downstream. Red arcs indicate that flow remains below capacity, allowing further vehicle movement. Black arcs denote movements with effectively unlimited capacity, such as left-turn flows that are not restricted by signal control. Application of the Ford–Fulkerson algorithm yields a maximum network flow of 204 vehicles. Figure 5(b) illustrates one feasible flow configuration consistent with Figure 5(a), displaying the distribution of flow along each path and confirming the total flow of 204 vehicles. Although multiple feasible path configurations may exist and differ structurally, the resulting maximum flow value remains invariant.



(a) The network graph with the flow value and the capacity on each arc.

Path	flow
S - 1 - 6 - 9 - 12 - 15 - 20 - 23 - 26 - 29 - 32 - T	5
S - 1 - 6 - 9 - 12 - 15 - 18 - T	10
S - 1 - 8 - T	31
S - 1 - 4 - T	4
S - 3 - 2 - T	10
S - 7 - 2 - T	5
S - 13 - 12 - 15 - 18 - T	5
S - 17 - 16 - 11 - 10 - 5 - 2 - T	5
S - 17 - 16 - 11 - 14 - T	30
S - 17 - 22 - T	32
S - 17 - 20 - 23 - 26 - 29 - 32 - T	9
S - 17 - 20 - 23 - 28 - T	8
S - 17 - 20 - 23 - 26 - 29 - 32 - T	5
S - 17 - 20 - 23 - 26 - 29 - 32 - T	10
S - 21 - 18 - T	5
S - 27 - 24 - 19 - 16 - 11 - 10 - 5 - 2 - T	10
S - 31 - 34 - T	5
S - 33 - 32 - T	15

Total flow = 204

(b) An example of the network flow with a total flow of 204.

Figure 5. The flow network graph of the observed area, with the flow value and the capacity on each arc.

Step 3 Calculating Traffic Signal Timing

The timing for traffic signals can be calculated based on the flow rates into and out of each intersection. The green light duration T_G for each outflow road is computed based on the inflow rates from various roads leading to the outflows as expressed in Equation (1), whereas the red signal duration can be deducted from one traffic circle duration, and green and yellow lights durations as expressed in Equation (2). In the observed area, the traffic signal duration for one cycle is set as $C_0 = 120$ seconds, the yellow light duration is $T_Y = 3$ seconds, and there are four junctions J_1, J_2, J_3, J_4 counting from left to right as appearing in Figure 2. Table 3 details the results of the traffic signal timings of green and red lights at each intersection in the study area.

Based on the green and red signal durations presented in Table 3, the computed timings are expressed in non-integer values (seconds), which are impractical for real-world implementation. Therefore, the signal timings are adjusted to integer values while preserving a fixed cycle length of 120 seconds at each intersection. Table 4 presents the revised signal timing plan derived from Table 3, referred to as the Maximum Flow (MF) model, and compares it with the timing scheme obtained using the Averaged-Time (AT) model. The AT model allocates equal green times per approach, assigning 30 seconds to each approach at four-leg intersections and 40 seconds at three-leg intersections. This averaged-time strategy is currently implemented for traffic signal control within the study area.

Table 3. The traffic light duration of green and red lights (in second) at each intersection.

