行政院國家科學委員會專題研究計畫 成果報告

以衝擊波理論推導最佳觸控號誌時制
研究成果報告(精簡版)

計 畫 類 別 ：個別型
計 畫 編 號 ：NSC 97-2221-E-009-118-
執 行 期 間 ：97 年 08 月 01 日至 98 年 07 月 31 日
執 行 單 位 ：國立交通大學運輸科技與管理學系（所）

計 畫 主 持 人：卓訓榮

計畫參與人員：博士班研究生-兼任助理人員：陳昱光
博士班研究生-兼任助理人員：黃恆
博士班研究生-兼任助理人員：徐嘉駿
博士班研究生-兼任助理人員：李日錦
博士班研究生-兼任助理人員：黃建嘉

報 告 附 件 ：出席國際會議研究心得報告及發表論文

處 理 方 式 ：本計畫可公開查詢

中 華 民 國 98 年 11 月 02 日

Shockwaves, upstream speed and flow detection for a signalized intersection

1 Introduction

Shockwave analysis has long been applied to traffic flows.[7] Shockwaves are defined as boundary conditions in the time-space domain that indicate a discontinuity in flow-density conditions [9], or the motion or propagation of a change in concentration and flow [6]. Shockwaves are caused by sudden temporal or spatial changes in roadway density due to capacity or volume changes. Shockwave analysis can effectively analyze flow and queuing problems [11,2]. Numerous schemes have been proposed for plotting shockwaves and forecasting traffic conditions [7,12]. Researchers have also applied this method to freeway bottlenecks and traffic signals [1,3,5].

Most previous analyses and applications determine shockwave values based on gap time, headway, speed [12], flow, and density [1,2,5,8,10,11]. However, these indirect parameters usually become inaccurate in a traffic jam. For example, speed and vehicle count are unstable measures in a traffic jam. Unreliable traffic parameters can lead to inaccurate shockwave values. In this case, shockwave application cannot produce valuable results in a traffic jam. For most traffic sensors, the presence parameter is the most stable traffic parameter in a traffic jam. Cho and Tseng [4] provided a method for detecting shockwaves using three new traffic parameters, called Stopped, Moving, and Empty, in addition to headway, speed, flow, and density. These three new traffic parameters remain stable and accurate in a traffic jam because they depend only on the presence of a vehicle. Shockwaves detected using these measures will remain stable in a traffic jam.

This paper extends the idea of Cho and Tseng [4], and offers many enhancements: 1) This study extends the backward arrival shockwave equations from a special case to general cases. 2) To extends one shockwave to five shockwaves. 3) Whereas equations in previous studies are only for a fixed red and green time, this study accommodates a dynamic red and green time. 4) The proposed method also corrects an error in the backward arrival shockwave equations. 5) This study provides the algorithm to show the usage of three new parameters and five shockwave equations. And, CORSIM simulations were performed for different combinations of scenarios to identify new traffic parameter behavior and the effectiveness of the computing algorithm. 6) Finally, this study provides an upstream flow and speed detection method that makes it possible to predict traffic information far from a sensor's location

2 Formulation

The formulation proposed in this algorithm comprises four sections. The first is to find the relations among shockwaves, speed, and flow. The second is the definition of three new traffic parameters: Stopped, Moving, and Empty. The following sections discuss departure shockwave detection, ideal arrival shockwave detection, backward arrival shockwave detection, and the forward arrival shockwave detection. The following subsection discusses the upstream speed and flow detection. Finally, this study presents an algorithm to demonstrate the usage of these new traffic parameters and shockwave equations.

2.1 Relations among shockwaves, speed and flow

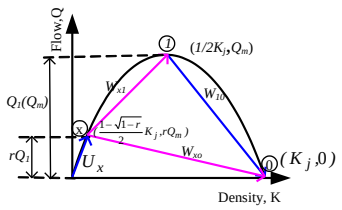


Fig.1. The relation between shockwaves.

