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Basic study on traffic transition of free flow and congestion

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Abstract: This paper aims to provide basic study on transition process between free flow and congestion. The flow rate and speed data were collected in 5 minute intervals from Korea Expressway Corporation open OASIS. For statistical tests, this paper applies independent sample t-test with SPSS 20.0. The results are, first, when transition occurs from free flow to congestion, the transition starts to appear at the level of flow rate that is much lower that the capacity. Secondly, there were two types in transition from congestion to free flow.

Keywords: flow, congestion, transition, fundamental traffic diagram.

Introduction

Recently traffic congestion is becoming intensified as traffic demand increased rapidly, and drivers are undergoing the inconvenience. Traffic demand is continuously increasing in Korea, however, because of the limited finances and land resources, managing demand by the construction of a new road or expansion of a road is difficult in reality. Thus, approach of traffic operations and management is needed.

For a proper operation of a road, it is required to understand the traffic properties both in free flow and in congestion. However, the traditional traffic flow theory that is used widely until now and Korea Highway Capacity Manual (KHCM) that is the base of designing and operating freeways in Korea are based on characteristics of free flow, so not very suitable to apply to the roads. Thus, for efficient traffic flow management, it is needed to study on both the traffic flow of free flow and congestion at the same time.

Under this background, this paper aims to analyze the transition process of free flow and congestion in the road where frequent congestion appears with flow and speed data that are used to assess traffic operations and level of service (LOS). First, this paper examines the characteristics of change in the speed-flow relationship when transition happens from free flow to congestion. Furthermore, this paper shows the characteristics of change in the speed-flow relationship for the transition from congestion to free flow, and propose new classification of this transition.

Literature Review and Implications

Previous researches on transition process of free flow and congestion mainly focused on transition from free flow to congestion, and there is almost no research on transition from congestion to free flow.

In Korea, Kim (1997) analyzed fundamental speed-flow-density model by each lanes and points using VDS data from basic sections and bottlenecks of freeways. Then he pointed out that the speed change in transition from congestion from free flow is higher than that of transition from free flow to congestion, and the whole transition process between the two shows the trace of ◇. Lee(1998) found a break point(the flow rate when there is a rapid change in speed) in the transition from free flow to congestion using time tracing for the analysis of traffic flow of basic sections, upstreams and downstreams of bottlenecks, and weaving sections' each lanes.

In foreign papers, Hall (1987) showed sudden change in speed in transition process and that change occurs in different flow levels through catastrophe theory. Kerner (2000) proposed three phase theory which explains the existence of synchronized phase between free flow and wide moving jam by flow-density data. Lorenz and Lily (2000) suggested that breakdown which happens when the flow rate exceeds capacity in the process of transition may happen at higher or lower level of maximum flow rate by probabilistic approach.

Until now, research on transition process of free flow and congestion mainly focused only on transition from free flow to congestion. Also, the study was based on single variable such as speed change or flow rate which made limited macro-analysis. Thus this paper intends to broaden the range of research of transition process by analyzing both transition from free flow to congestion and transition from congestion to free flow.

Methodology

Fundamental Traffic Model is presented in Fig. 1(a) showing speed-flow relationship. Traditionally, the upper side of speed at capacity is the free flow state, and the down side is the congested state.

According to the theory, the transition process occurs around capacity. Also, it assumes that the path of transition from free flow to congestion is same with that of transition from congestion to free flow because the model is presented on one single line.

However, as shown in Fig. 1.(b), the plotting of speed-flow relationship of data from Sep. 27th, 2013 at Dori JC~Jonam JC shows inconsistencies with the theory.

Therefore, this study will set transition from free flow to congestion as 'transition 1' and compare the level of capacity and break down using data.

Moreover, this study will set transition from congestion to free flow as 'transition 2' and look at how the speed-flow path appears, then suggest two types, 'transition 2-1' and 'transition 2-2'. Then compare those two types in terms of transition time, flow rate at congestion, and average speed of congestion.

Statistical tests are required for the analysis. This paper applies independent sample t-test which judges the average difference by comparing similar or contrasting samples.