Inflow Road	Outflow Roads	Total Outflow $\sum_{w \in O(v)} S_f(w)$	Total Vehicle Moving $\sum_{v \in J_i} S_n(v)$	Green light duration $T_G = \frac{\sum_{w \in O(v)} S_f(w)}{\sum_{v \in J_i} S_n(v)} \times 120$	Red light duration $T_R = 117 - T_G$
Intersection J_1 at roads numbered 1 to 8					
1	4, 6, 8	4+15+31 = 50	50+76+65+49 = 240	(50/240)*120 = 25	117-25 = 92
3	2, 6, 8	30+15+31 = 76		(76/240)*120 = 38	117-38 = 79
5	2, 4, 8	30+4+31 = 65		(65/240)*120 = 32.5	117-32.5 = 84.5
7	2, 4, 6	30+4+15 = 49		(49/240)*120 = 24.5	117-24.5 = 92.5
Intersection J_2 at roads numbered 15 to 22					
15	18, 20, 22	20+37+32 = 37	37+114+97+102 = 402	(37/402)*120 = 26.57	117-26.57 = 90.43
17	16, 20, 22	45+37+32 = 114		(114/402)*120 = 34.03	117-34.03 = 82.97
19	16, 18, 22	45+20+32 = 97		(97/402)*120 = 28.95	117-28.95 = 88.05
21	16, 18, 20	45+20+37 = 102		(102/402)*120 = 30.45	117-30.45 = 86.55
Intersection J_3 at roads numbered 23 to 28					
23	26, 28	29+8 = 37	37+18+39 = 94	(37/94)*120 = 47.23	117-47.23 = 69.77
25	24, 28	10+8 = 18		(18/94)*120 = 22.98	117-22.98 = 94.02
27	24, 26	10+29 = 39		(39/94)*120 = 49.79	117-49.79 = 67.21
Intersection J_4 at roads numbered 29 to 34					
29	32, 34	44+5 = 49	49+5+44 = 98	(49/98)*120 = 60	117-60 = 57
31	30, 34	0+5 = 5		(5/98)*120 = 6.12	117-6.12 = 110.88
33	30, 32	0+44 = 44		(44/98)*120 = 53.88	117-53.88 = 63.12

To evaluate the effectiveness of the proposed signal timings, the green-light travel distance D_G was computed using Equation (3), assuming an initial velocity $u = 0$ and a final velocity $v = 40$. km/h. Based on this distance, the maximum number of vehicles N_{max} was estimated by integrating D_G with road length and the proportional distribution of vehicle types, as defined in Equation (4). The resulting maximum traffic volumes (in vehicles) are presented in Table 4.

Table 4 compares traffic signal durations and traffic volumes obtained from the Maximum Flow (MF) and Averaged-Time (AT) models. The results indicate minimal differences in computed signal timings at intersections J_1 and J_2 , whereas substantial discrepancies are observed at J_3 and J_4 , particularly on Roads 25 and 31. When analyzing the overall network throughput, the MF model demonstrates superior traffic clearance performance, discharging a total of 445 vehicles across the network within a single cycle compared to only 410 vehicles achieved by the conventional AT model. This improvement stems from the dynamic adaptability of the MF model, which effectively eliminates wasted green time at underutilized approaches and reallocates those valuable seconds to high-demand critical paths. For example, at intersection J_4 , the MF model drastically reduces the green duration on Road 31 to 6 seconds to clear its minor traffic volume (7 vehicles), while dynamically extending the green phase on Road 29 to 60 seconds to accommodate a higher volume of 64 vehicles, thereby outperforming the static 43-vehicle clearance limit of the AT model. Furthermore, a comparison between traffic volumes and calculated roadway capacities shows that Roads 7, 21, 27, and 33 exceed their theoretical capacities. However, when evaluated alongside observed density data (Table 1), the actual vehicle counts remain below the estimated storage limits. As shown in Figure 2, these roads function as inbound lanes. Their capacities were determined based on effective storage length, defined as the distance from the signalized intersection to the downstream boundary (e.g., the next signalized intersection, secondary intersection, or roundabout). Thus, the theoretical capacity represents a length-based upper bound; in practice, queue lengths may vary due to operational and stochastic factors.

Table 4. The comparison of the traffic light durations and the traffic volume at each intersection computed by the Averaged-Time Model.