Before detecting the shockwaves, the relations between shockwaves must be explored. Suppose the traffic flow follows the Green-Shield model. In this case, Fig. 1 depicts the flow-density relationship. The state 0 (⓪ in Fig. 1) is defined as the state which has maximal density K_j. The flow and density of state 0 are denoted as Q_0 and $K_0 (= K_j)$. The state 1 (① in Fig. 1) is defined as the state which has the maximal flow Q_m. The Q_m is the flow rate for a green signal at an intersection. The flow and density of state 1 are denoted as $Q_1 (= Q_m)$ and K_1, respectively. Since the traffic flow follows the Green-Shield

model, $Q_0 = 0$ and $K_1 = 1/2\, K_j$. Let state x (ⓧ in Fig. 1) be a state different from state 0 or 1. The flow, density, and speed of state x are then denoted as Q_x, K_x, and U_x, respectively. Suppose $Q_x = rQ_m$, where r is a flow ratio between Q_x and Q_m. In this case, there are three shockwaves among the states 0, 1, and x: W_{10} is the shockwave between state 1 and 0, W_{x1} is the shockwave between state x and 1, and W_{x0} is the shockwave between state x and 0. The W_{x0} can be calculated as

$$W_{10} = \frac{Q_1 - Q_0}{K_1 - K_0} = \frac{2Q_m}{K_j} \tag{1}$$

The W_{x0} and W_{x1} can be calculated as some ratio of the W_{10} by using the following two equations.

$$W_{x1} = \frac{Q_x - Q_1}{K_x - K_1} = -(\sqrt{1-r})(\frac{2Q_m}{K_j}) = -(\sqrt{1-r})W_{10} \tag{2}$$

$$W_{x0} = \frac{Q_x - Q_0}{K_x - K_0} = \frac{r}{1+\sqrt{1-r}}W_{10} \tag{3}$$

The relation among W_{x0}, W_{x1} and W_{10} is

$$W_{10} = W_{x0} - W_{x1} \tag{4}$$

If the W_{x0}, W_{x1} and W_{10} are all detected by sensors, the flow ratio r between Q_x and Q_m can be calculated to be

$$r = \frac{2W_{10}W_{x0} - W_{x0}^2}{W_{10}^2} \tag{5}$$

While the W_{10}, Q_m and the flow ratio r for state x are found, the speed U_x and flow Q_x can be calculated as

$$U_x = \frac{Q_x}{K_x} = \frac{-r}{1-\sqrt{1-r}}W_{10} \tag{6}$$

$$Q_x = rQ_m = \frac{2W_{10}W_{x0} - W_{x0}^2}{W_{10}^2}Q_m \tag{7}$$

2.2 Three traffic parameters: stopped, moving and empty

Figure 2 defines Stopped, Moving, and Empty. Stopped means that a vehicle is present for more than a specified period of time. Moving means that a vehicle is present for less than a specified period of time. Empty means that no vehicle is detected during a specified time interval. All of these three new parameters depend only on the presence of a vehicle, which is the most reliable traffic parameter in a traffic jam. Hence, Stopped, Moving and Empty remain stable and pertinent during a traffic jam.

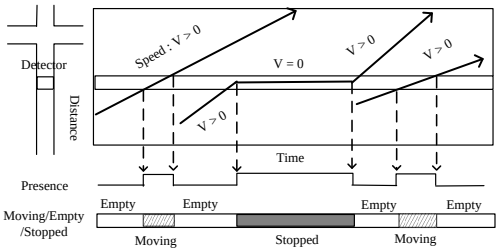


Fig. 2 The definition of three new traffic parameters: Moving, Empty and Stopped.

