EVALUATING THE IMPACT OF KINEMATIC WAVE ON REAR-END COLLISION USING SPATIOTEMPORAL WAVE RECONSTRUCTION

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1. INTRODUCTION
1.1. Background and research purpose
Attributes of backward moving kinematic waves which signal changes in traffic conditions have long been investigated in an effort to understand how they influence the likelihood of traffic collisions (Zheng et al., 2010; Chung et al., 2010; Xu et al., 2012; Li et al., 2014). Backward moving kinematic waves can accompany abrupt reduction in spacing and when the approaching traffic do not adjust their speed at opportune time, it can lead to rear-end type of collisions.

Zheng et al. (2010) reported that traffic oscillation measured by standard deviation of speed could be a significant variable for explaining crash occurrences. Xu et al. (2012) divided traffic flow into five different states using K-mean clustering, and showed that transition state from free-flow to congested flow and highly congested flow where backward moving wave occurs has the greatest impact on crash occurrences. Chung et al. (2010) investigated the attributes of kinematic waves preceding traffic collision by measuring the amplitude and speed of kinematic waves that were emanated from near recurrent bottleneck. Their finding suggested that fast backward moving wave with high amplitude increases the risk of traffic collisions. Li et al. (2014) proposed rear-end collision risk index (RCRI), which is defined by speed variance and occupancy of adjacent upstream and downstream detectors to evaluate factor affecting rear-end type of collisions and their findings indicate that RCRI and standard deviation of occupancy affect the rear-end collision likelihood.

These prior studies have shown that the effect of backward moving kinematic waves through various surrogate safety measure. However, because of the limitation of loop detectors which only collect the traffic data at specific points rather than over space, most of the studies assume that traffic conditions are homogeneous within adjacent detectors. Therefore, this assumption leads to biased effect on traffic state according to distance from the detectors, and it also make bias to traffic collision model.

In this study, we estimated traffic states between adjacent detectors using spatiotemporal wave reconstruction to overcome this limitation. This process reduces the bias from the homogeneous assumption on traffic flow, and allow us to evaluate the unbiased impact of kinematic wave to rear-end collision.
1.2. Research process
Our study is divided into two parts. The first part, spatiotemporal wave reconstruction consists of three stages as follows: (a) Sequential change detection for identifying traffic states transition; (b) Kinematic wave tracing using cross-correlations; (c) Adaptive smoothing for spatiotemporal wave reconstruction. In the second part, the impact of attributes of kinematic wave derived from the first part such as propagation speed, amplitude, and oscillation period are evaluated using logistic regression model. The detailed descriptions of the method are provided in the next section.

2. METHOD & RESULTS
2.1. Identifying traffic state transition
As mentioned in Xu et al. (2012), traffic state affects not only the forming backward moving kinematic wave, but also traffic collision itself. Therefore, it is necessary to identify traffic state transition. We conducted non-parametric sequential change detection based on the change point model (Ross, 2013). This processed sequentially over time using various statistics to judge whether the next observation is change point or not. We use the non-parametric sequential change detection based on Mann-Whitney and Mood statistics for detecting location and scale changes without distribution assumption. (Ross et al., 2011). Figure 1 shows the results of sequential change detection for 30sec aggregated flow data in US101-S (Abs PM 18.9 – 19.8), Los Angeles, California. Compared with the speed contour, this results from the adjacent detector accurately identify the transition from free-flow to congested flow where backward moving wave occurs.

![Figure 1: Sequential change detection results for 30s aggregated flow data.](image)

2.2. Kinematic wave tracing
Because most of the kinematic waves in congested traffic propagate from downstream to upstream, if some changes in flow are true wave, not random fluctuation by noise of data, it will appear similar pattern of changes in upstream and downstream. To capture this characteristic, cross-correlation, which is a measure of similarity of two series as a function of the time-lag of one relative to the others, is utilized. On the peak and valley of the 30sec aggregated flow data which is the candidate of kinematic wave, cross-correlation is calculated with changing the window size and time-lag. If the maximum cross-correlation of candidate with specific window size and time lag exceeds the threshold, it is defined as
backward moving kinematic wave. The optimal time-lag divided by distance between upstream and downstream detectors indicates the propagation speed, and the optimal window size becomes the oscillation period. Figure 2 presents kinematic wave tracing algorithm and results.

Figure 2: Kinematic wave tracing using Cross-correlation

2.3. Spatiotemporal Reconstruction: Adaptive smoothing with kinematic wave tracing

The Adaptive Smoothing Method (ASM) developed by Treiber and Helbing (2002) estimates the traffic state between adjacent detectors considering traffic state and wave propagation. It has several parameters such as congested wave speed, free-flow wave speed, threshold speed between free and congested flow, width of transition between free and congested flow, and spatiotemporal resolution. These parameters are directly obtained from observed data and kinematic wave tracing. Figure 3 represents an example of adaptive smoothing (Treiber and Kesting, 2013) with kinematic wave tracing.

Figure 3: Examples of spatiotemporal wave reconstruction

2.4. Logistic regression

The present study will evaluate the impact of propagation speed ($c_{cong}$), Amplitude (AP), and oscillation period (OP) using logistic regression, which is widely used model for analyzing the relationship between explanatory variables and the occurrence of traffic collisions (Abdel-Aty et al., 2004; Harb et al., 2008; Zheng et al., 2010; Xu et al., 2012; Li et al., 2014). The proposed model is based on case-control design to prevent the effect of confounding factors from contaminating the coefficient of independent variables. In our study, attributes of kinematic wave are used as independent variables, and road geometric, weather, and speed limit are considered as confounding factors which are controlled in sampling case and control groups. The logistic regression model to analyze the impact of attribute of kinematic waves is as follows.

$$
\log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_0 + \beta_1 \cdot c_{cong} + \beta_2 \cdot AP + \beta_3 \cdot OP
$$

(1)
3. CONCLUSION
Impact of kinematic wave on traffic collision has been studied in much previous research. Due to the inherent limitation of the loop detector’s data, however, most of them assumed homogeneous for traffic state of the adjacent detectors, which cause bias to model. To overcome these limitations, we proposed a spatiotemporal wave reconstruction algorithm consists of identifying traffic transition, kinematic wave tracing, and spatiotemporal reconstruction. Attributes of kinematic wave measured from this algorithm are represented directly in a time-space diagram; therefore, the quantitative impact of kinematic wave to rear-end traffic collision can be more accurately estimated in our model.

In this study, we proposed a new algorithm to measure the attributes of kinematic waves. However, there remains some limitation. The most important parts of the proposed algorithm are the kinematic wave tracing. We only used cross-correlation to trace wave; however, if another indicator capturing wave and proper denoising method to screen out the wrong candidates of wave (i.e., random fluctuation) added to this part, the accuracy of the measured attributes may be further increased.

REFERENCES
Treiber, M., & Helbing, D. (2002). Reconstructing the spatio-temporal traffic dynamics from stationary detector data. Cooper@ tive Tr@ nsport@ tion Dyn@ mics, 1(3), 3-1.