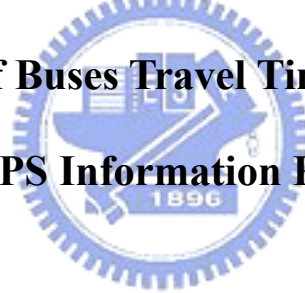# 國 立 交 通 大 學
運 輸 科 技 與 管 理 學 系

碩 士 論 文

有GPS資訊提供下之公車旅行時間之研究

The Study of Buses Travel Time Estimation

with GPS Information Provided

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中華民國 九十三年七月

有 GPS 資訊提供下之公車旅行時間之研究

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摘　　要

由於智慧型運輸系統(Intelligent Transportation Systems, **ITS**)中的先進大眾運輸系統(Advanced Public Transportation System, **APTS**)之電子技術能有效改善大眾運輸系統，進而吸引更多人搭乘大眾運輸系統，使得交通壅塞得以有效減輕。又先進大眾運輸系統中的即時車輛到站資訊可以改善大眾運輸系統中的派遣任務，並且提高乘客搭乘大眾運輸運具意願。因此旅行時間的預估就變的非常重要。

由於過去研究對於國道旅行時間預估多以佈設大量偵測器收集所需相關資料，然而要在市區佈設大量偵測器需耗費較大成本，加上近年來車輛運用全球定位系統(Global Positioning System, **GPS**)以達車輛自動定位漸漸普及，因此本研究將以市區公車裝配之 GPS 回傳的即時資料為本研究主要資料來源。

本研究將公車旅行時間切割為公車運行時間和公車停等時間。其停等時間又分為兩部分，第一部份為公車於交叉路口停等號誌之停等時間，第二部份為公車在停靠站牌載客上下車所發生之停等時間，本研究在停等時間僅針對第一部份停等時間預估。

本研究主要透過車輛歷史車速資料預估車輛運行時間，並自行發展預估模式來預估停等時間。其中在停等時間之預估，將以改變點分析將歷史資料庫依車速高低之不同型態切割成數個不同時段，而在不同車速之時段，本研究將以不同預估模式來預估公車於交叉路口停等號誌之停等時間。

最後本研究將以實際營運之公車業者為測試對象，並針對各站之預估到站時間、旅行時間和預估停等時間分析其準確度。

關鍵字：智慧型運輸系統，先進大眾運輸系統，全球定位系統，公車專用道

The Study of Buses Travel Time Estimation

With GPS Information Provided

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Abstract

Attracting more people to take advantage of public mass transit systems, the electronic technologies in Advanced Public Transportation Systems (APTS) of ITS can gradually ease traffic jams. Among all these, the real-time vehicle arriving information helps most on dispatching jobs, thus improves the will that people take public mass transit. Therefore, the importance of travel time estimateion cannot be over-emphasized.

In the past, most of the relative researches all gather their data through a lot of detectors which are needed to be installed, and that costs a big deal whether in time or money. But nowadays, as GPS (Global Position Systems) is generally popular in positioning vehicles, in this study we choose the real-time data by buses equipped with GPS to be our major data source.

We divide bus travel time into "bus running time" and "bus waiting time". The latter is composed of two parts: the first part is the waiting time that buses wait for signal change in intersections; the second part is the waiting time that passengers board on the buses at bus stops. In this study, we concern only the first part.

The methodology to estimate travel/waiting time in this study is through historical vehicle speed data and the estimateion model we construct. In the estimateion of waiting time, we classified the database by vehicle speed types into several periods; in each period, different estimateion models are used for estimateing the waiting time that buses wait for signal changes in intersections.

Also, we take real data as samples. In every bus stop, different estimateion time (arrival time, travel time and the waiting time) are respectively analyzed to test the accuracy of the model

Keywords: ITS (Intelligent Transportation Systems), APTS (Advanced Public Transportation System), GPS (Global Positioning System), Bus Lane.

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Chapter 1   Introduction

1.1 Motivation

As the economics develops fast, the number of motor vehicles also increases rapidly, and that makes traffic worse and worse. So, the traditional way of transportation engineering for solving this issue today has already not been good enough. And thus, more and more transportation agents adopt the Intelligent Transportation Systems (ITS) as a new way to solve this problem.

The three main goals of ITS are to relieve congestion, improve safety and save energy. Of ITS promises, one is to improve public transportation systems by applying advanced electronic technologies called Advanced Public Transportation System (APTS). If it attracts more people to use these systems, the traffic congestions can be generally reduced, for the traffic flow is down to a reasonable level.
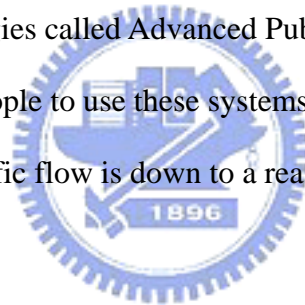
In APTS systems, real time traffic information is a very important component, especially the estimateed vehicle arrival time. With it, we can greatly improve the efficiency of dispatching jobs in APTS, and the passengers can also get more information about the accurate vehicle arrival time. In this way, passengers will be willing to take advantage of public transit, and that is considered as a suitable way for easing traffic jams.

Many different techniques for obtaining real time traffic information have been developed. Among all these, we use detector technologies most frequently, and the choices of detectors are also the widest   for example: microwave radar, passive and active infrared, ultrasound, acoustic, video image processing, inductive loop, and

probe vehicles that equipped global position system (GPS).

1.2 Scope

This study focus mainly on the real time traffic information of urban roads

(except bus lanes), and we use GPS equipped bus for collecting these data.

1.3 Objective

The objective of this study is to construct a real-time arrive time estimateion

model, by using the real-time GPS data. In the following chapters, real data will also

be used to test the accuracy of this model.

1.4 Study flowchart

There are five steps in the flowchart: 1.problem definition, 2.literature review,

3.model building, 4.model testing and modifying, 5.conclusion and suggestion. Here

we represent it diagrammatically as Figure 1.1.

To begin with, we define the problem and review relative research works. Then

we propose our real-time estimateion model. Finally, through analyzing the testing

results, we keep modifying our model and testing the accuracy of this model.

The outline of the paper is follows. In chapter 1, the objective of this study is

described. In chapter 2, reviews of papers related to this study are presented. In

chapter 3, we construct and describe a real-time arrival time estimateion model.

Chapter 4 describes how we test this model and shows testing results. In chapter 5, the

findings of this study and suggests are summarized, including several future possible

research topics.
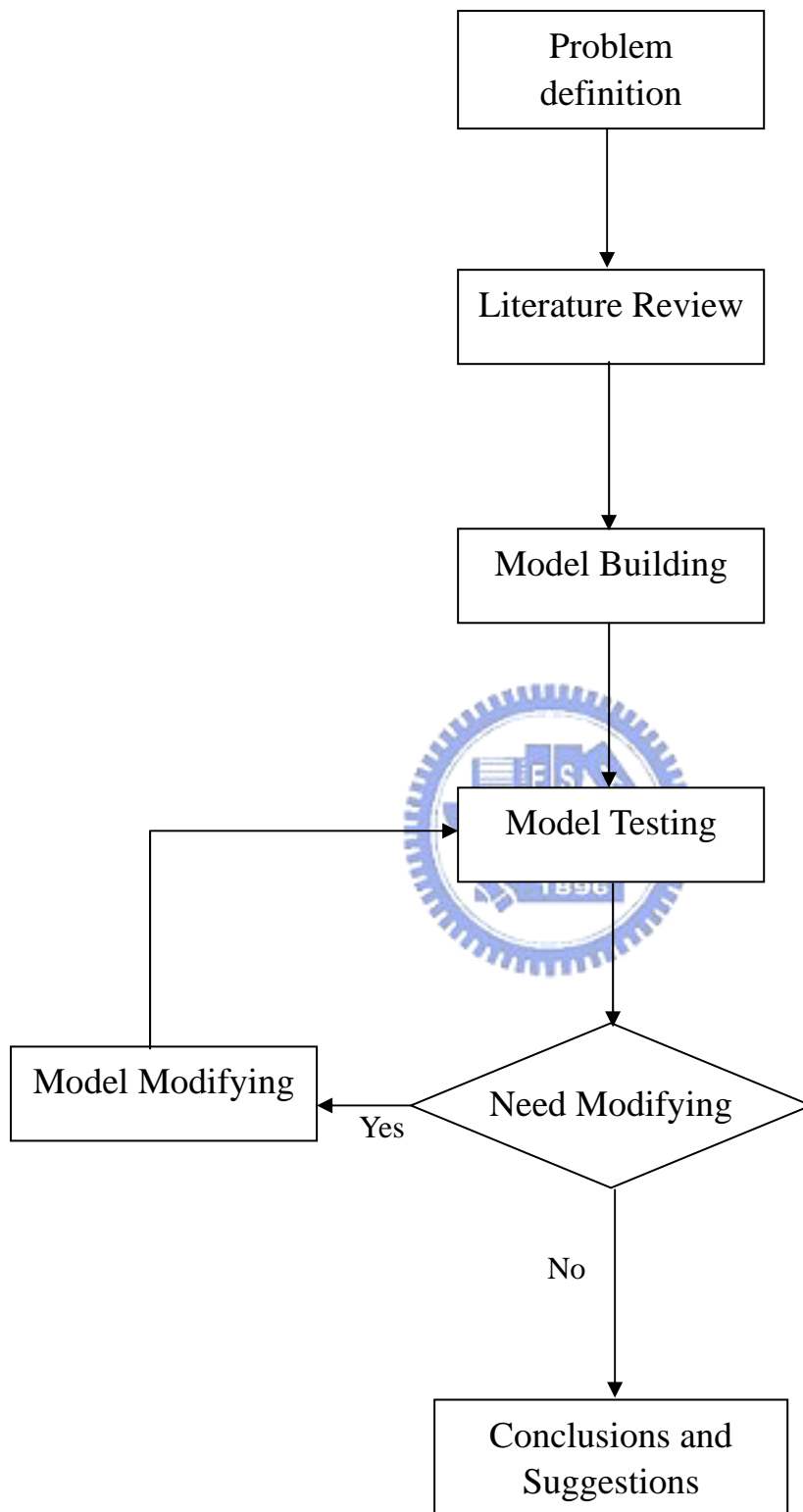
Figure 1.1 Study Flowchart

Chapter 2   Literature Review

In this chapter, we review papers related to travel time estimateion methods. Section 2.1 includes papers in corresponding with estimateion travel time on highway, while Section 2.2 is about that in urban area. Section 2.3 summarizes these reviews and makes a conclusion.

2.1 Review of the Literatures relating to estimateion travel time on highway

Most of the papers about travel time estimateion on highway are based on traffic flow theory and artificial neural network to estimate travel time.

Jasperse, Peterson, and Yamance use flow theory to estimate vehicle travel time, while Lee and Rong use artificial neural network. Concepts of these estimateion methods are explained as follows.
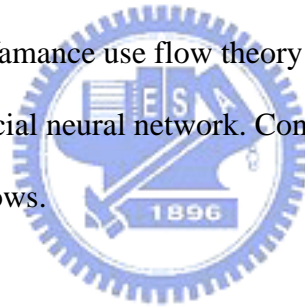
In order to provide drivers with useful and correct information, Jasperse [2] develop algorithms to calculate travel time and queue-length. Main source of the input data is from loop detector (vehicle speed and traffic flow). The algorithms are proved useful by comparing the outcome of the algorithms with real data recorded by another system. Also the algorithms will be briefly outlined. The findings are that in the common cases (short and long-closed road-segments) the estimation of travel time is satisfactory. The queue-length estimator for long closed road-segments seems also adequate. The algorithms doesn't function for open-long segments and with large absences of the input data.

Paterson [3] presents a new macroscopic algorithm for estimateing freeway

travel time. The proposed algorithms has the ability to be used in any traffic situation between two points. It also has the ability account for relative speeds and densities of vehicles within the traffic stream. Calibration and field testing of the new algorithm of has indicated that substantial improvements in travel time estimateion can be achieved when compare to existing system currently operational in Melbourne, Australia.

Yamance [4] develop the Travel Time Estimation System to estimate the travel tome using the data of Automatic Vehicle Identification (AVI) and ultrasonic vehicle detectors (UVDs). This system collects technique and estimates travel time for 106 major sections, taking account of data from UVDs. The key technology of the system is being able to estimate travel time accurately in various traffic situations. They develop a new algorithm for travel time estimation. In the algorithm, if the estimated travel time is considerably long, drivers may experience delays in receiving travel time information that may lead to incongruities with actual travel time. Therefore, they develop two more methods to overcome this problem.