2.3 Shockwaves for signalized intersection

Figure 3 shows five shockwaves for a signalized intersection. State 2 (② in Fig. 3) exhibits an ideal traffic flow, in which vehicles arrive regularly and are all discharged in green time. Gray lines represent the trajectories of individual vehicles, while black lines or black dash lines indicate Shockwaves, there are three shockwaves states 0, 1, and 2: W_{20}, an ideal forward arrival shockwave; W_{21}, an ideal backward arrival shockwave in; and W_{01}, a departure shockwave. State 3 (③ in Fig. 3) is a free state with no traffic flow. For example, state 3 has a higher traffic flow than state 2 in Fig. 3. There are three more shockwaves among states 0, 1, and 3: W_{30}, a forward arrival shockwave; W_{31}, a backward arrival shockwave; and W_{01}, a departure shockwave. Since state 3 has a higher traffic flow than state 2, $|W_{30}|>|W_{20}|$ and $|W_{21}|>|W_{31}|$, as Fig. 3 shows.

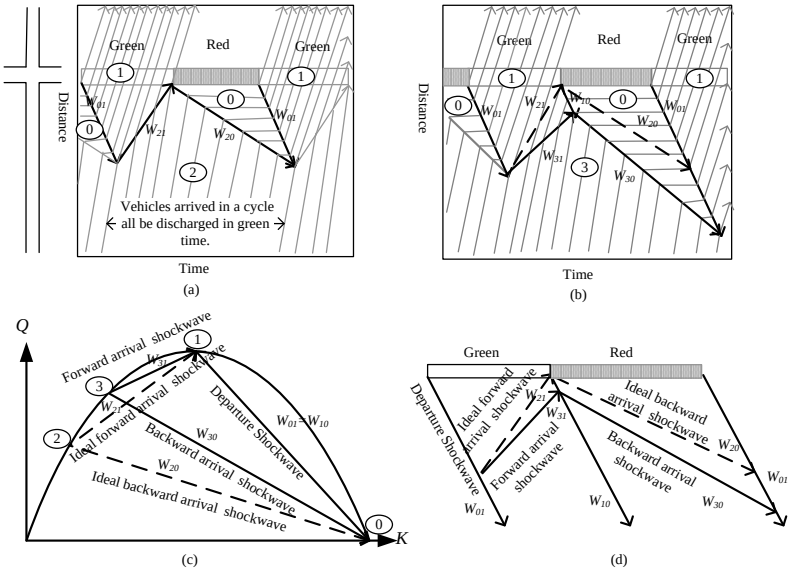


Fig. 3 (a) Ideal arrival shockwaves for a specified green and red phase time. In state 2, vehicles arrived in the cycle all be discharged in green phase time.

(b) Relation between the ideal arrival shockwaves and general arrival shockwaves.

(c) Five shockwave relations in Green-Shield model.

(d) Five shockwaves relations in time-space graph.

2.4 Departure shockwaves detection

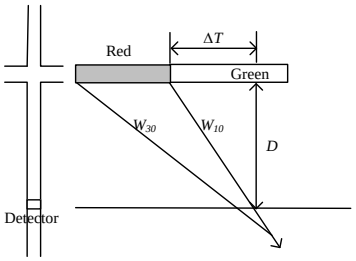


Fig. 4 Departure shockwave detection

When a traffic light turns green, the vehicles start to move forward and a departure shockwave W_{10} is formed. If a vehicle sensor with the capability of outputting three new traffic parameters has been installed at a distance D from the stop bar, it will change from Stopped state to Moving state after time ΔT . Therefore, the departure shockwave can be calculated as

$$W_{10} = -\frac{D}{\Delta T} \tag{8}$$

2.5 Ideal arrival shockwaves computation

State 2 exhibits an ideal traffic flow, which means that the vehicles arrive at a regular cycle time c, and are all discharged in the green phase time g. In green time, the flow is $Q_m (= Q_1)$. Therefore, Q_2 can be calculated as

$$Q_2 = \frac{g}{c} Q_m = rQ_m \tag{9}$$

The flow ratio *r* between Q_2 and Q_m equals *g/c.* To replace *x* with 2 in equation (2), the ideal forward arrival shockwave is calculated to be