Inflow Road	Traffic Capacity	The Maximum Flow Model			The Averaged-Time Model		
		Green light duration	Red light duration	Traffic volume	Green light duration	Red light duration	Traffic volume
Intersection J_1 at roads numbered 1 to 8							
1	222 Vehicles	25 Seconds	92 Seconds	27 Vehicles	30 Seconds	87 Seconds	32 Vehicles
3	265 Vehicles	38 Seconds	79 Seconds	41 Vehicles	30 Seconds	87 Seconds	32 Vehicles
5	35 Vehicles	32 Seconds	85 Seconds	34 Vehicles	30 Seconds	87 Seconds	32 Vehicles
7	31 Vehicles	25 Seconds	92 Seconds	27 Vehicles	30 Seconds	87 Seconds	32 Vehicles
Intersection J_2 at roads numbered 15 to 22							
15	87 Vehicles	27 Seconds	90 Seconds	29 Vehicles	30 Seconds	87 Seconds	32 Vehicles
17	250 Vehicles	34 Seconds	83 Seconds	37 Vehicles	30 Seconds	87 Seconds	32 Vehicles
19	61 Vehicles	29 Seconds	88 Seconds	31 Vehicles	30 Seconds	87 Seconds	32 Vehicles
21	29 Vehicles	30 Seconds	87 Seconds	32 Vehicles	30 Seconds	87 Seconds	32 Vehicles
Intersection J_3 at roads numbered 23 to 28							
23	61 Vehicles	47 Seconds	70 Seconds	51 Vehicle	40 Seconds	77 Seconds	43 Vehicles
25	49 Vehicles	23 Seconds	94 Seconds	25 Vehicle	40 Seconds	77 Seconds	43 Vehicles
27	31 Vehicles	50 Seconds	67 Seconds	53 Vehicle	40 Seconds	77 Seconds	43 Vehicles
Intersection J_4 at roads numbered 29 to 34							
29	49 Vehicles	60 Seconds	57 Seconds	64 Vehicle	40 Seconds	77 Seconds	43 Vehicles
31	124 Vehicles	6 Seconds	111 Seconds	7 Vehicle	40 Seconds	77 Seconds	43 Vehicles
33	36 Vehicles	54 Seconds	63 Seconds	58 Vehicle	40 Seconds	77 Seconds	43 Vehicles

On Roads 1 and 17, it is observed that the maximum traffic volume calculated by the MF model is lower than the actual vehicle density, shown in Table 1. Specifically, on Road 1, with $T_R = 92$, the computed maximum volume is $N_{max} = 27$, whereas the observed density was 50 vehicles. Similarly, on Road 17, with $T_R = 83$, the computed maximum volume is $N_{max} = 37$, compared with an observed density of 99 vehicles. This result is expected, as the study area involves traffic analysis across consecutive intersections. In particular, Roads 1 and 17 are directly connected to inbound Roads 9, 11, and 13, where no traffic signals are installed. Consequently, vehicle inflow from these uncontrolled intersections cannot be regulated, and the outflow from the signalized intersections must consider the receiving capacity of the downstream inbound intersections. Although residual queues may remain after one signal cycle, consideration of the roadway storage capacity (as presented in Table 1) indicates that all roads can still accommodate queued vehicles. Therefore, while temporary queue accumulation may occur, the system does not reach a state of traffic gridlock or complete blockage.

5. Conclusions

This study examined traffic management in an area comprising consecutive intersections by modeling the road system as a directed graph and applying Maximum Flow theory to determine appropriate signal timings. The proposed framework integrates graph-based network analysis with vehicle capacity estimation to compute optimal green-time allocations. Fundamental kinematic principles were further employed to estimate vehicle volumes at each intersection, providing a systematic mechanism to verify the consistency between signal timing, roadway capacity, and observed traffic conditions.

Using actual traffic data, the findings demonstrate that signal timings derived from the Maximum Flow model promote continuous vehicle movement and mitigate congestion, particularly at downstream unsignalized intersections. Although variations in signal durations were identified between the Maximum Flow (MF) and Averaged-Time (AT) models at certain locations, overall network performance remained stable. Moreover, despite instances where estimated inbound volumes exceeded theoretical capacity, observed density levels confirmed that queues remained within available storage limits, preventing gridlock.

Overall, the proposed methodology offers a mathematically rigorous yet practically applicable framework for traffic management in complex urban networks, especially in environments with consecutive intersections and limited real-time traffic data.