Lee [7] uses artificial neural networks to build a travel time forecasting model. The input data is the real time traffic information. The traffic information involves the GPS data of bus, the data of vehicle detector and the data of incident. The section of highway in this research is from Xi-luo to Yong-kang interchange. It was divided into several segments for model building. The effects of four separating ways to the travel time forecasting are discussed fewer data sources. This study showed very promising practical applicability of the proposed models in the Intelligent Transportation System (ITS) context.

Rong [13] defines two phases in this research. First, he uses situation to produce

traffic information in first phase. Second, he uses artificial neural network with three layers, fully connected and feed-forward, and backpropagation algorithm to build forecasting highway travel time models. Using simulation to produce the relative data of traffic character detected by vehicle detector sequentially for the base of artificial neural network training and testing. The result of this research can be provided to forecast travel time in real time highway travel time estimation.

2.2 Review of the Literatures relating to estimateion travel time on urban area

Most of the papers about travel time estimateion in urban area are based on traffic flow theory and mathematics models to estimate travel time.

Sanghoon uses flow theory to estimate vehicle travel time, while Chang and Wu used mathematics algorithm. Concepts of these estimateion methods are as follows.

Sanghoon Bae [10] uses Automatic Vehicle Location (AVL) system equipped buses as probe vehicles to estimate bus travel time. Since many transit organizations throughout the North America are currently operating these AVL buses on their bus routes, in a sense, existing AVL bus would be the most cost-effective probe vehicle that can be utilized for data collection in the proactive mode. The initial objective for the first goal was to model and simulate the dynamic bus behaviors at a single and multiple buses using time varying passenger arrival rate and passenger boarding rate. Then, a prototype arrival time estimation model is simulated by adopting the Parameter Adaptation Algorithm (real-time identification). Later in the research, a dynamic link travel time function was developed by dividing the conventional arterial

link into two regions.

Kuo [15] divided the estimateion model for bus arrival time into the long-term and short-term models by time lag to fulfill the different demand of passengers. In the building of long-term model, this paper applies dynamic and stochastic travel time to calculate the expectation and variance of link travel time and uses Fast Fourier Transform (FFT) to obtain the function types. In the other hand, this study proposes three short-term estimateion models and evaluates them by precision, robustness and stability After model building, this study finds that the point of demarcation of long term and short-term estimateion models is 35 minute. In validation, it discusses the estimateion error with respect to route distance, time lag and intersections. At last, this study also validates the model precision on the multi-route through reality investigation.

Wu [8] used GPS positioning information to estimate vehicle travel time. In this research mainly using vehicle historical travel information to estimate vehicle travel time. In order to make the estimation module to fit both the interurban and urban trips, he divided the vehicle travel time into vehicle running time and vehicle delay time. At the same time, in order to amend the shortcoming that it could not response the sudden change of vehicle running pattern of using historical travel information to estimate vehicle travel time. He use the GPS positioning information, includes vehicle average running speed and former vehicle travel time information to adjust the vehicle running time estimation. And he used the vehicle real stopping behavior to adjust the vehicle delay time estimation.

Chang [9] proposes a data processing model to process the real-time travel data collected by the buses instrumented with GPS, and estimate the average speed in a

link. However the buses have their main missions to do, such as carrying passengers, we must filter out the unneeded data to provide accurate travel information. The data processing model includes two parts. One is the data filtering model to filter out the un-normal low speeds resulted from stops for collecting passengers or red light. The other is the data-cutting model. This model using the change point analysis of statistic theory to find a cutting point where the data has significant difference. The result showed that the data filtering model and the data-cutting model could work well.

2.3 Summary

1. I this study, we choose to focus our research on travel time estimation in urban area. The reason is that, although we found that most papers are mainly written for that on highway but rarely for urban area, the importance of urban area travel time estimation in APTS, however, is still none the less.

2. This study takes GPS as its main data source for the sake of cost and labor. A majority of papers are based on traffic flow theory and artificial neural network. But through those methods, we have to install a lot of detectors in urban area, and that costs much.

3. Former researches have done well in processing travel time and historical vehicle speed data. So, by using those reviewed results, this paper is intended as a further research in waiting time estimateion, hoping for estimateing bus traveling time more accurately.

Chapter 3   Model Building

This section explains principles of the estimation model. We divide the bus travel time into two categories: "bus running time" and "bus delay time". The former refers to the total sum of running time in each sub-section, and the latter means the total sum of the waiting time at each intersection. Concepts of the estimation model are explained in section 3.1.

In this study, we take GPS as the major data source. Thus, before we start to construct our model, we should preprocess these data, build databases for historical average speed and predecessor bus speed to meet the needs of this model. The processing of bus speed data is explained in section 3.2.

By using average speed, we are able to estimate the running time. When the traffic status is normal, we use the historical bus average running speed to estimate running time. And when the traffic status is abnormal, we switch to front platoon's speed data to estimate running time. The concept of running time estimation is explained in section 3.3.

The bus delay time is divided into two parts: the first part is the time for vehicles waiting for traffic signals; the second part is the time for passengers boarding on buses. In this study, we even divide the first part into "the time waiting for red light" and "the time waiting for the front platoon dismissing". The details will be explained in section 3.4.

3.1 Concept of Bus Travel Time Estimation

First, we have to define the most elementary concepts here: links and nodes. Both of them have two kinds individually: link and sub-link, stop node and intersection node, and each of them is described as follows:

A stop node refers to the point where the bus stop is placed (Figure 3.1), and a intersection node refers to where the intersection is. (Figure 3.2) A link means the segment between two stop nodes (Figure 3.3), while the sub-link means the distance between an intersection node or a bus node and another intersection node (Figure 3.4).
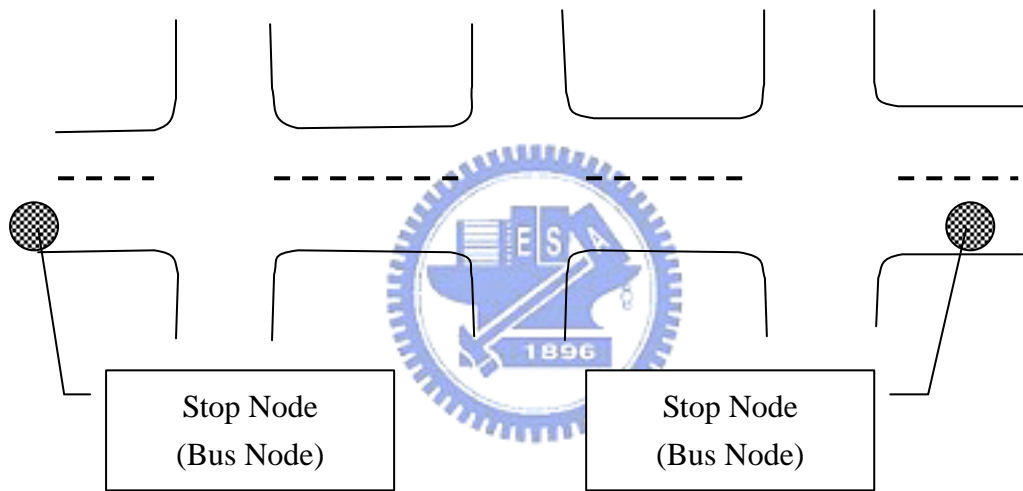
Figure 3.1 Stop Node
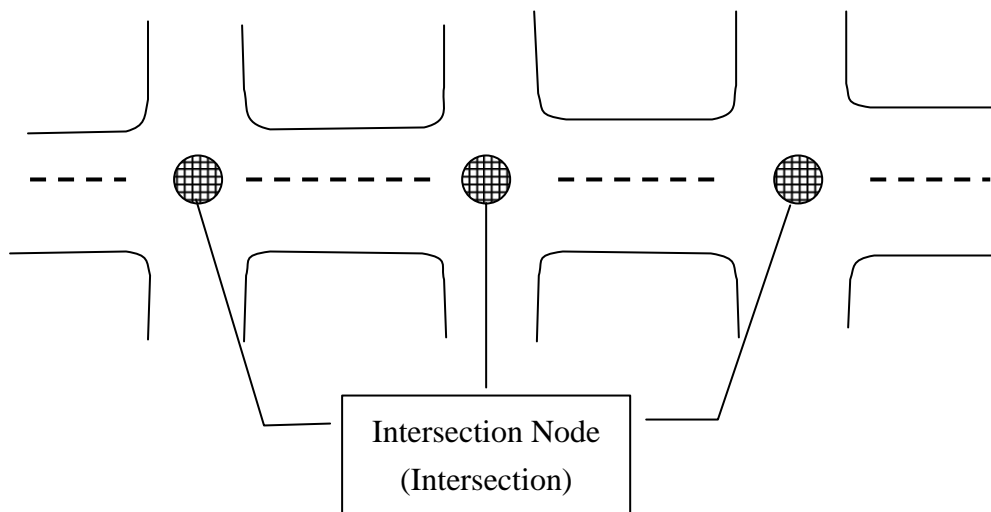
Figure 3.2 Intersection Node
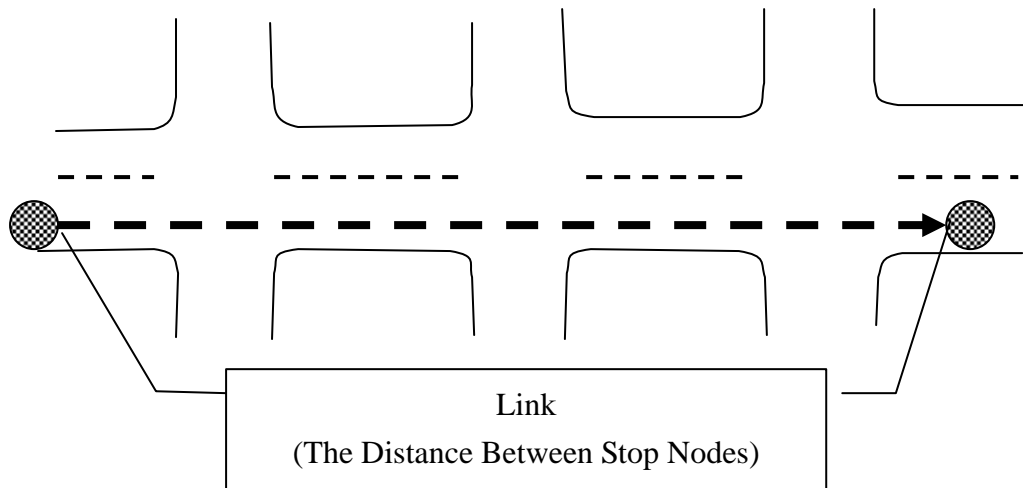
Figure 3.3 Link
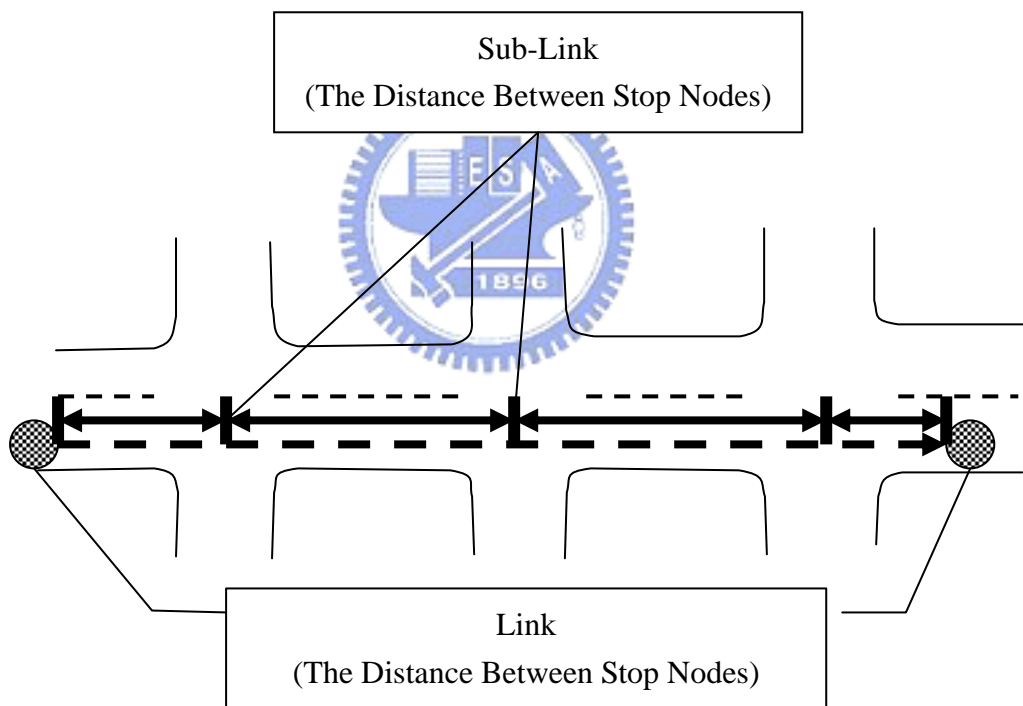
Figure 3.4 Sub-Link

In this study, bus travel time is divided into bus running time and bus waiting time. The former means the total sum of the running time in each sub-link; the latter is the sum of the waiting time at each intersection.