$$W_{21} = -\sqrt{1-r}W_{10} = -\sqrt{1-g/c}W_{10} \tag{10}$$

Similarly, to replace x with 2 in equation (3), the ideal backward arrival shockwave is calculated as

$$W_{20} = W_{10} + W_{21} = (1-\sqrt{1-g/c})W_{10} \tag{11}$$

The equations above show that the ideal arrival shockwaves, W_{21} and W_{20}, can be simplified to a ratio of the departure shockwave W_{10}. If a sensor can detect W_{10} and phase time of the traffic light is known in advance, the ideal arrival shockwaves can be calculated by Eq. (10) and (11).

2.6 Forward arrival shockwave detection

The forward arrival shockwave can easily be calculated using Eq. (4). To replace x with 3, the forward arrival shockwave is calculated to be

$$W_{31} = W_{30} - W_{10} \tag{12}$$

In general, the departure shockwave W_{10} is detected first, followed by the backward arrival shockwave. The forward arrival shockwave W_{31} is the last shockwave to be calculated.

2.7 Upstream speed and flow detection

This sub-section focuses on the speed and flow of state 3. If all shockwaves of state 3 have been detected, the arrival flow can be calculated by Eq. (5) and (7). To replace x with 3 in Eq. (5), the arrival flow ratio r is

$$r = \frac{2W_{10}W_{30} - W_{30}^2}{W_{10}^2} \tag{13}$$

The flow is calculated as the following equation.

$$Q_3 = rQ_m = \frac{2W_{10}W_{30} - W_{30}^2}{W_{10}^2} Q_m \tag{14}$$

where Q_m is the flow of the green phase time, which can be collected in advance using many traditional methods. The speed of state 3 can be derived from Eq. (6).

$$U_3 = \frac{-r}{1-\sqrt{1-r}} W_{10} \tag{15}$$

If all shockwaves of state 3 have been detected, the arrival flow and speed of state 3 can be calculated using Eq. (14) and (15). As in Fig. 3(b), state 3 is an area which is not only a point near the sensor. A sensor is not always in state 3 during the cycle time, but it may be in states 0, 1, or 3. Although, the points of area of state 3 may be far from the sensor's location, it can still predict the arrival flow and speed at any point of state 3.

3 Simulation results

This study uses a CORSIM framework to simulate the three new traffic parameters and the proposed shockwave detection algorithms. A single intersection with four links is created in the CORSIM environment. Two vehicle sensors are located 300 and 730 feet from the stop bar on a link of intersection, as Fig. 5 illustrates. Figure 6 shows the phase time and input traffic flow of the link. As the traffic flow

increases, the green phase time also increases. Thus, the green phase time changes dynamically according to the traffic flow.

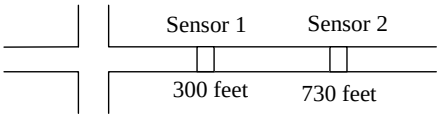


Fig. 5. The intersection of simulation: a link and two sensor locations

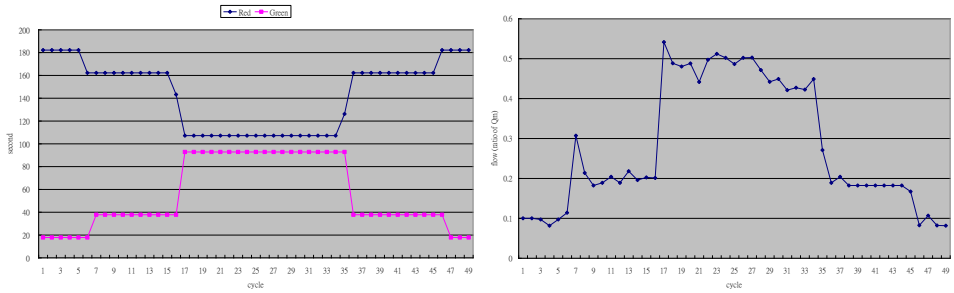


Fig. 6 (a) The phase times of the intersection. (b) The input flow of the link.

