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ANALYSIS OF TWO-FLUID MODEL USING GPS DATA

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Abstract: It is difficult to macroscopically characterize urban transportation network with various traffic operation components. Two-fluid model that was suggested by Herman and Prigogine (1979) is well known as a predominant method based on traffic flow theory, which provides a macroscopic measure of the quality of traffic service in an urban transportation network. The two-fluid model needs individual probe vehicle data such as total travel time, stop and running time per unit distance. Therefore, it is very difficult to collect these input data for practical applications.

This paper presents the application of GPS data to the two-fluid model for the "Kangnam" supernetwork in Seoul. The result shows that the GPS data is reliable to estimate the two-fluid model parameters. There are many applications of two-fluid model to urban transportation network in the world, and if more researches are conducted, it is obvious that the two-fluid model would be a useful method to analyze urban transportation network theoretically.

Key Words: two-fluid model, GPS data, network characteristic

1. INTRODUCTION

1.1 Background

As the urban network reliability has become an increasingly important issue, various attempts are tried to evaluate macroscopic characteristics of the network performance. In most important researches average speed, stop time per unit distance, acceleration noise and fuel consumption are generally used as a performance index (Chang and Herman, 1987; Herman et al., 1978). But the two-fluid model, proposed by Herman and Prigogine (1979), is a predominant one that is based on traffic flow theory.

The two-fluid model is based on the idea that the network performance can be described by the average traffic flow characteristics, e.g. speed, travel time, stop time, the fraction of moving vehicle, etc. Since the model was first proposed in late 1970's there have been lots of researches about its application. However, the chance of wide spread application is inevitably limited because it is difficult to collect basic input data, which should be collected on individual vehicles.

Recently the GPS is widely used in location tracking, automated navigation, land surveying, etc. The GPS has an advantage that the user can obtain one's coordinates and travel speed regardless of the location. Furthermore, due to its time cumulative data structure the GPS data can offer not only the real-time location but also the trace of movement, which is very useful feature for the traffic analysis.

This paper suggests the methodology for constructing the input data for two-fluid model using GPS equipment. Field data are applied to the model and the result is compared with previous work to validate data reliability.

1.2 Scope and Contents

This paper aims to seek the possibility of GPS data application to the two-fluid model and some issues, e.g. sampling strategy, minimum number of probe-vehicle, driver behavior, etc, are not seriously considered.

The framework of this paper is as follows. Next chapter provides the brief reviews of two-fluid model and other works relevant to GPS data collecting and its applications. In Chapter 3, the procedure to construct GPS data for the two-fluid model is suggested and it also contains some basic assumptions in reducing and the adjusted concept of cutoff speed. The last part of the paper gives the analysis and comparison of the result.

2. LITERATURE REVIEW

2.1 Two-Fluid Model

The two-fluid model was proposed by Herman and Prigogine at late 1970's. It assumes a curvilinear relationship between trip time and stop time per unit distance, and the subject of the model is not a single node or link but a relatively large network. The two-fluid model divides the entire vehicles on the network into moving ones and stopped ones, and herein the 'stop' means that being stopped by the factor which influence to traffic flow, e.g. signal, loading and unloading, congestion, etc, excluding the intentional stop such as parking or temporal standing.

Two basic assumptions, the two-fluid model is based on, are as follows.

- Average travel speed is proportional to the fraction of moving vehicles.
- Over a sufficiently long period of time the fraction of stop time of probe vehicle in a network approaches the average fraction of stopped vehicles in that network during the time period.

The second assumption is known as the ergodic assumption and it has been verified through ground-based and aerial observations of the two-fluid variables (Ardekani and Herman, 1987). And from those assumptions we can derive basic formulae (1), (2).

$$V_r = V_m \cdot f_r^n \tag{1}$$

$$f_s = T_s / T \tag{2}$$

And the boundary conditions of (1) are as follows.

$$f_s = 0 \quad \rightarrow \quad V = V_m \tag{3}$$

$$f_s = 1 \quad \rightarrow \quad V = 0 \tag{4}$$

From (1) and (2), substituting speed term by time term, equation (5.1) and (5.2) are derived.