Take figure 3.5 for example, node S and node S+1 refers to bus stop nodes, and node N and node N+1 are intersection nodes. In Figure 3.5, we illustrate the bus travel time between the stop node S and the stop node S+1: the running time is the sum of the running time of sub-link j, j+1 and j+2, and the waiting time is the sum of the waiting time on intersection node N and N+1.

When the bus travels from the stop node S to the intersection node N, its travel time in the sub-link j equals to T_{r_j}. And by that time, the bus arrives at the intersection with red light and fleet ahead. Thus we divide the bus waiting time into two parts. The first part (the time for the bus to wait for traffic signal change) equals to T_{Df_N}. The second part (the waiting time for the platoon ahead to dismiss) equals to T_{Ds_N}.
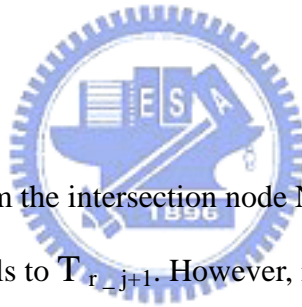
When the bus travels from the intersection node N to the intersection node N+1, its travel time in link j+1 equals to T_{r_j+1}. However, if the bus arrives at the intersection with red light but without fleet ahead, the bus waiting time is only composed by the time for the bus to wait for traffic signal change, namely, T_{Ds_N+1}.
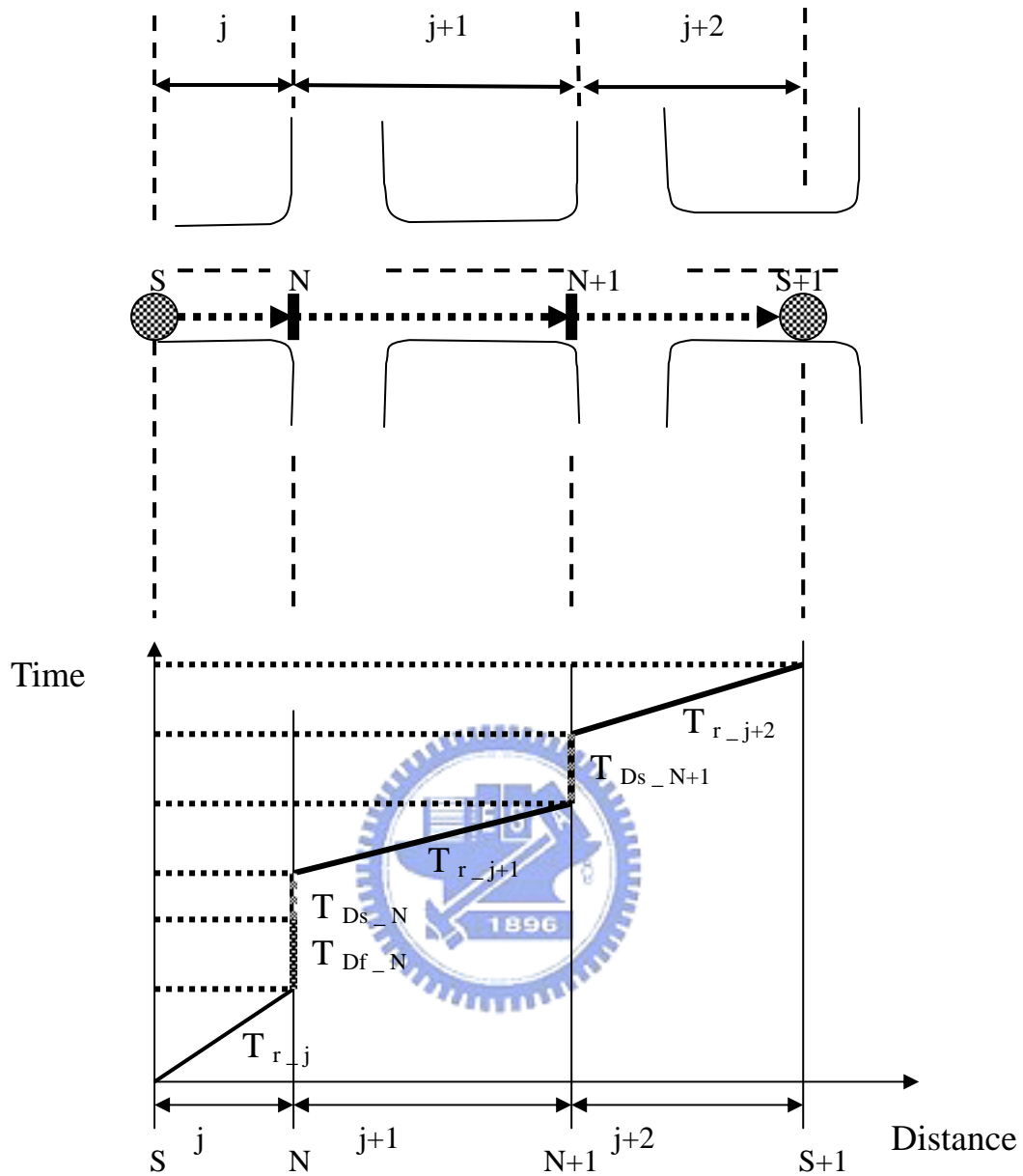
Figure 3.5 The Theory of Bus Travel Time Estimateion

3.2 Processing of bus speed data

Before the estimation, we must process the bus speed data in advance, in order to

compute the average speed in each sub-link more precisely. For some abnormal bus

speed data may affect the accuracy of the average bus running speed. There are some

reasons for the occurrence of abnormal bus speed data: 1. buses have to wait for

passengers boarding at bus stops 2.wait for the red light at intersections 3.encounter congested or abnormal traffic situations ,such as accidents or rush hours.

3.2.1 Data filter model of historical bus average running speed data

We use a data filter model to filter out those abnormal data that we don't need, to provide more accurate historical bus average running speed. Concepts of the filter model are explained as a flowchart in Figure 3.6. [9].

First, the model filters out some bus speed data whose speed value equals zero and deletes it. Also, it deletes the bus speed data by ten seconds before and after the time when the bus speed equals zero. The stop range is within a certain distance from bus stop or intersection.
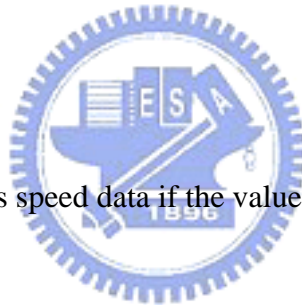
Secondly, it filters out bus speed data if the value is under the threshed speed.
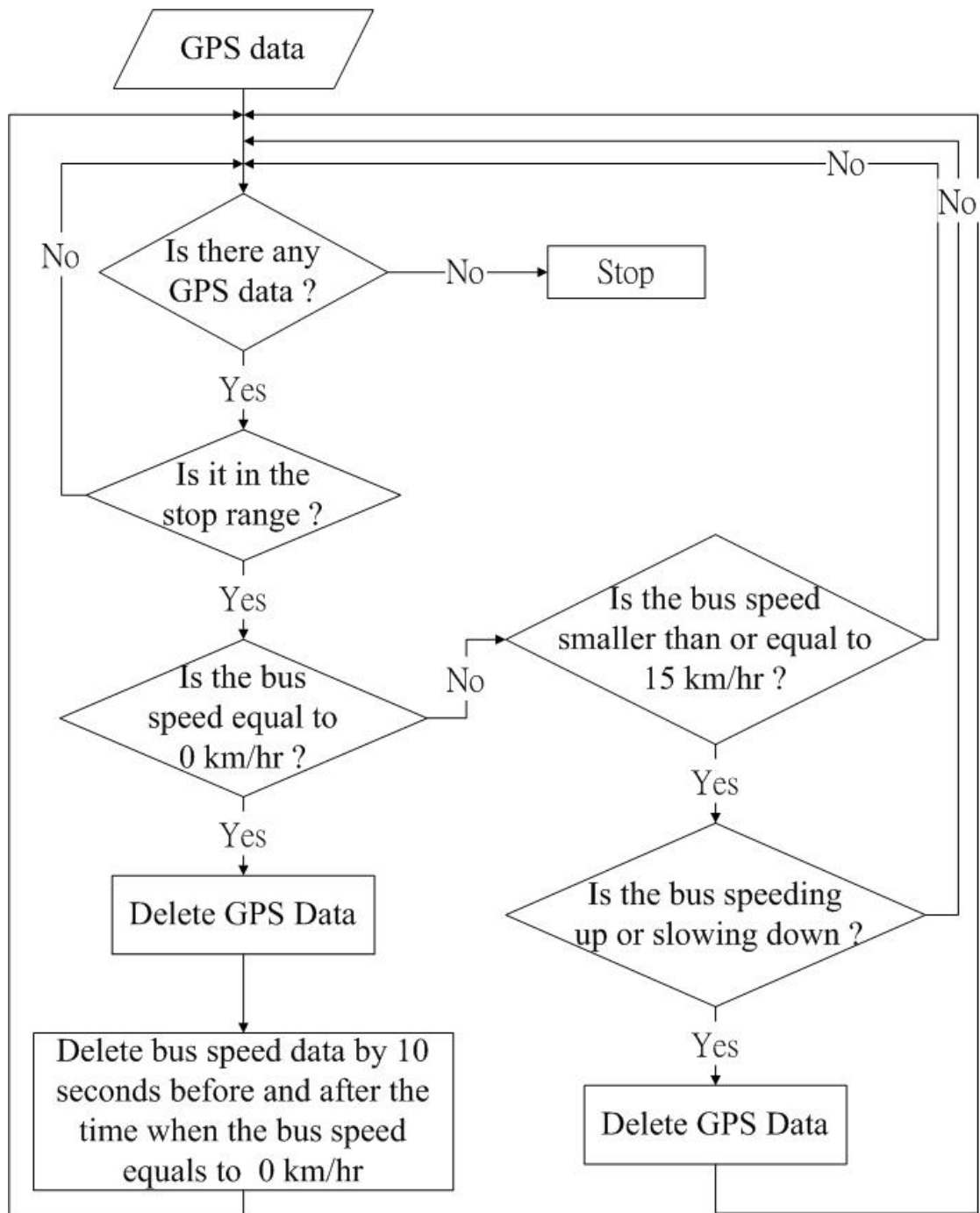
Figure 3.6 Data filter model Flowchart (cited from [9])

The average bus speed in different links may vary much in one day, moreover, due to the constant changes of the average speed in different links, buses may may have higher or lower average speed in a single day. So in this study we apply

"Point-Changing Analysis" to cut the historical average speed database into different speed type time periods, preparing for estimation of waiting time or for previous bus speed database. "Point-Changing Analysis" should be constructed on the basis of the hypothesis that there is not changing point. If this hypothesis is rejected, then it means that there are changing points existing in that bus speed data. Therefore, we start to estimate to position of these points. After these positions are all found, periods with different speed data are just what we need, for example, Figure 3.7.
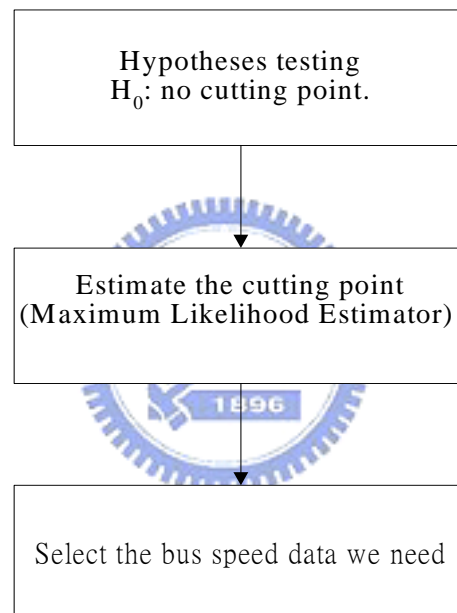
Figure 3.7 Data-cutting model flowchart(cited from [9])

3.2.2 Front platoon bus running speed data

When the traffic is in an abnormal situation, such as accident or congestion, the previous bus running speed data is used to compute the average speed to estimate the bus running time.

