IMPLEMENTATION OF RAMP METERING TO IMPROVE SAFETY OF CONGESTED EXPRESSWAY WEAVING SEGMENTS

Ling Wang
Department of Civil, Environmental and Construction Engineering
University of Central Florida
Orlando, Florida, USA
College of Transportation Engineering, Tongji University, Shanghai, China
Phone: +1-407-823-0300 E-mail: lingwang@knights.ucf.edu

Mohamed Abdel-Aty
Department of Civil, Environmental and Construction Engineering
University of Central Florida
Orlando, Florida, USA

1. AIM
In weaving segments, traffic merges, diverges, and weaves in a limited space. These traffic maneuvers might result in high crash hazards. In order to improve the safety of congested expressway weaving segments, this study tested three ramp metering (RM) strategies in microsimulation. One RM strategy was the traditional ALINEA algorithm, which decides the RM rate only by the traffic operation condition on the mainline (Papageorgiou and Kotsialos, 2000). Additionally, this study proposed two new ALINEA RM strategies that decides RM metering by both the traffic operation and the traffic safety of weaving segments. Among these two RM strategies, one controls the queue length by increasing green phase time when the queue length on ramp is more than ten vehicles; and the other strategy does not control the queue length.

2. METHOD
Crash odds and the Surrogate Safety Assessment Model (SSAM) were used to evaluate the impact of RM strategies on traffic safety. The crash odds were calculated based on a real-time safety analysis model for weaving segments. Field crash observations were collected, and their corresponding traffic information, which was 5-10 minutes before the crash occurrence, was matched to each crash; meanwhile, non-crash observations along with their traffic information were gathered. Based on a logistic regression model, the real-time crash estimation model was built and the crash odds could be captured by using this model. As for SSAM, it processes the vehicle trajectory file from a well calibrated and validated microsimulation and then identify conflicts (Gettman et al., 2008). The conflict has been proven to be a valid crash surrogate by previous researchers ((Sayed and Zein, 1999; Gettman and Head, 2003). SSAM is able to detect three types of multi-vehicle crashes, i.e., crossing, rear-end, and sideswipe, among which, rear-end and sideswipe crashes are the main crash types for weaving segments. Hence, SSAM is appropriate to be used in the safety analysis of weaving segments.

The implementation of RM was carried out in microsimulation VISSIM, version 7.0. VISSIM allows users to program and regulate vehicle movements through the Component Object Model interface that was achieved by implementing Visual Basic for Applications from Excel in this study. The VISSIM network was well calibrated and validated by comparing the traffic condition of the simulated network and the field: the calibration and validation results showed that 96.4% of observed Geoffrey E. Havers were less than five (Yu and Abdel-Aty, 2014), and 86.46% of the aggregated speeds in the simulation

1(4)
were within eight kmh of field speeds (Nezamuddin et al., 2011). Then, data collection points were put in the microsimulation to collect traffic information, which was used to calculate crash risk; and detectors were used to obtain the occupancy. The detailed information is shown in Figure 1.

![Figure 1: Studied weaving segment microsimulation network](image)

As for the new RM algorithm, it is a modified ALINEA algorithm which additionally considers safety conditions. The ramp-metering rate is based on the occupancy and the crash risk of the studied weaving segment. The metering rate at time step \( k \) is calculated in Equation (1):

\[
r(k) = r(k-1) + K_R(\hat{o} - o_{k-1}) + K_S(\hat{p} - p_{k-1})
\]

Where \( r(k) \) is the metering rate (veh/h) at time interval \( k \), \( r(k-1) \) the metering rate at the previous time interval \( k-1 \), \( K_R \) the occupancy regulator parameter (veh/h), \( \hat{o} \) the critical occupancy (%), \( o_{k-1} \) the occupancy (%) at time interval \( k-1 \), \( K_S \) the safety regulator parameter (veh/h), \( \hat{p} \) the critical crash risk, and \( p_{k-1} \) the crash risk at the time interval \( k-1 \).

The ramp metering is achieved by adjusting the timing of the ramp signal. The metering signal permits on-ramp vehicles to enter the weaving segment only when the signal turns to green. The green-phase duration at time interval \( k \), \( g(k) \), is calculated as follows,

\[
g(k) = \frac{r(k)}{r_{sat}} C
\]

\[
g_{min} \leq g(k) \leq g_{max}
\]

Where \( C \) is the fixed cycle time (10 seconds), \( r_{sat} \) the ramp saturation flow (1800 veh/(h.lane)), \( g_{min} \) is 3 seconds, and \( g_{max} \) the maximum green-phase duration (10 seconds). Meanwhile, in order to prevent the ramp metering rate from increasing greatly and resulting in a large amount of vehicles entering the mainline at a time interval, the maximum increment of \( r(k) \) for each time interval was set to be 60 veh/h.