$$T_r = T_m^{\frac{1}{n+1}} \cdot T^{\frac{n}{n+1}} \tag{5.1}$$

$$T_s = T - T_m^{\frac{1}{n+1}} \cdot T^{\frac{n}{n+1}} \tag{5.2}$$

where,

V : average travel speed

V_m : average maximum speed

V_r : average running speed

T : trip time per unit distance

T_m : average minimum trip time per unit distance, *two-fluid parameter*

T_r : running time per unit distance

T_s : stop time per unit distance

f_r : fraction of vehicles running

f_s : fraction of vehicles stopped

n : *two-fluid parameter*

Trip time and running time per unit distance from field data are divided into 1~2 mile unit and employed to estimate equation (6), which is a logarithm transform of equation (5.1).

$$\log T_r = \frac{1}{n+1} \cdot \log T_m + \frac{n}{n+1} \cdot \log T \tag{6}$$

where T_m and n are the two-fluid parameters which represent the intercept and slope of the log-linear equation respectively.

T_m is average minimum trip time per unit distance. Due to control devices like signals field data always reflects a degree of congestion even the density is nearly zero. The lower T_m means the better network performance. n, in general, has a positive value which means that running time, not only stop time, is also increasing as the traffic density increases. According to earlier studies n has a value between 0.8~3.0 and the lower value means the better capacity against the demand increase.

2.2 GPS Data Applications

After the selective availability (SA; intentional degradation of the accuracy for unauthorized users) is removed the role of the GPS in transportation, alike the other fields, is highly raised and many interests are concentrated to the performance of the post-SA GPS and the practical use of the GPS data in the field of transportation engineering and planning. Ochieng, et al. (2001) tested the data with SA, data without SA and data from DGPS and conclude that there is an significant improvement in the level of accuracy without SA compared to the data with SA. Furthermore, no significant difference is seen between the level of accuracy achievable with DGPS data and post-SA GPS data.

Cesar A., et al. (1998) emphasize the need for shorter sampling periods, e.g. 1~2 sec, in order to minimize the GPS errors in their travel time study with GPS data. And through the central tendency analysis the interesting fact is shown that median speeds from the GPS data are more robust estimators of central tendency than harmonic mean speeds from the same data set.

There are many studies which try to use the GPS data practically. For example, the use of GPS receivers tailored for mobile applications, and able to provide direct observations of vehicle speed and travel direction, coupled with database management using geographic information systems (GIS) software, was found to provide a reliable and efficient system for vehicle monitoring. (Zito, 1995) And many other researches are conducted for the practical use of the GPS data.

3. GPS DATA APPLICATION

3.1 Structure of GPS Data

The structure of GPS data follows the protocol of the National Marine Electronics Association (NMEA, USA). Generally GPS receives 26 types of information and data formats. ($GPAAM~$GPZDA) But most frequently used sentence codes transmitted by GPS unit are following 6 types. Each title of the sentence codes and its short description is presented at Table 1.

Table 1. Formats of GPS Data

Code	Description
GGA	Global Positioning System Fix Data
GLL	Geographic Position, Latitude and Longitude
GSA	GPS DOP and Active Satellites
GSV	Satellites in View

RMC	Recommended Minimum Specific GPS/Transit Data
VTG	Track Made Good and Ground Speed

Among these we can obtain the essential information for the two-fluid model from RMC format, which offers time (Universal Time Coordinated; UTC), receiving status, latitude and longitude, speed over ground (knot), date (UTC), track made good, magnetic variation and check sum.

Table 2. Properties of RMC Format

Expression	**Property**	**Remark**
hh	Hours	UTC
mm	Minutes	UTC
ss.sss	Seconds	UTC
a	Status	A : valid / V : invalid
dd	Latitude	-
mm.mmm	Degree	-
n	Direction	-
ddd	Longitude	-
mm.mmm	Degree	-
w	Direction	-
z.z	Speed over Ground	knot
y.y	Track made Good	-
dd	Day	UTC
mm	Month	UTC
yy	Year	UTC
d.d	Magnetic Variation	-
v	Variation Sense	-
cc	Check Sum	-