Every bus speed data closest to present time in every link is saved as the

previous bus running speed data in a database, and real-time GPS data is received to update it.

Owing that bus speed in every link changes differently with time, if the database is not updated with new data after a certain period of time, data in the database may not be able to represent present traffic situations. So, we set a restriction of time in the validity of data.

The restriction of time means whether current time passes through a different speed type time period. If it does, then the previous bus running speed database will be refreshed by latest data.

3.3 Concept of Bus running time Estimation

The flowcharts of bus running time estimation are explained as follows. (Figure 3.8)

Step 1: When receiving GPS data, we check the vehicle number of the data and which link it is in.

Step 2:Store the bus speed data in historical bus speed database and the previous bus speed database.

Step 3: determine whether the GPS data is from our testing traveling route or not. If yes, go to next step; else, continue to receive the coming data.

Step 4: Determine whether the traffic is in a normal situation or not. The criterion

is whether the difference of vehicle speed of GPS data and historical average speed over-weights the critical value. If yes, then it is regarded as an abnormal situation.

Step 5: If it is abnormal, we obtain the bus average speed from the previous bus running speed data. Otherwise, we compute the bus average speed from the history bus average running speed data.

Step 6: This estimation model uses the bus average speed to compute the bus running time in each sub-link as equation 3.3.1.

$$T_i\_R\_j = L_j / AveSpeed (j) \hspace{3cm} 3.3.1$$

Where, $T_i\_R\_j$ = running time of bus i in the sub- link j

i = bus number

L_j = distance of the sub- link j

$AveSpeed (j)$ = average speed of the sub- link j
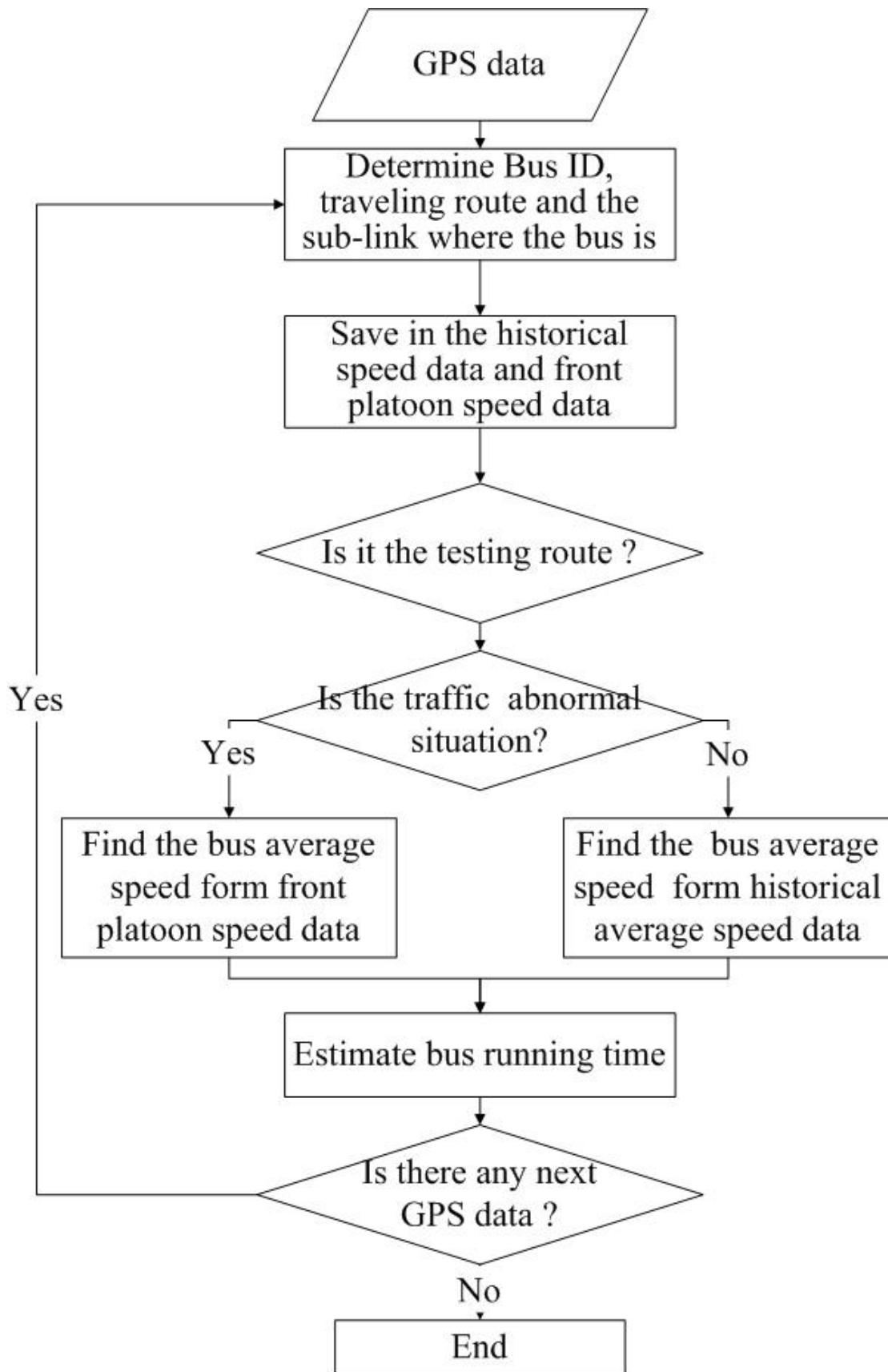
Figure 3.8 Running time estimation flowchart

3.4 Concept of Bus Waiting time Estimation

The bus delay time is divided into two parts. the first part is the time for vehicles waiting for traffic signals; the second part is the time for passengers boarding on buses. In this study, we additionally divide the first part into "the time waiting for red light" and "the time waiting for the front platoon dismissing"

We set two situations in estimation of waiting time. The first is that, when the current time is in a higher vehicle speed time period, we determine whether the buses need to stop at every individual intersection or not, and then we estimate the waiting time. The second is that, when the current time is in a lower vehicle speed time period, we determine whether the bus has to wait at the next intersection, and waiting time is estimateed in that intersection. As for other intersections, we set an expected waiting time. Above concepts are explained in Figure 3.9.
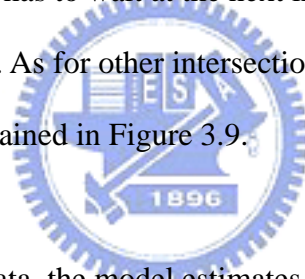
Step 1: Receiving GPS data, the model estimates the arriving time at the next intersection. If the bus is in a sub-link, the model estimates the running time for those coming roads it hasn't take. With the bus in the range of stop node and zero bus speed, the model sets waiting time as zero, and estimates the running time at next sub-link, to get the arriving time at the next intersection. But if the bus is in the range of intersection node and is at zero speed, the model estimates waiting time by current time; if the speed is not zero, then it estimates the running time in the next sub-link, to get the arriving time at next intersection.

Step 2: The model has to check whether it is now at a higher speed vehicle speed time period.

Step 3. The model set two situations in the estimation of waiting time: (1)if it is now at a higher speed time period, the model decides whether the buses will meet the red light or not, according to the time arriving at each intersection and phase planning table. If needed, then it estimates the waiting time.(2) if it is now at a lower speed time period, the model decides whether the buses has to wait at the next intersection or not. If needed, then it estimates the waiting time. For other intersections, expected waiting time is applied.
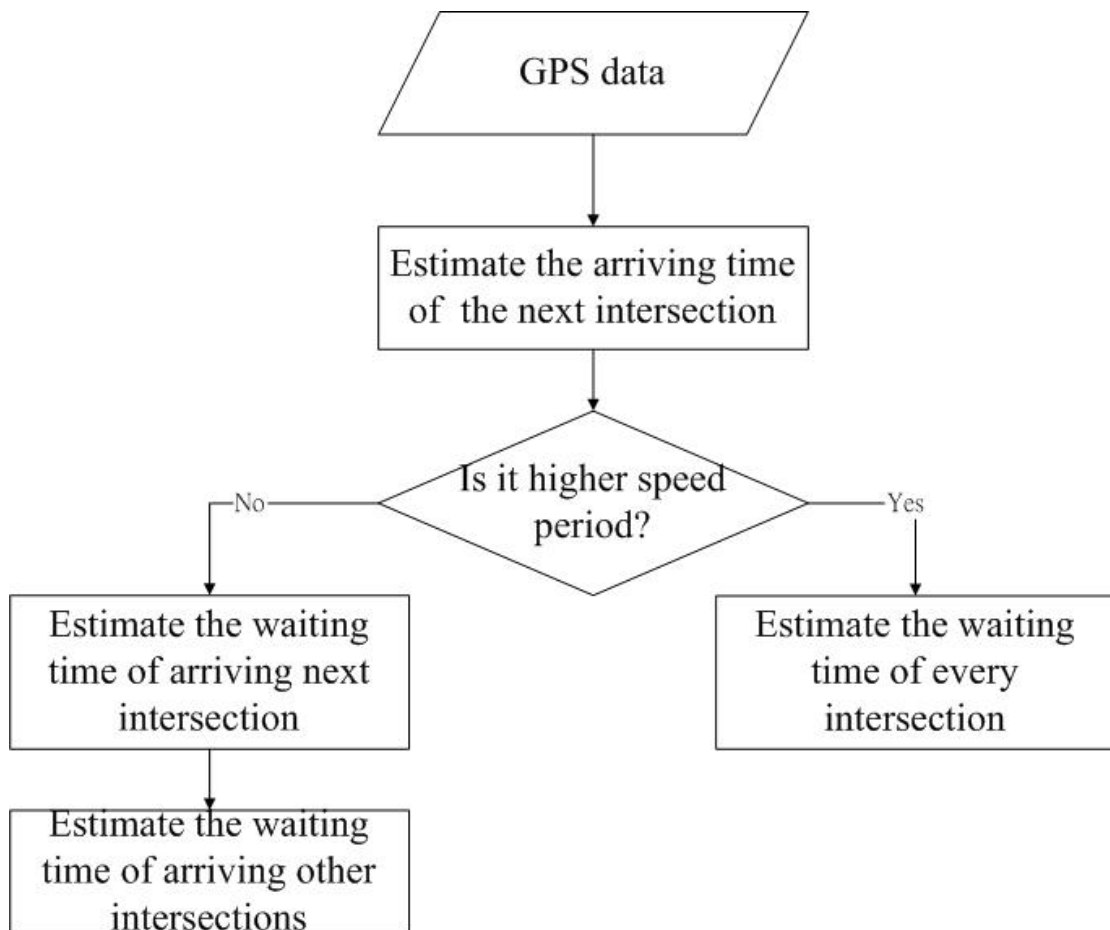
Figure 3.9 Estimation waiting time flowcharts

If it is now in a higher speed time period, then the model will estimate waiting

time for every intersection. The concepts will be shown illustrated as Figure 3.10.

Step 1:The model decides whether the buses encounter a red light or not, according to the arriving time at the next intersection and the phase planning table of that intersection.

Step 2:if waiting for a red light is needed, the model calculates the seconds left of the red phase. Being not needed, then the waiting time is set to be zero.

Step 3: Based on the waiting time estimated in above stops, we obtain the starting time of the bus from that intersection.