3.1 Three new traffic parameters

Figure 7 displays three traffic parameters for two vehicle detectors. Due to changes in phase time, some cycle times are shorter or longer than others. When traffic flow is low, the two sensors only output Empty and Moving time. The Stopped time of sensors is presented when a traffic queue is shown on the detection area. Figure 8 shows the relation between the Stopped time and red phase time. Notably, the Stopped time of two sensors occasionally approaches the effective red time, indicating that many vehicles are discharged for more than two cycles. In other words, if the Stopped times of two sensors are almost the same as the red phase time, the traffic queue has reached the location of sensor 2. Furthermore, because traffic is queued from sensor 1 to sensor 2 and disappears from sensor 2 to sensor 1, the cycle numbers of the sensor1's Stopped time are always longer than sensor 2.

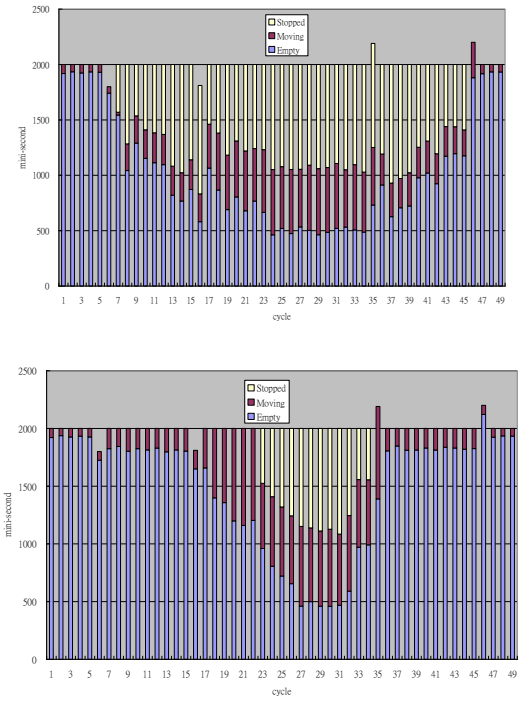


Fig. 7 (a) The Stopped, Moving and Empty time of sensor 1. (b) The Stopped, Moving and Empty time of sensor 2.

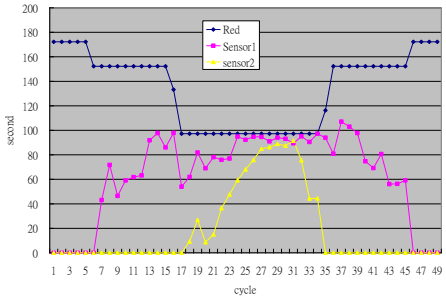


Fig. 8 Relation between the Stopped time and red phase time.

3.2 Shockwaves

According to the backward arrival shockwave detection equations in section 2 and the characteristics of the new three parameters, each equation can only detect backward arrival shockwave accurately during a specific time interval. For example, Eq. (14) should be used when the Empty and Moving times are the outputs of the sensor; Figure 9 shows the results of the algorithm in Fig. 9(b). This section focuses on the Stopped time detection method. The delta Stopped time in the graph is scaled down to show the relation with the backward arrival shockwave. The change of the delta stopped time is positively related to the change of the backward arrival shockwave. When the delta stopped time changes to a smaller value, the backward arrival shockwave becomes smaller. When the delta stopped time changes to a higher value, the backward arrival shockwave becomes higher.