Table 3. Example of Collected RMC Format Data

$GPRMC,hhmmss.sss,a,ddmm.mmm,n,dddmm.mmm,w,z.z,y.y,dd,mm,yy,d.d,v,cc
$GPRMC,083442.019,A,3730.8259,N,12703.4616,E,4.03,77.41,231003,,*30
$GPRMC,083443.019,A,3730.8261,N,12703.4624,E,2.51,77.80,231003,,*37
$GPRMC,083444.019,A,3730.8262,N,12703.4632,E,2.44,79.20,231003,,*34
$GPRMC,083445.019,A,3730.8264,N,12703.4641,E,2.72,77.27,231003,,*3B
$GPRMC,083446.019,A,3730.8267,N,12703.4655,E,4.15,80.72,231003,,*31

$GPRMC,083447.019,A,3730.8270,N,12703.4677,E,6.50,79.56,231003,,*35

…

3.2 Data Collection

A set of PDA, GPS module and software for data storage is employed to collect data. The equipment receives 6 types of NMEA format information every seconds and stores them automatically.

Figure 1. GPS Equipment

Figure 2. GPS Equipment (Installed)

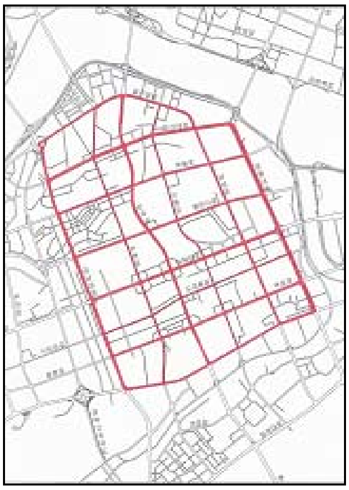

Figure 3. Map of Network

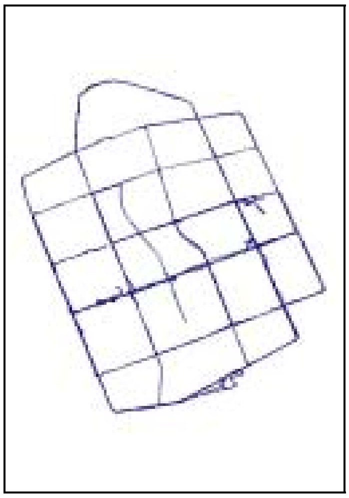

Figure 4. Sample Distribution (example)

In our experiment "chase car technique", which means that the test vehicle is intended to passively sample other vehicles in the network, is used to collect data. Even the chase car technique has some problem that the chase car is typically close to the previously followed vehicle and likely to experience similar traffic conditions, we do not seriously consider about the sampling strategy problem in this paper. But to avoid extremely partial sampling we examine sampling result briefly and the samples are quite uniformly distributed. Figure 4. is an example distribution of acquired data.

The experiment is conducted with 4 vehicles with a set of GPS equipment and environmental conditions are as follows.

- Date: 23. Oct ~ 24.Oct, 2003
- Location: Kangnam network in Seoul, South Korea
- Time: AM 7:00~10:00, PM 15:00~20:00
- Weather: Fine

3.3 Methodology of Data Reduction

As we collect the NMEA format raw data it is necessary to reduce them suitably. First, RMC format, which contains time, location and speed, is extracted and exclude the unnecessary information, e.g. track made good, magnetic variation and check sum. In case of data loss the invalid speed at time t is substituted by the speed at time $t-1$. This revision of speed data is not unreasonable because there is just 0.83% of data loss during the time period.

Then the speed is integrated by the time duration to deduce cumulative moving distance. And whether the vehicle is on moving or stop is determined by the cutoff speed. The cutoff speed means the speed under which is regarded as stop and it is set up to avoid the influence of non-zero speed due to GPS error. More detailed process is introduced at next section.

Finally, divide the cumulative moving distance into smaller microtrips of 1.5 km long, which is unit distance of analysis, and calculate the travel time, running time and stop time of the each microtrip as basic input data for the two-fluid model. The length of the microtrip, 1.5 km, is from the previous work of Williams and Herman (1995) and the influence of the microtrip length requires more research. All of the process is summarized at Figure 5.