Step 4:Then the model determines if there are any intersections needing the estimation of waiting time. If yes, then we continue the estimation; else, we bring it to an end.
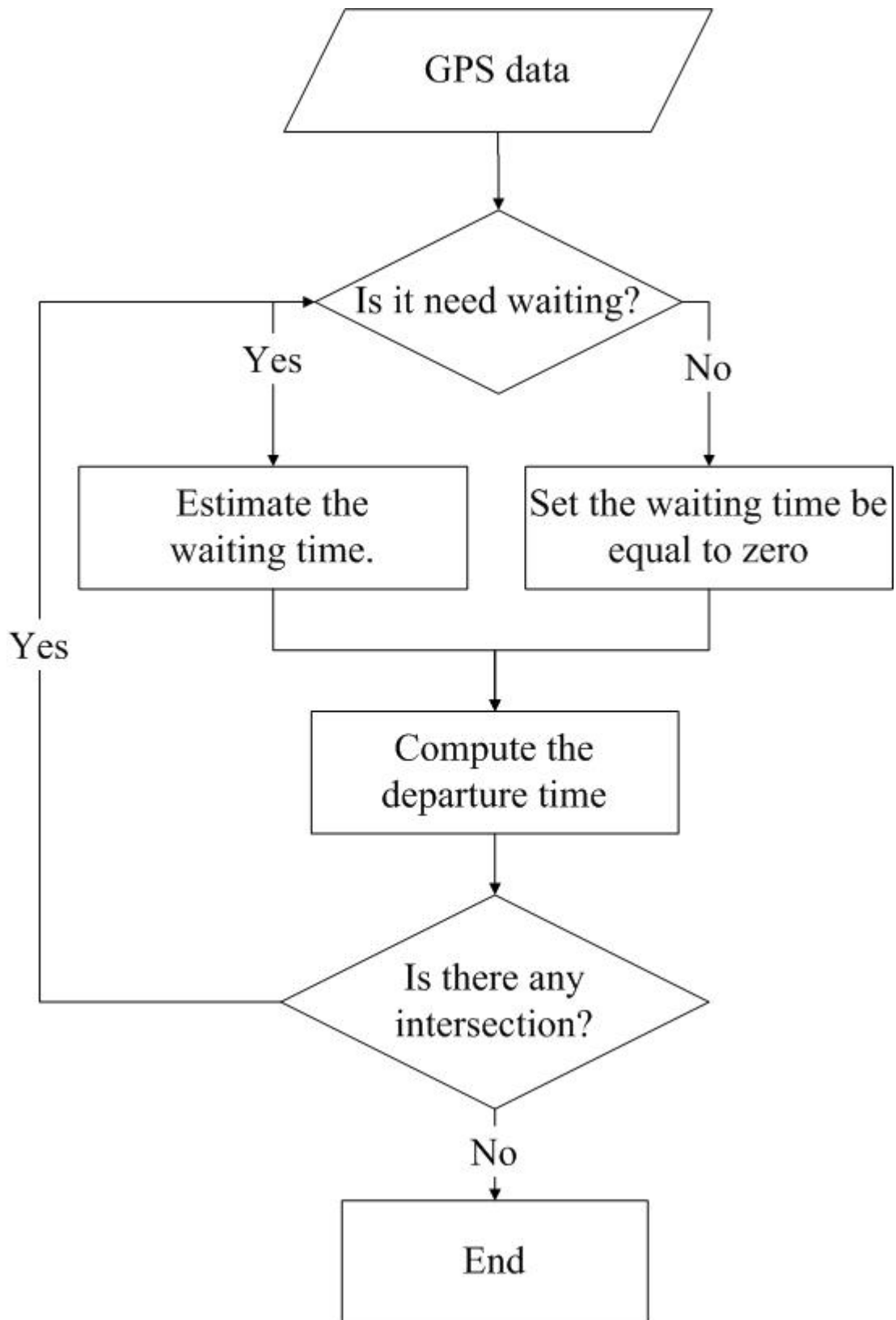
Figure 3.10 Estimation waiting time flowcharts（Ⅰ）

If it is currently in a lower vehicle speed time period, the model has two steps in

the estimation of waiting time. The first step is to estimate the waiting time at the next

intersection, as the flowchart in Figure 3.11.

Step 1:The model decides whether the buses encounter a red light or not,

according to the estimated arriving time at the next intersection and the phase

planning table.

Step 2:if waiting for a red light is needed, the waiting time of that intersection

equals to the seconds left of the red phase. Otherwise the waiting time is set to be

zero.

Step 3: Based on the waiting time estimated in above stops, we obtain the

starting time of the bus from that intersection.
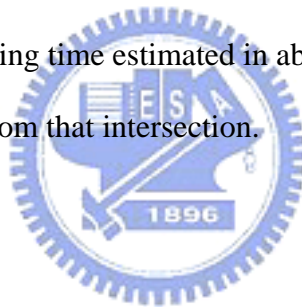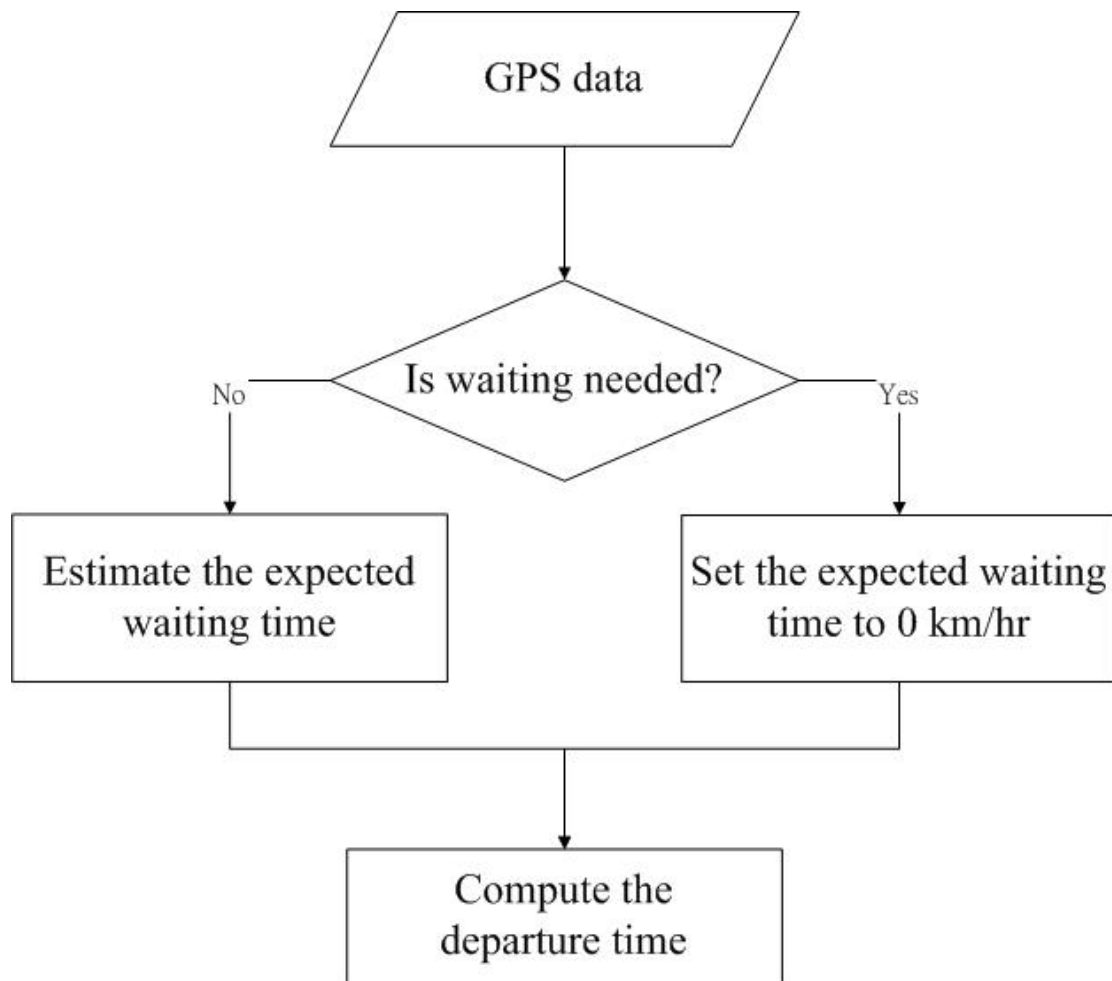
Figure 3.11 Estimation waiting time flowchart (I)

In the second step, the model estimates the waiting time of other intersections, as

Figure 3.12

Step 1: The model calculates the expected waiting probability of each

intersection. The probability equals to red phase split, the ratio that red phase

over total cycle length.

Step 2: Expected waiting time is taken as the estimated waiting time of each

intersection. This time is obtained by expected waiting probability multiplies

two-third of the length of red phase.

Step 3: Then the model determines if there are any intersections that need the estimation of waiting time. If yes, then we continue the estimation; else, we bring it to an end.
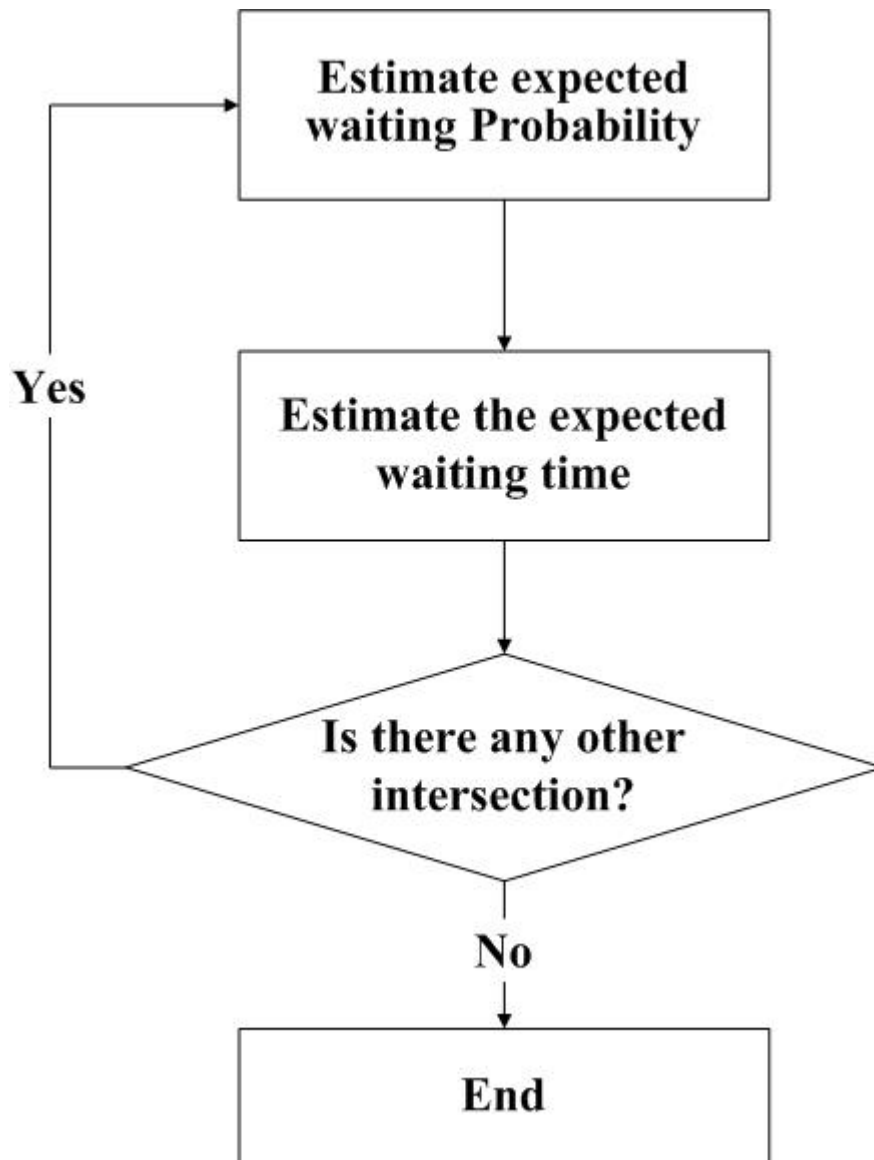
Figure 3.12 Estimation waiting time flowchart (II)

Chapter 4 Model Testing

This section explains the framework and result of model testing. The initial process of the model testing is explained in section 4.1. The result of the model testing is presented in section 4.2.

4.1 Initial process of Model testing

This section explains how we perform the model testing. In section 4.1.1, we define the testing targets and the reason why they are chosen. In section 4.1.2, we explain how historical data is collected and how we process it. Section 4.1.3 explains the parameter setting of this estimation model. And in section 4.1.4, the procedure of this estimation model is described.

4.1.1 Explanation of testing target

We choose the route number 106 of TaiChung City Bus as the testing target. In this route, eight bus stops are chosen as shown in Figure 4.1, and the real travel time from first stop to the eighth stop is about ten minutes.

