Development of a Method for Detecting the Occurrence of Network Traffic Flow Breakdown

Toshio Yoshii[a], Kotaro Yamashiro[a], Sho Takahashi[a]

[a] *Hokkaido University*

(e-mail yoshii@eng.hokudai.ac.jp)

Abstract

In network traffic flow, a phenomenon occurs where the network traffic throughput is significantly reduced due to mutual interaction between bottlenecks. In this paper, this phenomenon is named 'Network traffic flow BreakDown (NBD)' and is defined. Then, a method to detect its occurrence is developed. Once the NBD phenomenon occurs, the traffic capacity of bottlenecks is substantially decreased due to the congestion caused by other bottlenecks. It leads to severe traffic congestion. In some cases, a gridlock phenomenon occurs, where it becomes impossible to identify the specific bottleneck. This congestion requires time for resolution, causing significant social losses. In this study, 'Area Traffic State (ATS)' is defined to indicate the network traffic flow state which consists of two physical variables: Aggregated Traffic Flow (ATF) and Aggregated Traffic Density (ATD). These variables are evaluated by aggregation both spatial and temporal dimensions over a fixed space and time periods. Based on the time transition of ATS, a method to detect the occurrence of NBD is developed. Furthermore, this detection method is applied to real data from actual networks and verify its effectiveness.

Keyword: network traffic breakdown, area traffic state, aggregated traffic flow, aggregated traffic density

Introduction

Traffic congestion can be divided into two types: Demand-exceeding Congestion and Capacity-drop Congestion. The former one occurs when demand exceeds the capacity of the road or network, on the other hand the latter one occurs when the possible throughput of the road or network is decreased. Capacity-drop Congestion can further be classified into Incident Congestion and Network traffic flow BreakDown (NBD) Congestion. These congestions occur due to capacity drop of a link and reduction of possible network traffic throughput respectively. In this paper, the latter congestion is defined as NBD Congestion. Since the congestion management measures for the three types of congestion are different, it is essential to detect the occurrence of NBD Congestion in order to mitigate the losses caused by NBD. Takata et al. (2022) proposed a method for representing the network traffic flow state using two variables: the number of vehicles in the network (aggregated traffic density) and the flow rate (aggregated traffic flow). Then, suggested a method to detect the occurrence of breakdowns using these state variables. However, since this method uses a threshold without objective support, this study aims to develop a method for objectively detecting NBD based on the time transition of Area Traffic State (ATS).

3 types of congestion

Traffic congestion occurs at bottlenecks when demand exceeds capacity. Similarly, network traffic flow congestion also occurs when demand exceeds its capacity, but due to differences in the causes of occurrence, it can be classified into the following three types of congestion:

Demand-exceeding Congestion

This type of congestion occurs when peak traffic demand exceeds the capacity of a bottleneck in the network. In Japan, this type of congestion is referred to as "natural congestion."

After congestion occurs, when demand falls below the capacity, congestion is alleviated. During this period, length of the congested section decreases whose traffic density and traffic flow rate are higher than that of free flow section. Also, traffic density and traffic flow rate on free flow section decrease due to the reduced demand. As a result, both the Aggregated Traffic Density (ATD) and Aggregated Traffic Flow (ATF) decrease. Figure 1 shows the transition of the Area Traffic State (ATS).

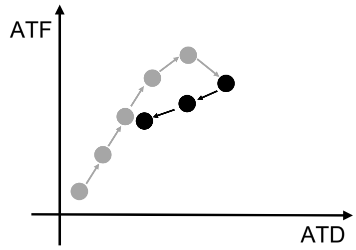

Figure 1 Transition of ATS on Demand-exceeding Congestion

Capacity-drop Congestion

This type of congestion occurs when the capacity of a bottleneck or a network drops. In Japan, the former type of congestion is referred to as "accident congestion". On the other hand, the latter type of congestion is still unnamed.

Incident Congestion (accident congestion)

When an incident occurs, such as an accident, and the throughput of a road section drops below demand, traffic congestion occurs. This type of congestion generally leads to more severe congestion compared to Demand-exceeding Congestion, with lower flow rates and higher densities in the congested flow.

After congestion occurs and when the capacity recovers, congestion is alleviated starting from the downstream side. During this period, as the traffic flow rate increases and the length of the congested section decreases, ATD decreases and ATF increases. Figure 2 shows the transition of the ATS.

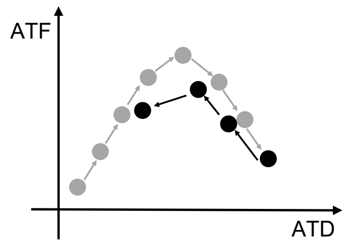

Figure 2 Transition of ATS on an Incident Congestion

NBD Congestion

Even without the occurrence of an incident, congestion can occur due to the mutual interaction of multiple bottlenecks. This type of congestion leads to a drop in the throughput of the network.