Acknowledgement

This research was fully financially supported by the Research Career Development Grant 2025 under the Office of Research Affairs, Faculty of Science and Technology, Prince of Songkla University, Thailand. The authors acknowledge the use of AI tools to assist with English translation and language refinement. The final content was reviewed and approved by the authors.

Conflict of Interest

The authors do not report any financial or personal connections with other persons or organizations, that might negatively affect the contents of this publication and/or claim authorship rights to this publication.

ORCID

Nifatamah Makje : <https://orcid.org/0000-0002-0465-5675>

Asma Yafaad : -

Aniruth Phon-On : <https://orcid.org/0000-0002-1808-1545>

Areena Hazanee : <https://orcid.org/0000-0002-0661-7971>

Publication Ethic

This manuscript has not been submitted to or is not under consideration in any print or online journal or other source.

References

- Baruah, N., & Baruah, A. K. (2012). On a traffic control problem using cut-set of graph. *International Journal of Advanced Networking and Applications*, 3(4), 1240–1244.
- Bondy, J. A., & Murty, U. S. R. (2008). *Graph theory*. Springer.
- Chatrakijvarun, A. (1991). *Graph theory and its applications*. Department of Mathematics, Faculty of Science, Prince of Songkla University (in Thai).
- Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2009). *Introduction to algorithms* (3rd ed.). MIT Press.
- Darmaji, D., Lubis, U. K., Fitriani, R., Bulayi, M., Ade, J. A., Allahverdiev, K., & Sangsuwan, A. (2024). Optimizing traffic light timing using graph theory: A case study at urban intersections. *Interval: Indonesian Journal of Mathematical Education*, 2(2), 149–163. <https://doi.org/10.37251/ijome.v2i2.1361>
- Ford, L. R., Jr., & Fulkerson, D. R. (1956). Maximal flow through a network. *Canadian Journal of Mathematics*, 8, 399–404. <https://doi.org/10.4153/CJM-1956-045-5>
- Mandanaka, T., & Lekhadiya, H. (2024). Optimizing urban traffic flow with graph theory-based light scheduling. *Indian Journal of Natural Sciences*, 14(81), 66352–66357.
- Muhiuddin, G., Takallo, M. M., Jun, Y. B., & Borzooei, R. A. (2020). Cubic graphs and their application to a traffic flow problem. *International Journal of Computational Intelligence Systems*, 13(1), 1265–1280. <https://doi.org/10.2991/IJCIS.D.200730.002>
- Ngaosai, A., & Chawachat, J. (2018). Traffic signal management using maximum flow approach for consecutive intersections. In *Proceedings of the 15th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)* (pp. 457–460). IEEE. <https://doi.org/10.1109/ECTICon.2018.8620034>
- Rahman, R., Mamun, M., Rofi, R. I., Paul, G., & Hasan, N. (2025). Smart traffic signal optimization using real-time data and geotextile-based road sensors: A review. *Open Access Journal of Applied Science and Technology*, 3(1), 1–4.
- Roess, R. P., Prassas, E. S., & McShane, W. R. (2011). *Traffic engineering* (4th ed.). Pearson.
- Rosen, K. H. (2000). *Discrete mathematics and its applications* (4th ed.). McGraw-Hill.
- Setiawan, E. K., & Budayasa, I. K. (2017). Application of graph theory concept for traffic light control at crossroads. *AIP Conference Proceedings*, 1867, Article 020054. <https://doi.org/10.1063/1.4994457>

- Wang, X., & Shao, W. (2025). Networked sensor-based adaptive traffic signal control for dynamic flow optimization. *Sensors*, 25(11), 3501. <https://doi.org/10.3390/s25113501>
- Webster, F. V. (1958). *Traffic signal settings* (Road Research Technical Paper No. 39). Road Research Laboratory, Her Majesty's Stationery Office.
- Xing, Y., Li, W., Liu, W., Li, Y., & Zhang, Z. (2022). A dynamic regional partitioning method for active traffic control. *Sustainability*, 14(16), 9802. <https://doi.org/10.3390/su14169802>