In order to test the estimation model in different traffic flow situations, we perform our test on Wednesday evening and Saturday noon. We estimate the arrival time and travel time of buses, and then analyze the difference in the arrival time between the actual and the estimation value.
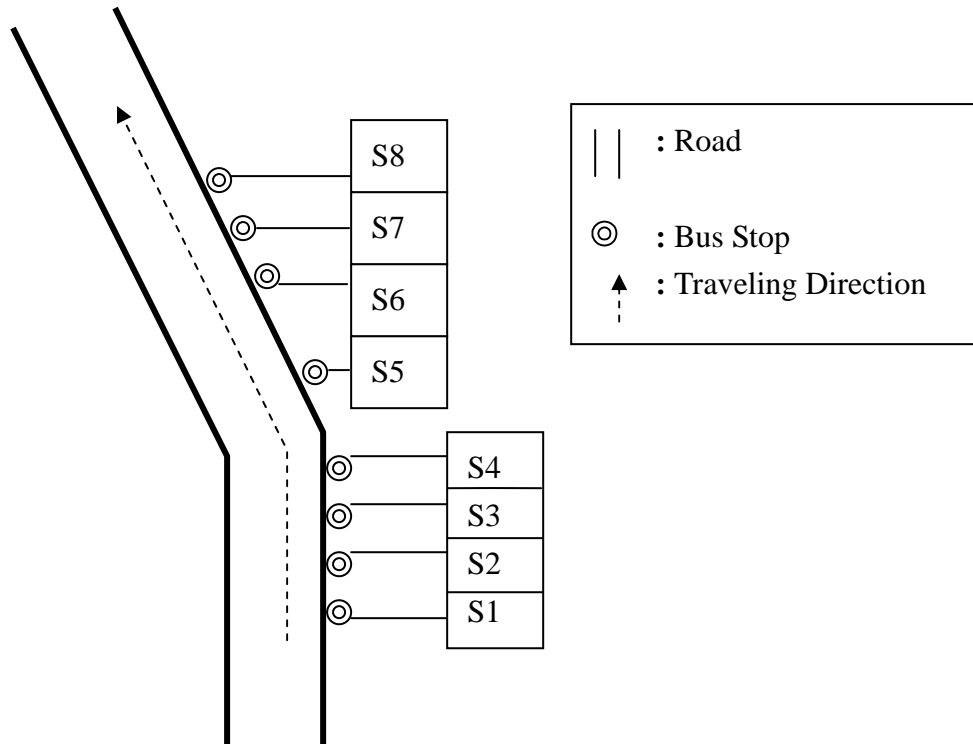
Figure 4.1 The Route 22 of Taichung City Passenger Transport

4.1.2 Processing of historical speed data

In order to compute the historical bus average speed, we have to collect enough speed data. Thus, GPS data of the testing target as long as forty-eight days has been collected for this purpose, and each data is received every twenty seconds.

Then, we filter out the unneeded data before using these GPS data to compute the historical bus average running speed, for abnormal bus speed data will greatly affect the accuracy of average running speed. Generally, abnormal bus speed data is resulted from passengers boarding, accidents, or congested traffic.

And then we compute the historical average speed of each sub-link. In order to reflect the real situation correctly, we have to choose a historical average speed that is most like the current situation. For example, if current testing time is 10:30, then

we'll choose the average speed in the period from 10:00 to 11:00 in historical speed database.

Moreover, we apply "Point-Changing Analysis" to split historical average speed data into several sections as follows: 06:00 to 12:00, Table 4.1; 12:00 to 18:00, Table 4.2; 18:00 to 24:00, Table 4.3. Since we have no GPS data from 00:00 to 06:00, we do nothing in this section.

After the analysis, we have four periods in which the bus speed is higher: 06:00 to 07:45; 09:45 to 11:30; 14:00 to 18:15, and 20:00 to 23:29. Also, three periods in which the bus speed is lower: 07:45 to 09:45; 11:30 to 14:00, and 18:15 to 20:00, as listed in Table 4.4.

Table 4.1 Result of using the change point analysis (I)

Time	AvgSpeed	Operation 1	Operation 2	Operation 3
06_00~06_15	32.00			Delete
06_15~06_30	28.55			Delete
06_30~06_45	23.06			Delete
06_45~07_00	25.10			Delete
07_00~07_15	22.26			Delete
07_15~07_30	21.31			Delete
07_30~07_45	22.58			Delete
07_45~08_00	23.86		Cutting-point	Delete
08_00~08_15	15.01			Delete
08_15~08_30	18.57			Delete
08_30~08_45	23.64			Delete
08_45~09_00	23.01	Cutting-point	Delete	
09_00~09_15	19.88		Delete	
09_15~09_30	26.62		Delete	
09_30~09_45	23.32		Delete	
09_45~10_00	22.50		Delete	Cutting-point
10_00~10_15	22.66		Delete	

Time	AvgSpeed		Operation	
10_15~10_30	23.09		Delete	
10_30~10_45	23.12		Delete	
10_45~11_00	23.83		Delete	
11_00~11_15	24.32		Delete	
11_15~11_30	24.58		Delete	
11_30~11_45	21.66		Delete	
11_45~12_00	18.91		Delete	

Table 4.2 Result of using the change point analysis (II)

Time	AvgSpeed	Operation 1	Operation 2	Operation 3
12_00~12_15	22.07		Delete	
12_15~12_30	22.24		Delete	
12_30~12_45	21.47		Delete	
12_45~13_00	18.91		Delete	
13_00~13_15	20.96		Delete	
13_15~13_30	18.20		Delete	
13_30~13_45	16.81		Delete	
13_45~14_00	19.26		Delete	
14_00~14_15	24.93			Cutting-point
14_15~14_30	24.72			
14_30~14_45	23.43			
14_45/~15_00	24.31	Cutting-point		Delete
15_00~15_15	24.78			Delete
15_15~15_30	24.05			Delete
15_30~15_45	24.60			Delete
15_45~16_00	23.59			Delete
16_00~16_15	23.89			Delete
16_15~16_30	22.61			Delete
16_30~16_45	23.47			Delete
16_45~17_00	21.86			Delete
17_00~17_15	22.25			Delete
17_15~17_30	22.00		Cutting-point	Delete
17_30~17_45	20.91			Delete
17_45~18_00	20.50			Delete

Table 4.3 Result of using the change point analysis (III)

Time	AvgSpeed	Operation 1	Operation 2
18_00~18_15	20.39		Delete
18_15~18_30	20.16	Cutting-point	
18_30~18_45	19.68		
18_45~19_00	19.96		
19_00~19_15	22.74		
19_15~19_30	21.21		
19_30~19_45	25.75		
19_45~20_00	24.31		
20_00~20_15	23.10		Cutting-point
20_15~20_30	21.91		
20_30~20_45	21.41		
20_45~21_00	22.23		
21_00~21_15	23.21		
21_15~21_30	21.08		
21_30~21_45	22.60		
21_45~22_00	20.20		
22_00~22_15	19.67		
22_15~22_30	24.19		
22_30~22_45	24.54		
22_45~23_00	26.31		
23_00~23_15	37.75		
23_15~23_30	37.33		

Table 4.4 Period of different average speed type

Period	Average speed	Type of average speed
00_00_00~00_06_00	Null	Null
00_06_00~07_45_00	24.98	Higher average speed
07_45_00~09_45_00	21.74	Lower average speed
09_45_00~11_30_00	23.44	Higher average speed
11_30_00~14_00_00	20.05	Lower average speed
14_00_00~18_15_00	23.08	Higher average speed
18_15_00~20_00_00	21.97	Lower average speed
20_00_00~23_59_59	24.68	Higher average speed

4.1.3 Parameter setting

Three parameters need be set before using this estimation model to estimate the bus travel time: the threshed speed, the stop range of filter model, and the critical value of speed error.

In setting the threshed speed, because our data is received every 20 seconds, we will have problem judging the real critical value of speed. Therefore we follow the value 15 km/hr mentioned in the previous paper.[9]

The word "stop range" refers to a certain distance from bus stop or intersection, and the criteria to set it is "the distance that covers 90% of the low speed data". According to those collected GPS data, we re-calculate the speed of the four buses and their distance from the stop node, as listed in Table 4.5, 4.6, 4.7 and 4.8. After calculating, we found that there are 95.24% of the speed data occurred in less than 50 meters. So, we set the value to 50 meters.

Table 4.5 Stop range (Bus1)

Time	Length	speed
195037	15	40
195057	15	40
195117	20	0
195137	34	44
195157	34	44
195217	50	29
195237	34	31
195257	34	31
195317	15	0
195337	13	0
195357	13	0
195417	8	22

Table 4.6 Stop range (Bus2)

Time	Length	speed
185915	0	20
185935	0	38
185955	0	37
190015	68	18
190036	53	12
190055	34	0
190115	34	0
190135	35	0
190156	26	12
190216	20	25
190235	44	24
190256	48	40
190316	33	0
190336	33	0
190356	53	0
190416	50	9

Table 4.7 Stop range (Bus3)

Time	Length	speed
155932	14	14
155952	14	14
160012	14	14
160032	0	38
160052	0	0
160112	0	0
160132	0	0
160152	0	0
160212	0	25
160232	29	33
160452	12	0
160512	15	0
160532	15	0
160552	21	0
160612	17	0

Table 4.8 Stop range (Bus4)

Time	Length	speed
142032	19	35
142052	35	7
142112	35	7
142132	11	38
142152	5	9
142212	5	9
142232	17	35
142252	10	0
142212	10	0
142231	10	0
142252	30	0
142312	30	0
142332	33	35
142352	31	40
142412	31	40
142432	33	5
142452	30	0
142512	30	0
142532	28	0
142552	25	40
142612	0	22
142632	46	1
142652	38	38
142712	38	38
142732	46	0
142752	48	0
142812	48	0
142832	48	0

By threshed speed, we can judge whether we should use the previous bus speed or historical speed data as the current bus speed. If the differential of vehicle speed is larger than threshed speed, then it is regarded as abnormal situation, and we'll take the

previous bus speed as the average speed of the link.

The restriction of time in the validity of data is decided by point-changing analysis, and from that, we may divide the database into different periods of speed type, as listed in Table 4.4. Therefore, when current time cover the next period, the previous bus running speed database will be refreshed.

4.1.4 Procedure of estimation model

This section explains the procedure how we estimate the bus travel time. Figure 4.2 is the flowchart that explains all these steps.

.
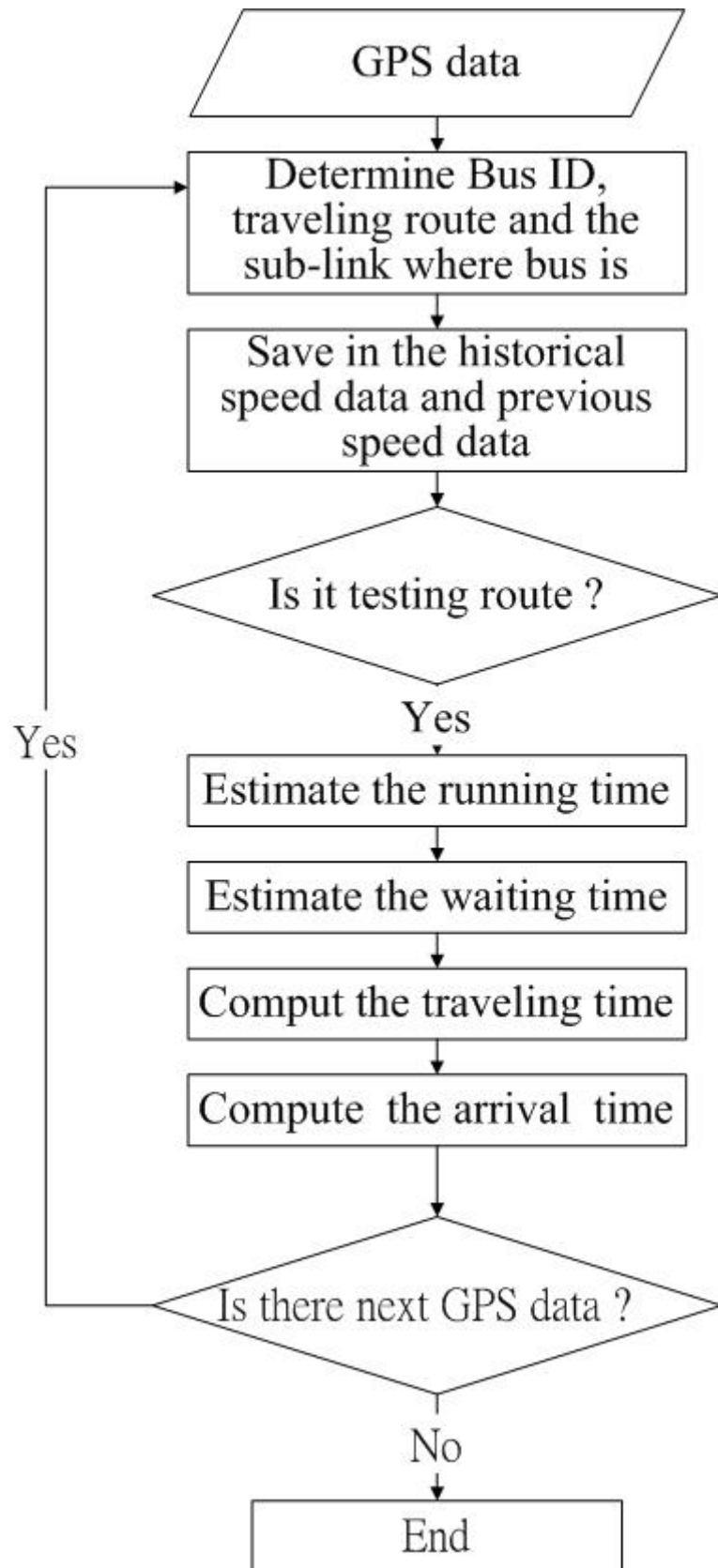
Figure 4.2 Traveling time estimation flowcharts