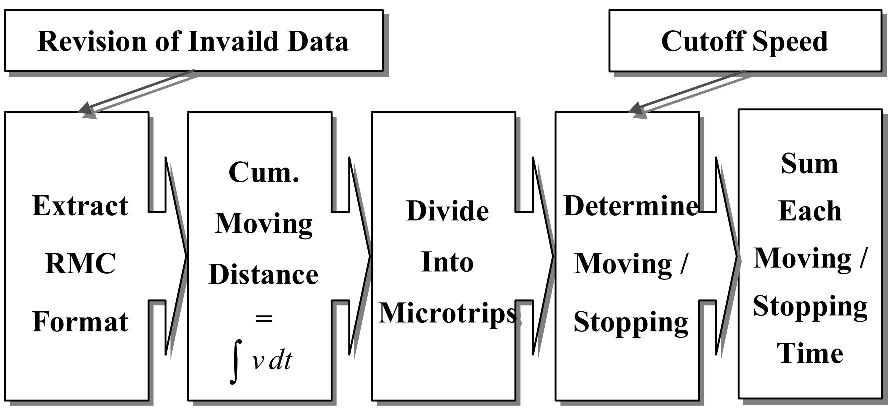

Figure 5. Process of Data Reduction

3.4 Selection of Cutoff Speed

The GPS data always include some errors caused by atmosphere condition, ephemeris data, clock drift, measurement noise, multipath, etc. Also there is a difference between driver deceleration behaviors, that is, some drivers do not stop their vehicle immediately and keep reducing the gap between the front vehicle very slowly even if the traffic flow substantially stops. So the necessity arises to set up the cutoff speed and determine the minimal speed values, which is lower than the cutoff speed, as zero.

In the work of Ardekani, et al. (1987) the stop time is judged and recorded by the driver assistant with stop watch and the experts finally determine the cutoff speed by comparing the acquired data from field survey with the aerial photo of the same time period. As a result the cutoff speed is determined as 2.5 mph.

In this study we reset the cutoff speed considering the change of survey method. During the continuous stop time, expected as stop at a signal intersection, it is considered as GPS error if there is non-zero speed for a short time interval. For example, the speed value at $t = 3$ can be a GPS error but relatively long movement like $t = 8 \sim 13$ can be real short movement in the stop-and-go condition. (Figure 6) All the possible error points are investigated and the value of error ranges from 0.88 kph to 1.74 kph.

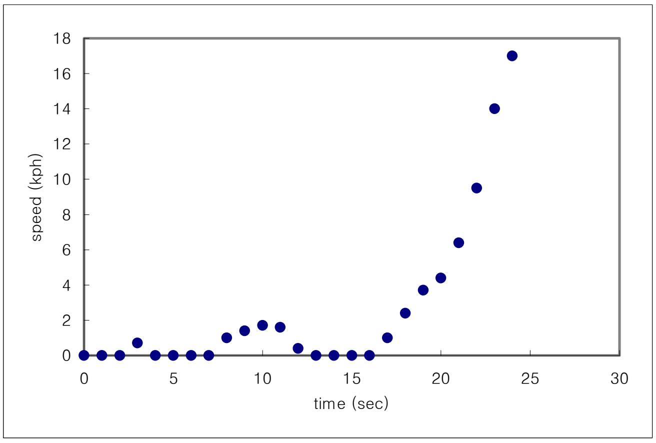

Figure 6. GPS Error Estimation

Then we perform sensitivity analysis for the cutoff speed to examine the effect of the cutoff speed variation to the two-fluid parameters. (Table 4) As the cutoff speed decreases the sum of squared error (SSR) increases and distinctive change occurs between 1 kph and 2 kph.

(Figure 7)

Table 4. Sensitivity Analysis of the Cutoff Speed

Cutoff Speed	n	T_m (min/ $mile$)	r^2	SSR
1 kph	1.680	1.922	0.777	10.294
2 kph	1.320	1.966	0.750	9.908
3 kph	1.123	2.007	0.722	9.869
4 kph	0.944	2.061	0.686	9.845

Note: The unit of T_m is represented as 'min/mile' for convenient compare with earlier studies

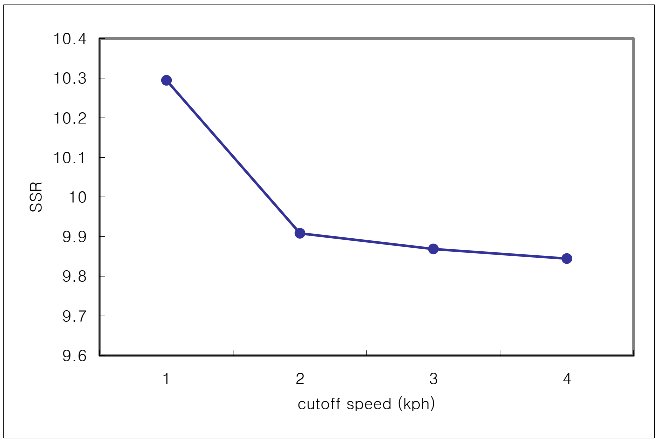

Figure 7. Effect of Cutoff Speed (Cutoff Speed vs. Sum of Squared Error)