When this type of congestion occurs, traffic throughput in the local network caused NBD, which is a part of the whole area road network, significantly decreases. As a result of this, congestion extends to the surrounding network. The process of congestion alleviation begins with the resolution of congestion in the surrounding network due to reduced demand. Then, the throughput in the local network is recovered. Therefore, first, similarly to the alleviation process of Demand-exceeding Congestion, both ATD and ATF decrease. Subsequently, as the throughput recovers, ATF increases, but since demand in the surrounding areas has decreased, ATD decreases. Eventually, the congestion is resolved, but it takes a considerable amount of time to fully alleviate. Figure 3 shows the transition of ATS.

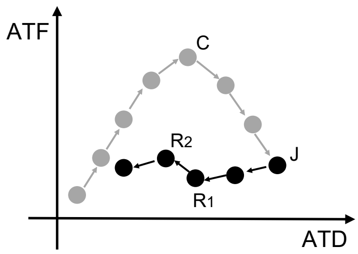

Figure 3 Transition of ATS on a NBD Congestion

NBD Congestion detection method

In this paper, we focus on the differences in the transition of ATS during the resolution time periods after congestion, and a post hoc detecting method is proposed to classify network-scale congestion into the three types using the following steps:

Step 1: Detecting the occurrence of congestion

Congestion at the network-scale is detected to have occurred when the following condition is satisfied. When transitions from the state that provides the peak ATF (state C in Fig.3) to the state that provides the peak ATD (state J in Fig.3), both a significant decrease in ATF and significant increase in ATD are observed.

Step 2: Detection of the alleviation process of Demand-exceeding Congestion in the initial stage of congestion resolution.

If significant decreases in both ATF and ATD are observed during the initial stage of the congestion resolution process, that is immediately after ATS J in Fig.3, it can be concluded that the congestion is not Incident Congestion.

Step 3: Detection of the rise in ATF during the congestion resolution process.

As shown in the transition from R_1 to R_2 in Figure 3, in the congestion alleviation process, if a significant increase in ATF is observed, it is determined as NBD Congestion.

Application to an actual road network

For the verification, the proposed NBD congestion detection method was applied to the road network of Sapporo City (Figure 4). The period of study was from December 1, 2021, to March 31, 2022, spanning a total of 4 months (117 days in total, excluding days with missing data). ATF and ATD were calculated using probe data. The occupancy rate of the probes was approximately 4%.

Results

The NBD Congestion detection method was applied to the 117-day data, and NBD congestion was detected over a period of three days. Figure 5 shows the 2 examples of the corresponding ATS hysteresis.

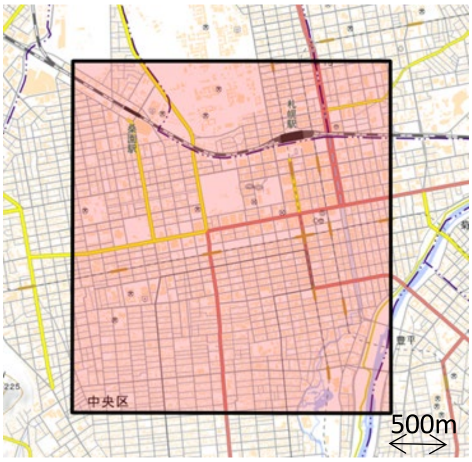

Figure 4 Applied study road network (Sapporo City)

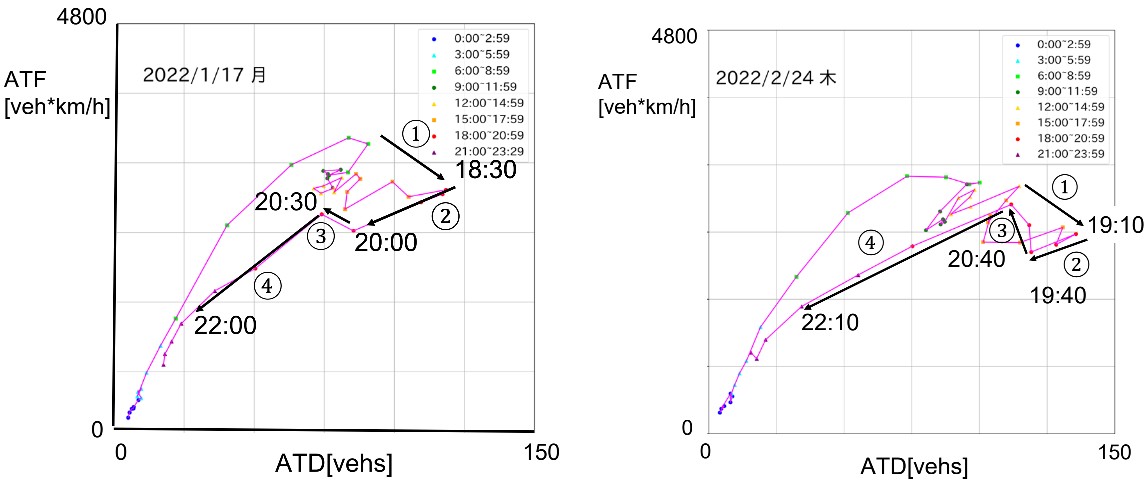

Figure 5 The examples of ATS hysteresis on the days when NBD congestion was detected

References

Takata, K., Morimoto, Y., Yoshii, T. and Tsubota, T.: Method for Detecting the Appearance of Macroscopic Congested State, proceeding of the 42nd conference of Japan Society of Traffic engineering, 2022.