Step 1:

   When receiving GPS data, we determine the vehicle number of the data and
which route or sub-link the bus is in.
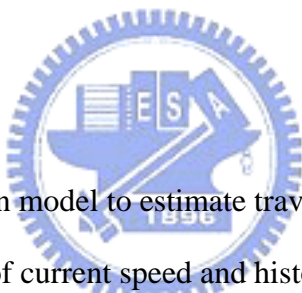
Step 2:

   Store the speed data into historical speed database and previous car speed
database.

Step 3:

   Check if the bus traveling route is the testing route or not. If yes, go to next
step; otherwise we continue to receive the next GPS data.

Step 4:

   Apply the estimation model to estimate traveling time. At first, we check
whether the differential of current speed and historical speed is in the range of
threshed speed (5 km/hr). If yes, then we take historical speed data as the
average speed at the link. Otherwise, we take the previous speed data. In this
way, running time can be derived from the distance of sub-links divided by
average speed.

Step 5:

   The model determines which period in the historical database the current
time is in. If it is in the period of higher speed, .our model will judge whether the
bus has to wait for a red light or not, according to the arrival time and the phase
planning table. Also, we will computer the needed waiting time.

If it is in the period of lower speed, the model will merely judge if the bus has to wait at the next intersection. If the signal turns red, then we calculate the waiting time and set expected waiting time to other intersections.

Step 6:

The travel time is set as the total sum of the running time and the waiting time..

Step 7:

By adding the next travel time to current time, we get the time when the buses reach the next stop. Thus the time buses reach every bus stops is obtained.

4.2 Result of model testing

We choose the route 106 of TaiChung City Bus as the testing target. The testing time was on May 28, 2003 and May 31, 2003. We performed these tests on four different buses.

4.2.1 Analysis method

The accuracy of this estimation result is analyzed in this section. Several parameters are also computed out: the average error of the estimation waiting time, the error and the maximum error at each stop, the average absolute error and the percentage of average absolute error of estimation travel time. Finally, we perform a goodness-of –fit test of the estimation travel time at each link.

The error of estimated arrival time at every stop node is equal to the value that the actual arrival time subtracts the estimation arrival time, as shown in equation 4.2.

The maximum error of arrival time at every stop is equal to the maximum value of

estimated arrival time errors, as shown in equation 4.3.

$$Es = Ps - As \qquad\qquad 4.2$$
$$Max\ (Es) = Max\ (\ |\ \ Ps - As\ |\ \ ) \qquad 4.3$$

Where, **Es** = the error of this estimation arrival time at **s**th stop.

Max(Es) = the maximum error of this estimation arrival time at **s**th stop.

As = the actual arrival time at **s**th stop.

Ps = the estimation arrival time at **s**th stop.

s = stop number

The average error of the estimated waiting time equals to the total sum of the

value that the actual waiting time subtract the estimation waiting time and divided by

the number of data, as equation 4.3

$$E_w = \frac{\sum P_w - A_w}{N_i} \qquad\qquad 4.1$$

Where, **E**$_w$ = the average error of the estimation waiting time..

N$_i$ = the number of data.

A$_w$ = the actual waiting time.

P$_w$ = the estimation waiting time.

The average absolute error is constructed to understand the difference between

the estimated travel time and the real travel time, as shown in the equation 4.4.

$$E_{\text{mean}} = \frac{\Sigma \ |P_t - A_t|}{N_i} \qquad 4.4$$

Where, E_{mean} = the average modulus error.

N_i = the number of data.

A_t = the actual travel time.

P_t = the estimation travel time.

We compute the percentage of average absolute error of estimation travel time as another estimation index, because the value involved in absolute error could not give out the comprehensive evaluation of our test.

$$E_{\text{percentage}} = \frac{\Sigma \ \dfrac{|P_t - A_t|}{A_t}}{N_i} \qquad 4.5$$

Where, $E_{\text{percentage}}$ = the percentage of average modulus error of estimation travel

time

A_t = the actual travel time.

P_t = the estimation travel time.

N_i = the number of data

We perform the goodness-of -fit-test that could determine whether the error is in acceptable range or not as shown in the equation 4.5.

$$\chi^2 = \sum_{i=1}^{k} \frac{(Oi - e_i)^2}{e_i} \qquad\qquad 4.6$$

The degree of freedom (v) is equal to (k-1).

Where, **Oi** = the observation value, the estimation travel time.

e_i = the actual value, the actual travel time.

4.2.2 Result analyzing

1. Error of arrival time

We performed these tests on two different buses and in the period of lower speed when the traffic is congested. If the error value is positive, then it means that we over-estimate the arrival time. Otherwise, it means that we under-estimate. The results of the errors computed are as illustrated in Table 4-9 and Table 4-10(Figure 4.3 and Figure 4.4).
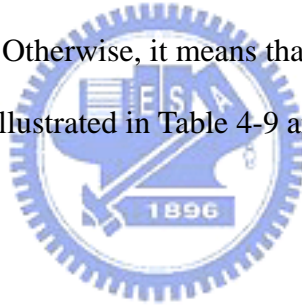
From these results, we can find that the errors of the estimated arrival time are roughly about 30 seconds, and the maximum one is 33 seconds. We may say that in this case, it performs well in arrival time estimation.

Table 4-9 Error of arrival time (bus 1)

Bus stop	From 19:48:50 To 19:57:43; Wednesday (Error of this estimation arrival time: second)									
stop1	70	70	86	0	0	0	0	0	0	0
stop2	46	46	49	-24	0	0	0	0	0	0
stop3	-6	-6	28	-76	-53	-53	0	0	0	0
stop4	24	24	36	-46	-23	-23	0	0	0	0
stop5	32	32	77	-38	-15	-15	-4	-4	0	0
stop6	30	30	53	-40	-17	-17	-6	-6	-2	0
stop7	-4	0	50	-62	-47	-51	-36	-36	-24	0
stop8	-67	-63	-13	-65	-50	-54	-39	-39	-27	-33
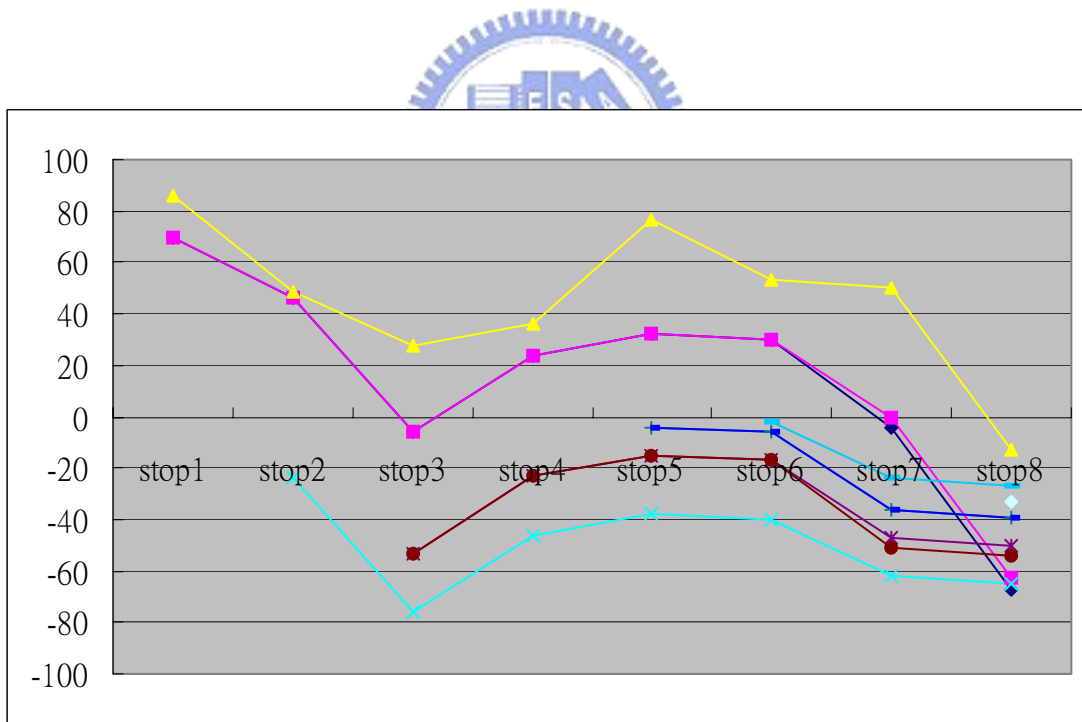
Figure 4.3 Error of arrival time (bus 1)

Table 4-10 Error of arrival time (bus 2)

Bus stop	From 18:59:25 To 19:11:20 (Error of this estimation arrival time: second)																	
Stop1	-1	-3																
Stop2	-7	-9	1	-13														
Stop3	-44	-46	-33	-47	-42	-17	-17	-17	-17									
Stop4	-50	-75	-76	-90	-105	-60	-60	-60	-60									
Stop5	-111	-113	-94	-108	-123	-78	-78	-78	-78	-18								
Stop6	-124	-126	-107	-121	-136	-91	-91	-91	-91	-31	-13	-13	-13	-13	-13			
Stop7	-151	-156	-136	-150	-165	-120	-120	-120	-120	-60	-42	-42	-42	-42	-42			
Stop8	-60	-80	-56	-70	-85	-40	-40	-40	-40	-40	-22	-22	-22	-22	-22	-22	-19	-19
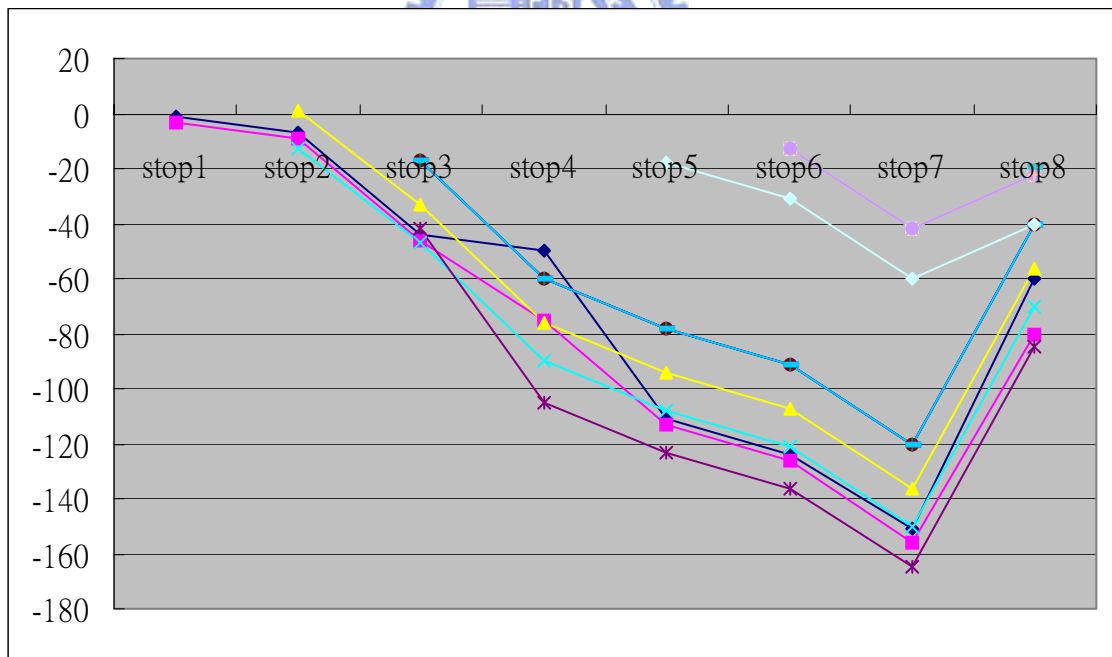
Figure 4.4 Error of arrival time (bus 2)

We performed these tests on two different buses and in the period of higher

speed when the traffic is not congested. If the error value is positive, then it means

that we over-estimate the arrival time. Otherwise, it means that we under-estimate.