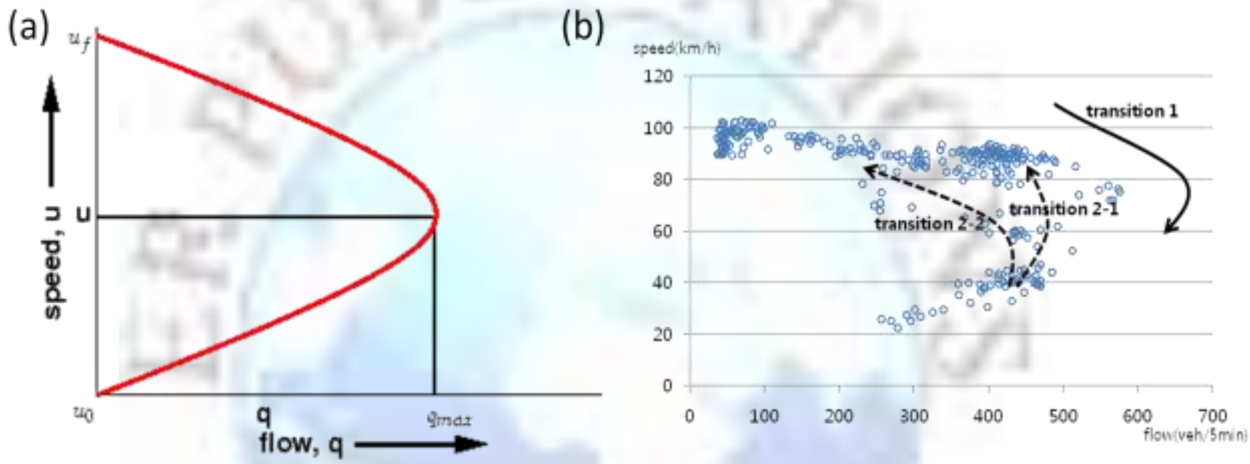

Figure 1. (a) Theoretical speed-flow relationship and (b) Speed-flow data plotting

Indicators of Transition Process

To look at the characteristics of transition 1 and transition 2, this paper set flow rate(q), speed(v), and time(t) as variables. As mentioned above, flow and speed are used to assess the traffic operations and LOS, and time variable is important since it is an indicator that road users can actually experience and notice the congested condition. Unit is veh/5min, km/h, and min for each.

To analyze the properties of transition 1, using flow data, capacity (q_{max}) and flow level at break point will be compared. For the properties of transition 2, flow rate, speed, and time variables were used as indicators. Maximum flow rate in congestion (q_c) was used for flow rate, average speed in congestion (v_c) was used for speed, and the difference between the time congestion started to recover(t_1) and the time congestion completed to recover(t_2), $t_2 - t_1$, were used for time variable.

Especially, drivers can also notice the state of congestion by speed. So, speed is also an important indicator of representing congestion.

Therefore, in this study, the transition process was designated with the points in which rapid speed change appeared. It is represented as a formula:

$$\Delta v = v_{t+1} - v_t . \qquad (1)$$

Where, Δv is the indicator of transition process and v_t, v_{t+1} are space mean speed at t and t+1 each.

The criteria of rapid speed change was set where the absolute value of speed change in 5min data ($|\Delta \mathrm{v} = \mathrm{v}_{t+1} - v_t|$) which is higher than the quartile of absolute speed change values ($|\Delta \mathrm{v}|_4$) appears twice in a row. Transition 1 and transition 2 can be represented in a formula. For transition 1,

$$\Delta \mathrm{v} < 0, |\Delta \mathrm{v}_t| > |\Delta v|_4 \, and |\Delta \mathrm{v}_{t+1}| > |\Delta v|_4 \qquad (2)$$

and same for transition 2,

$$\Delta \mathrm{v} > 0, |\Delta \mathrm{v}_t| > |\Delta v|_4 \, and |\Delta \mathrm{v}_{t+1}| > |\Delta v|_4 . \qquad (3)$$

Finally, the transition 1 and transition 2 can be represented as in Fig. 2 in 24 hour speed graph.