Figure 10 illustrates the summary results of the algorithm proposed in Fig. 9(a). The ideal forward arrival shockwave W_{12} is a basic curve for general forward arrival shockwave W_{13}. The shockwave W_{13} is

lower than the shockwave W_{12} when the arrival traffic flow is discharged for more than two cycles. On the contrary, the shockwave W_{13} is higher than the shockwave W_{12} when the arrival traffic flow is discharged for a single cycle. Similarly, the ideal backward arrival shockwave W_{20} is a basic curve for general backward arrival shockwave W_{30}. The shockwave W_{30} is higher than the shockwave W_{20} when the arrival traffic flow is discharged for more than two cycles. On the contrary, the shockwave W_{30} is lower than the shockwave W_{20} when the arrival traffic flow is discharged for a single cycle. Figure 10 illustrates that the algorithm can yield good results. The detected arrival shockwaves are almost identical to the direct measure shockwave of CORSIM.

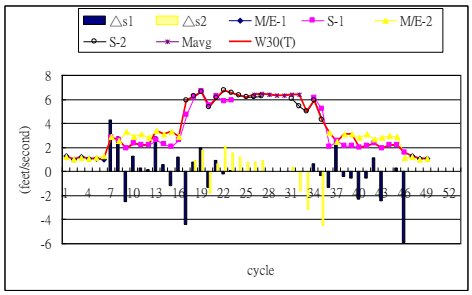


Fig.9

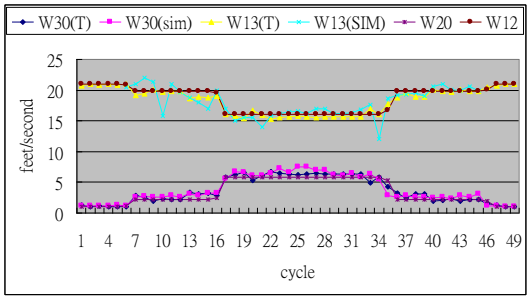


Fig.10

Fig.9 Results of the backward arrival shockwave detection algorithm. Δ Si : the delta Stopped time for sensor i; S-i : Using Stopped time for sensor i ; M/E-i : using Empty and Moving for sensor i ; Mavg : using moving average; W30(T) : the combined results.

Fig. 10 Shockwaves of the link. A symbol (T) indicates the proposed algorithm's results. A symbol (Sim) means direct measure in simulation environment.

3.3 Flow and speed

If all shockwaves of state 3 have been detected, the arrival flow and speed of state 3 can be calculated by Eq. (14) and (15). These calculations provide an upstream flow and speed detection method that makes it possible to determine traffic information far from a sensor's location. Figure 11 shows the predicted results for flow. To see the effect of method, the predicted flow is presented as a ratio of green time's flow (Q_m). The new predicted flow is almost the same as simulation. Figure 12 shows the predicted results for speed, which is a little lower than the previous simulation.

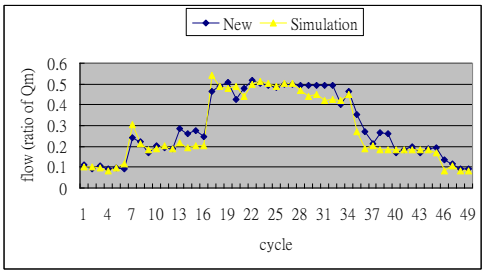


Fig.11.The predicted traffic flow of state 3

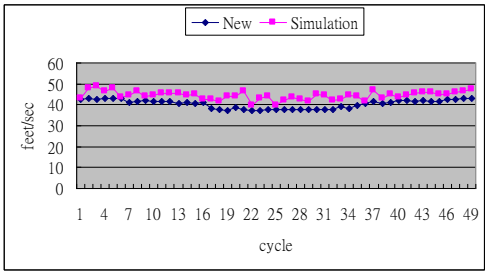


Fig.12 The predicted traffic speed of state 3

4 Conclusions

This study proposes three new traffic parameters and a new approach to detect five shockwaves for a signalized intersection. This study also provides an upstream flow and speed detection method that makes it possible to determine traffic information far from the sensor's location.