The results of the errors computed are as illustrated in Table 4-11 and Table

4-12(Figure 4.5 and Figure 4.5).

From these results, we can find that the errors of the estimated arrival time are

roughly about 30 seconds, and the maximum one is 34 seconds. We may say that in

this case, it performs well in arrival time estimation.

Table 4-11 Error of arrival time (bus 3)

| Bus stop	From 14:20:15 To 14:29:41 (Error of this estimation arrival time: second)													
Stop1	-34	11	11	1	1									
Stop2	-78	-13	-13	-27	-27	-28	-4							
Stop3	-61	43	43	28	28	27	51	30						
Stop4	-107	15	15	-3	-3	-4	20	-1	-31	-31				
Stop5	-134	25	25	5	5	4	8	7	-23	-23				
Stop6	-93	80	80	60	60	59	63	66	32	32	25	25		
Stop7	-107	96	96	69	69	64	68	67	33	33	26	26		
Stop8	-106	99	99	70	70	65	69	68	64	64	57	57	31	31
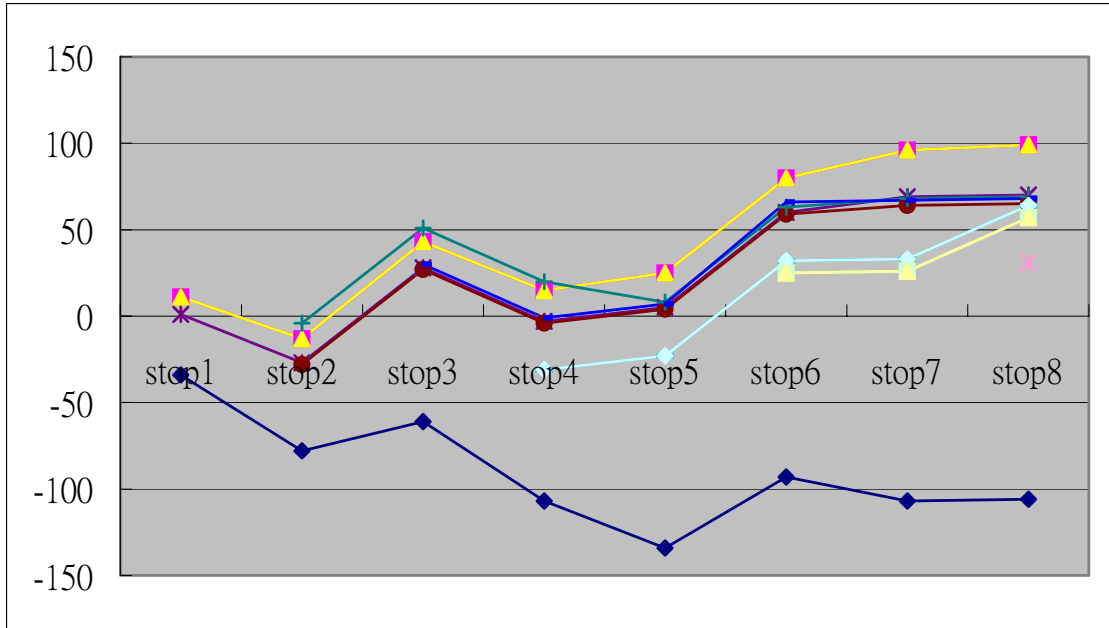
Figure 4.5 Error of arrival time (bus 3)

Table 4-12 Error of arrival time (bus 4)

Bus stop	From 15:59:01 To 16:06:05 (error of this estimation arrival time: second)												
Stop1	-56												
Stop2	-37	19	18	18	12								
Stop3	-44	12	9	9	1	12	12						
Stop4	-4	52	45	45	38	25	25						
Stop5	-3	53	45	45	36	23	23	2					
Stop6	16	72	64	64	55	42	42	17					
Stop7	18	77	64	64	51	38	38	13	4	4			
Stop8	9	68	55	55	42	29	29	4	5	5	9	9	5

Figure 4.6 Error of arrival time (bus 4)

2. Average error of the estimation waiting time
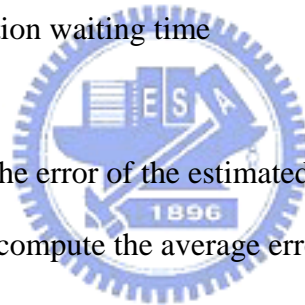
In order to analyze the error of the estimated waiting time, we perform the test on four different buses to compute the average error of the estimation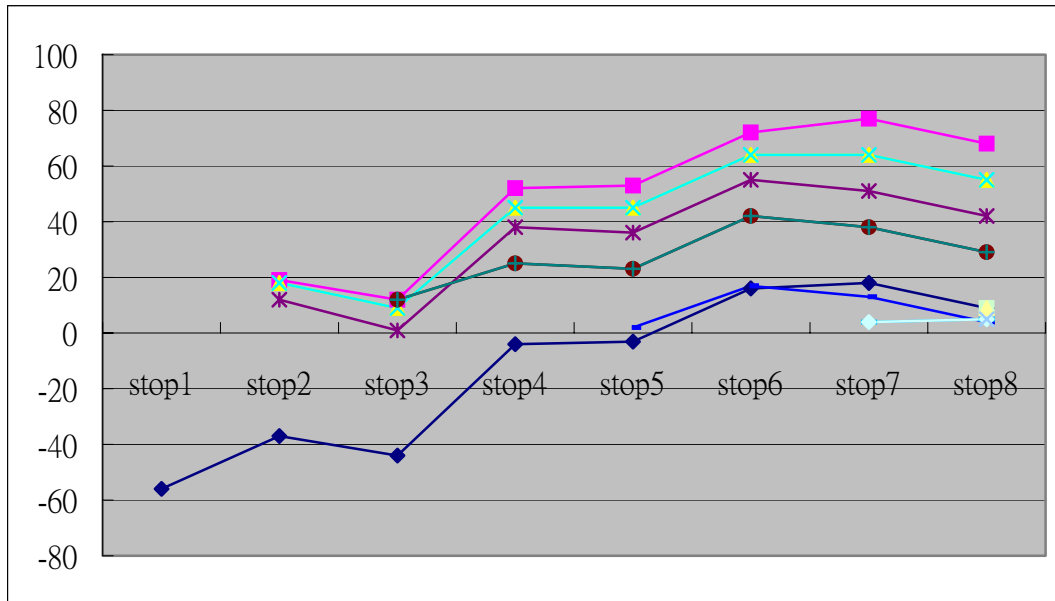 waiting time. If the error value is positive, then it means that we over-estimate the arrival time. Otherwise, it means that we under-estimate. The results of the errors computed are as illustrated in Table 4-13.

From these results, we can find that the errors of the estimated arrival time are roughly about 20 seconds, and the maximum one is 36 seconds. We may say that in this case, it performs well in arrival time estimation.

We analyze the results and find that, the error under lower speed situation is greater, and can even be as large as 36 seconds. There are two reasons to be so. First, the estimation model is constructed in higher speed situation, therefore if the police

manually adjust the phase planning table, a larger error will therewith occur. Moreover, since the error enlarges as the previous error, intersections in the end of the route will be affected more.

Table 4-13 Average error of the estimation waiting time

Bus stop	Bus 1 (second)	Bus 2 (second)	Bus 3 (second)	Bus 4 (second)
stop1	51.000	36.000	43.000	98.000
stop2	29.000	35.250	28.000	25.000
stop3	3.800	11.800	6.000	6.000
stop4	-8.333	-5.000	14.667	14.778
stop5	-16.00	-14.000	13.000	11.200
stop6	-0.545	13.636	24.545	22.364
stop7	-11.000	-13.000	10.000	10.400
stop8	-11.389	-7.277	11.556	3.500

3. Percentage of average absolute error of estimation travel time

In order to analyze the error of the estimated travel time, we perform the test on four different buses to compute the average absolute error of estimated travel time and average absolute error percentage. The results of the errors computed are as illustrated in Table 4-14.

From these results, we can find that the average absolute errors of the estimated travel time are all within 15 seconds, and the maximum one is 14 seconds. The average absolute error percentage is roughly less than 30%, and the maximum one is 93% We may say that in this case, it performs well in travel time estimation.

According to the results, we analyze and find that although we have only 12 seconds in average absolute error, but the average error percentage is as high as 93%.

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This is mainly because that the travel time in that route is as short as 15 seconds, so that the percentage is also higher.

Table 4-14 Average absolute error of estimation travel time

Number of Sub-link	Average modulus error	Percentage of average modulus error (%)
Link 1	38.22222	16.74738
Link 2	40.1	75.23565
Link 3	98.1	181.5063
Link 4	91.33333	172.7671
Link 5	24.94444	77.98737
Link 6	45	101.0223
Link 7	33.1	117.2838
Link 8	64.05	46.57097

4. Goodness-of –fit test

We perform the goodness-of -fit-test to test if the error of estimated travel time and actual travel time falls in acceptable range or not. We take four buses to take to test, and the results are shown in table 4-15.

According to the results, after the test, all the estimated travel time in eight routes all fall in an acceptable range.

Table 4-15 Goodness-of -fit-test

Number of Sub-link	χ^2	$\chi^2_{(0.95, 7)}$
Link 1	3.609	14.07
Link 2	5.003	14.07
Link 3	12.410	14.07
Link 4	8.877	14.07
Link 5	2.315	14.07
Link 6	14.05	14.07
Link 7	9.218	14.07
Link 8	1.629	14.07

4.3 Summary

According to the results of the model testing in section 4.2, we draw some conclusions as follows:

1. Whether in periods of higher speed or lower speed, the error of estimation travel time is about 30 seconds, and that falls in an acceptable range.

2. Whether in periods of higher speed or lower speed, the error of estimation waiting time is about 15 seconds, and that falls in an acceptable range.

3. The model may over-estimate or under-estimate the waiting time and sometimes a large error may occur. The reason is that the police manually adjusts the phase planning table, thus makes the error occur.

4. When the travel time in the route is shorter, we may obtain higher error percentage in estimation of travel time in that route.

Chapter 5   Conclusions and Suggestions

In this section, we make conclusions and suggestions about this research. Section 5.1 and 5.2 discuss on conclusions and suggestions, respectively.

5.1 Conclusions

1. Whether in high or low speed period, the errors of travel time estimation and waiting time estimation usually fall in an acceptable range. Therefore, we may say that we have a good estimation result.

2. We may overestimate or underestimate the waiting time of the next intersection, mainly because of the traffic control performed there by the police during peak hours or estimation errors in the present intersection. In this way, owing to the errors, we may have a bigger error in the following intersections.

3. In some intersections where travel time is shorter, the average absolute error percentage will be higher, but the average error value is still in an acceptable range.

4. Through the analysis method of changing points, we divide the historical average speed database into some different categories by its vehicle speed. Then we found that it matches the real situations, and can surely improve the model's domination on them.

5.2 Suggestions

In this section, we make some suggestions for future researches as follows:

1. This study didn't leave a mark on boarding time, but due to its importance, we suggest that be counted in future researches.

2. Not encountering abnormal situations, so that we didn't have a chance to test the model in estimateing the travel time in that situation. And we also suggest future researches do some further research on it.

3. Random adjusting of signal timings in intersections makes the errors worse. Thus, it is recommended to have a further research on it in the future.

4. The transmitting frequency of GPS data effects greatly in estimateing travel time: the errors varies worse as the frequency becomes lower. So, we suggest that future researches think more on it.

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