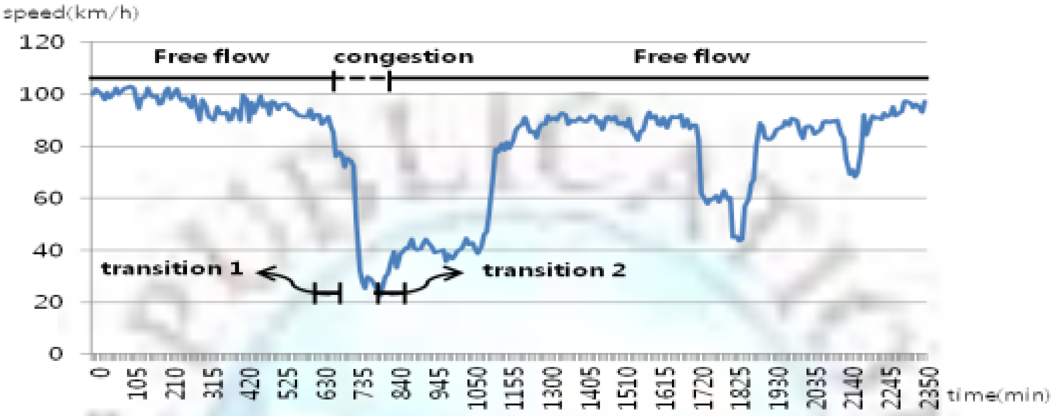

Figure 2. 24 hour speed graph

Data collection and organization

The flow rate and speed data were collected in 5 minute intervals from Korea Expressway Corporation open OASIS. This paper used data from September 2013, excluding national holidays and weekends when congestion did not occur.

The analysis object link Dori JC~Jonam JC is located in a beltway of Seoul, which has 4 lanes and goes through congestion frequently.

Results of transition 1

As a result of an analysis of speed-flow relationship of the link in congested periods, in transition 1, it appeared that break point fell short of capacity levels significantly.

For example, as shown in Fig. 3.(a) that shows transition 1 in speed-flow relationship on Sep. 30th, break point is 466(veh/5min) and this is way smaller that the capacity level 540 (veh/5min).

HCM tells that the down side of speed-flow graph shows congested condition and LOS F. However, the break point where drivers start to realize congestion because of rapid speed decrease appears at the lower level than capacity.

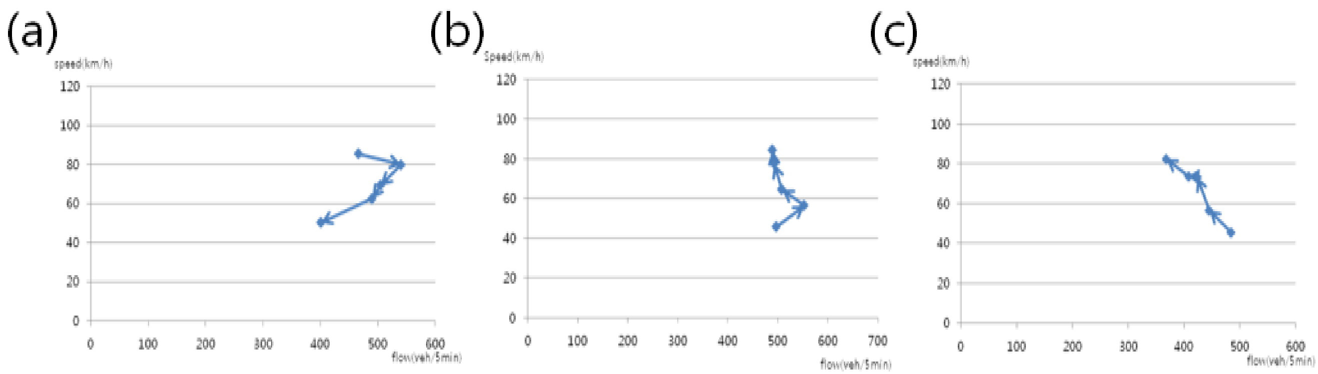

Figure 3. (a) Transition 1, (b) Transition 2-1, and (c) Transition 2-2

To verify statistical significance of the difference between break point and capacity in transition 1, t-test was conducted.

The t-test showed p-value of 0.034, which is smaller than 0.5 at the 95% confidence interval, and that means the flow rate when rapid speed decrease occurs and the capacity has statistically significant difference between them. The average of break point was lower than the average capacity by 47.5(veh/5min) as shown in Table 1.

That is, drivers experience the start of congestion before reaching the level of capacity, which is inconsistent with the traffic flow theory.

Table 1. Results of t-test for transition 1

(veh/5min)	mean	standard deviation	standard error
break point	502.44	76.19	19.05
capacity	549.94	39.34	9.83

Results of transition 2

After examining speed-flow relationship in transition 2, transition 2 could be divided into two types of path, transition 2-1 and transition 2-2.

Transition 2-1 which is shown in Fig. 3.(b) is a type that shows vertical path because the flow rate at the start of recovery of congestion( ) and the flow rate at the completion of recovery of congestion( ) is similar. Fig. 3.(b) shows data from Sep 12th. On Sep 12th, the flow rate at the start of congestion recovery is 497(veh/5min) and the flow rate at the completion of congestion recovery is 489(veh/5min).