Table 4 and Figure 7 reflect that most vehicles which are reducing their speed are moving at 1~2 kph and, that is, drivers tend to continuously moving at low speed away from stop line rather than stop immediately. Therefore it would be rational to take very low speed like 1~2 kph as stop from the aspect of total traffic flow.

From these two points about the maximum GPS error and sensitivity analysis the traffic flow moving under 2 kph can be regarded as being at stop state substantially.

4. RESULT

The acquired field data was applied to the two-fluid model to estimate the model parameters. Log-linear equation of the two-fluid model and its parameters are presented and the possibility of GPS application to the two-fluid model is derived.

The result of log-linear regression is presented at Figure 8 and equation (7).

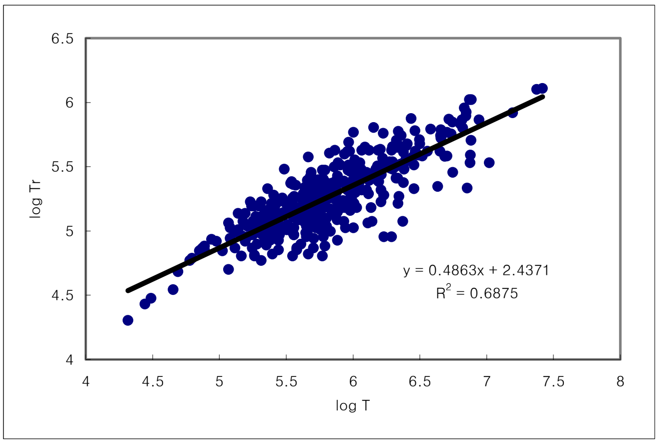

Figure 8. Result of the two-fluid model

$$\ln T_r = 0.486 \cdot \ln T + 2.437 \qquad (r^2 = 0.688) \tag{7}$$

The two-fluid parameters were presented and compared with the earlier works which had been performed at the same network by C. Lee (2003). (Table 5) In the work of C. Lee the data was collected by the probe vehicles of the private company and microtrips were divided by the link, not the constant distance.

Table 5. Result and Comparison with the Previous Work

	n	T_m $(min/mile)$	r^2
Result	1.123	2.007	0.688
Previous Result	0.90	2.170	0.690

Even though there are some differences of data collecting method the results show quite similar two-fluid parameters. There is no significant study about the critical value of the two-fluid parameters to confirm the identity of network performance. But some studies showed that the n value was changed about 1.0 point by the adjustment of traffic facilities (R. Herman, et al., 1987) and 0.5 point by the weather condition, like snow or rain (C. Lee, 2002). Considering these results, it can be said that the results in this paper have significant similarity.

5. CONCLUSION

The two-fluid model has potential power to evaluate the network-wide performance but the difficulty of constructing the basic input data prevents the broad application. In case of Seoul, South Korea, the GPS equipped vehicles are highly increasing. And the probe vehicles of the private company for offering traffic information and the collected information from the presently settled Bus Information System (BIS) are becoming another new sources of GPS data, which would enable the researchers to access to the GPS data easier.

A methodology was suggested to construct the data for the two-fluid model and inspect the possibility of application by collecting field data with GPS equipped probe vehicles. And the cutoff speed was setup to consider the GPS error and decelerating behavior of drivers. The GPS data application yielded highly similar result with the previous studies, and it is able to be used as a new approach to the data acquisition method.

Our result, undoubtedly, can be used to assess the network-wide mobility and the evaluated performance index can be practically applied to such fields as the analysis of the effect of the ITS establishment, the analysis of the effect of new traffic facility, the monitoring of macro scale traffic flow, etc.

One of the most important issues is to set up the cutoff speed which is the criterion of dividing the running and stopping vehicles. From the earlier studies and analysis of the collected field data 2 kph is set as a cutoff speed but more careful research about the cutoff speed would be required hereafter.

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