The proposed detection approach includes five shockwaves: departure shockwave, ideal backward arrival shockwave, ideal forward arrival shockwave, general backward arrival shockwave, and forward arrival shockwave. The new traffic parameters are Stopped, Moving, and Empty. The proposed algorithm demonstrates how to use sensors, new parameters, and shockwave equations to detect five shockwaves. This study also performs simulations to identify the effectiveness of the proposed algorithm. Simulation results indicate that the proposed algorithm for vehicle sensors can accurately detect shockwaves, upstream speed, and flow.

This study demonstrates the feasibility of using shockwave equations and the proposed algorithm for shockwave detection in urban intersections. This algorithm is easily applied and cost-effective because low-cost detectors can be used to generate these three parameters and detect shockwaves. Further research may extend this concept to adaptive traffic signal control or highway applications.

References

[1]. Abu-Lebdeh, G., Benekohal, R. F., Development of Traffic Control and Queue Management Procedures for Oversaturated Arterials, Transportation Research Record. 1603 (1997) 119-127.

[2]. Cho, H.-J., Lo, S. C., Modeling of Self-consistent Multi-class Dynamic Traffic Flow Model, Physica A. 312 (2002) 342-362.

[3]. Cho, H.-J., Tseng, M.-T., A Novel Computational Algorithm for Traffic Control SoC, WSEAS Transactions on Mathematics. 5 (2006) 123-128.

[4]. Cho, H.-J., Tseng, M.-T., Shockwave detection for electronic vehicle detectors, Lecture Notes in Computer Science.4490 (2007) 275-282

[5]. Dion, F., Rakha, H., Kang, Y.-S., Comparison of delay estimates at under-saturated and over-saturated pre-timed signalized intersections, Transportation Research-B. 38 (2004) 99-122.

[6]. Gerlough, D.L. ,Huber, M.J., Traffic flow theory: a monograph, Transportation Research Board, 1975.

[7]. Gazis, D.C., The Origins of Traffic Theory, Operation Research. 50 (2002) 69-77.

[8]. Greenshields, B.D., A study of traffic capacity. Proceedings of the Highway Research Board. 14 (1934) 448-477.

[9]. May, A. D., Traffic Flow Fundamentals, Prentice Hall, Englewood Cliffs, New Jersey 07632, 1990.

[10]. Michalopoulos, P. G., Stephanopoulos, G. ,An Application Of Shock Wave Theory To Traffic Signal Control, Transportation Research B, 15(1981)35-51

[11]. Zhang, H.M., A theory of nonequilibrium traffic flow, Transportation Research B. 32 (1998) 485-498.

[12]. Zhang, H.M., A stochastic wave propagation model, Transportation Research B. 42 (2008) 619-634.

出國報告書

報告人姓名	陳昱光	系所	運輸科技與管理學系博士班
出國目的/發表論文題目	2008 ICCMSE 希臘/Crete The online vehicle type classifier design for road-side radar detectors		

一、參加經過

於 2008 年投稿一篇名為 The online vehicle type classifier design for road-side radar detectors 的會議論文於 International conference of computational methods in sciences and engineering 發表.

二、心得

會議地點位於南歐希臘的一個小島, 在那邊所面臨的臉孔幾乎都是歐美人士, 在會議報告的時候,有部份的挑戰是聽得懂他們的語言, 與看懂他們所使用的符號, 另外一方面的挑戰是如何有條理的將自己所做的研究, 讓與會人士能夠快速掌握.

與會人員幾乎都是各個領域的專家, 包含物理, 化學..等等.不同領域可能也會應用到相同的科學運算. 因此在那邊參與會議, 如果能夠稍微掌握問題的本質, 然後再進一步瞭解那些科學運算的細節, 相信所觀摩到的技巧與觀念可以內化, 進而應用在其他領域.

三、建議

由於歐美是相較於台灣比較遙遠的地區, 且若要全程參與會議的開會時段, 機票加上生活費在國科會的補助下會稍嫌不足. 期盼能夠進行交通與生活費的實報實銷補助, 政府也應多鼓勵學生出國報告與交流, 以增進學生的世界觀.