There were four parameters in the modified ALINEA RM algorithm which needed to be calibrated: the critical occupancy (\( \hat{o} \)), the occupancy regulator parameter (\( K_R \)), the critical crash risk (\( \hat{p} \)), and the safety regulator parameter (\( K_S \)). These parameters were set as follows:

1. According to previous studies (Abdel-Aty et al., 2007; Papamichail et al., 2010), the critical occupancy (\( \hat{o} \)) was set be 23%, and the occupancy regulator parameter (\( K_R \)) was 70 veh/h.
2. In order to reduce the false alarm percentage, the threshold of identifying a crash was set to be 0.15.
3. The safety regulator parameter (\( K_S \)) was set to be 0 and then to be \( 2.5 \times 10^3 \). When \( K_S \) was 0, the ALINEA algorithm was the same as the traditional ALINEA algorithm. And when the \( K_S \) was \( 2.5 \times 10^3 \), it is the modified ALINEA algorithm.
3. RESULTS

From the real-time safety model (Table 1), the increase of weaving influence length will increase crash risk and the weaving influence length is positively decided by weaving ratio, so the decrease of weaving ratio would decrease the crash risk in weaving segments. Hence, it provides a solid base that RM would improve safety by reducing the weaving ratio in hazard conditions.

Table 1: Real-time Crash Estimation Model for Weaving Segments

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Std.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-7.86</td>
<td>0.79</td>
<td>0.00</td>
</tr>
<tr>
<td>Speed difference between the beginning and the end of weaving segments (kmh)</td>
<td>0.068</td>
<td>0.019</td>
<td>0.00</td>
</tr>
<tr>
<td>Log(Vehicle count in 5 minutes)</td>
<td>0.65</td>
<td>0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>Weaving segment configuration (1=minimum number of lane change for a weaving vehicle is 0; 0=otherwise)</td>
<td>0.57</td>
<td>0.20</td>
<td>0.01</td>
</tr>
<tr>
<td>Weaving influence length ($L_{max}$) (meter)*</td>
<td>0.069</td>
<td>0.023</td>
<td>0.00</td>
</tr>
<tr>
<td>Wet pavement condition (1=wet; 0=dry)</td>
<td>1.22</td>
<td>0.24</td>
<td>0.00</td>
</tr>
<tr>
<td>Training ROC</td>
<td></td>
<td>0.716</td>
<td></td>
</tr>
<tr>
<td>Validation ROC</td>
<td></td>
<td>0.704</td>
<td></td>
</tr>
</tbody>
</table>

*L_{max}=(5728(1+VR)^{1.6}-1566N_{WL})/3.28*, VR is weaving ratio and $N_{WL}$ is weaving lanes

Overall, the results in Table 2 showed that the new RM strategies, which were proposed by this study, were able to better improve the safety of the studied congested weaving segment than the traditional ALINEA model. It indicates that considering the traffic safety in RM algorithm indeed improve the RM performance from the safety aspect. The proposed ALINEA RM algorithms without queue control, which took both lane occupancy and segment traffic safety into consideration, outperformed the traditional ALINEA algorithm from a safety perspective, but it largely increased the average travel time. The proposed ALINEA RM with queue control, which added queue control to increase the green phase for on-ramp vehicles when the queue length was long, largely decreased the average travel time but did not improve the safety as much as the proposed ALINEA. The results illustrated that the new ALINEA RM strategy with queue control reduced the conflict number by 11.9% and decreased the crash odds by 8.0% without significantly increasing average travel time.
## Table 2: Simulation Results

<table>
<thead>
<tr>
<th>Case</th>
<th>Weaving segment</th>
<th>Non-weaving segment</th>
<th>Whole</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conflict</td>
<td>Conflict change %</td>
<td>Crash odds</td>
</tr>
<tr>
<td>No-RM</td>
<td>705</td>
<td>NA*</td>
<td>1.00</td>
</tr>
<tr>
<td>Traditional ALINEA</td>
<td>653</td>
<td>-7.3</td>
<td>1.01</td>
</tr>
<tr>
<td>New ALINEA without queue control</td>
<td>555</td>
<td>-21.2</td>
<td>0.95</td>
</tr>
<tr>
<td>New ALINEA with queue control</td>
<td>621</td>
<td>-11.9</td>
<td>0.92</td>
</tr>
</tbody>
</table>

*# Average Travel Time in second

* NA: Not Applicable

## 4. CONCLUSION

In order to improve the safety of congested weaving segments, RM was installed at the end of on-ramps. Both crash odds and conflict frequency were used to measure the safety impacts of RM. The results showed that the new ALINEA RM strategies, which took both traffic operation and safety into consideration, significantly improved the safety of the congested weaving segment. However, the average travel time of the new ALINEA without queue controlling was significantly higher than the non-RM case and also higher than the traditional ALINEA case. In order to improve the traffic efficiency, queue control was added to the modified ALINEA. The results showed that it shortened the average travel time and still improved the safety of the congested weaving segment. Hence, overall, the new ALINEA with queue control was recommended.

## REFERENCES