Transition 2-2 as in Fig. 3.(c) shows left-up path because the flow rate at the completion of congestion recovery is lower than the flow rate at the start of congestion recovery. Fig. 3.(c) shows data from Sep 2nd. On Sep 2nd, the flow rate at the start of congestion recovery and the flow rate at the completion of congestion recovery is 484(veh/5min) and 368(veh/5min) each. It is easy to find out that the two flow rate levels in transition 2-2 are quiet different as compared to transition 2-1.

In particular, transition 2-1 and transition 2-2 can be divided because they show statistically significant difference in the flow rate at the completion of congestion recovery( ). By comparing that flow rate between the days that showed transition 2-1 and transition 2-2 as in Table 2, transition 2-1 showed about 435(veh/5min) and transition 2-2 showed about 393(veh/5min). The p-value was 0.028, so it supports that the two types can be seperated at the 95% confidence interval.

After the division of the two, Table 3 shows the difference of transition time($t_2 - t_1$), maximum flow rate in congestion(q_c), and average speed in congestion(v_c).

T-test showed that average transition time of transition 2-2 was around 27min which is longer than that of transition 2-1 which was around 18min. This means that the recovery progressed slower in transition 2-2. In addition the maximum flow rate in congestion of transition 2-2 was about 534(veh/5min) and this is bigger than that of transition 2-1 which is 489(veh/5min) At last, the average speed in congestion was lower in transition 2-1 instead of transition 2-2 by 46.61(km/h) and 54.03(km/h). All these results show that the p-values are smaller than 0.05, which shows that these results are statistically significant in 95% confidence interval. For the average speed in congestion, the p-value is exactly 0.05, so it is hard to say it is very significant in 95% confidence interval, however, it is still significant at the 90% confidence level.

It can be concluded that transition 2-1 has lower average speed and shorter transition time, so it shows more concentrated and shorter congestions. However, considering transition time, flow rate, and speed as a whole, transition 2-2 shows higher flow rate and longer transition time, so it can be concluded that transition 2-2 represents more serious congestion. That is, more serious a congestion, the speed-flow relationship tends to show left-up path, which means speed increases as flow rate decreases, when congestion recovering. When the congestion is relatively less serious, the speed increases through similar flow levels and so, the speed- flow relationship represents vertical line.

Table 2. Division of transition 2-1 and 2-2

	mean		standard deviation		t	p
	2-1	2-2	2-1	2-2		
q_2	434.63	393.00	31.09	36.38	2.46	0.027

Table 3. Comparison of transition 2-1 and 2-2

(veh/ 5min)	mean		standard deviation		t	p
	2-1	2-2	2-1	2-2		
$t_2 - t_1$	18.13	26.88	4.58	9.61	-2.324	0.042
q_c	488.88	534.38	44.67	36.74	-2.225	0.043
v_c	46.61	54.03	6.78	7.02	-2.149	0.05

It can be interpreted that when congestion is recovering, if congestion is more serious, the entering volume continues to decrease so that the flow rate at the completion of congestion recovery becomes much lower by traffic information.

Conclusion

This paper aims to provide basic study on transition process between free flow and congestion with data from road with frequent congestions. This can lead to more efficient operation of congested flow.

The results are, first, when transition occurs from free flow to congestion, the transition starts to appear at the level of flow rate that is much lower that the capacity. The speed rapidly decreased before reaching the capacity, so the division of LOS E and LOS F becomes ambiguous in speed-flow relationship.

Secondly, there were two types in transition from congestion to free flow. First is the path that shows vertical line, which means the speed increased with relatively similar level of flow rate throughout the recovery. The other shows left-up path which means speed increases as the flow rate decreases through recovery. The first one appears where there is relatively less serious congestion with shorter recovering time, and the latter one appears in serious congestion with lower volume and longer recovering time.

In Korea, it is hard to find the research on transition process between free flow and congestion, and also in foreign studies, the research on transition from congestion to free flow is very limited. More thorough examination of the process of the transition of free flow and congestion will lead to more efficient operations for congestion.

This paper used 5 min interval flow rate and speed data. For more precise study, shorter interval data, such as 1 min data or 30 sec data should be used.

Also, there may be intervention of researcher's subjective when designating the point of transition process. More objective way should be considered.

Finally, this paper examined one link. However more data and links with various kinds of roads, geometric structures, and traffic environment should be examined to complement the analysis of the transition process.

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