Exploratory Data Project: Freight Resiliency Performance Measures

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16. Abstract

Exploratory Data Project: Freight Resiliency Performance Measures. (2009-10) FHWA's Office of Freight Management and Operations, through a partnership with the American Transportation Research Institute (ATRI), established a Freight Performance Measurement Program (FPM) to assess the performance of freight significant highways and US international land border crossings. The end-goal of this program is to utilize these data and information to identify areas of significant freight congestion and bottlenecks and guide decision-making on future transportation improvement.

This project explored the use of FPM data for quantifying the robustness and responsiveness measures for resiliency. FPM date before, during, and after two major weather events was used to plot the resiliency of highway segments along the I-90/94 Corridor from Hudson to Beloit, Wisconsin. Results include recommendations for evaluating freight transportation resiliency.

17. Key Words

Freight, performance measures, Mississippi Valley, bottlenecks, resiliency

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Overview of Resiliency and Resiliency Measures

Resiliency measures are used to understand vulnerabilities in transportation networks. Resiliency is the capacity of a service to absorb the impacts of a disruption, and the ability to recover or adjust from a sudden change. Resiliency measures may be used to guide infrastructure investments that protect against disruptions and accelerate recovery after a disaster.

In this study, the researchers used data from the American Truck Research Institute (ATRI), collected through the Freight Performance Measurement Initiative, a partnership between the Federal Highway Administration (FHWA) and ATRI, to illustrate measures for freight transportation resiliency of an interstate corridor. The availability of travel speeds and relative truck counts prior to, during, and after two significant weather events enabled the researchers to compute and illustrate two resiliency performance measures: robustness and rapidity. The concept of a resiliency triangle, which helps to visualize the magnitude of the impact of a disruption on the infrastructure, was used to evaluate these performance measures.

The resiliency triangle, a concept that emerged from disaster research, is shown in Figure 1. At t_0 the system experiences a sudden loss of function from damage and disruption. The system slowly returns to the pre-disaster performance level. Full recovery occurs at t_1. The depth of the triangle shows the severity of damage; the duration of the recovery period is t_1–t_0.

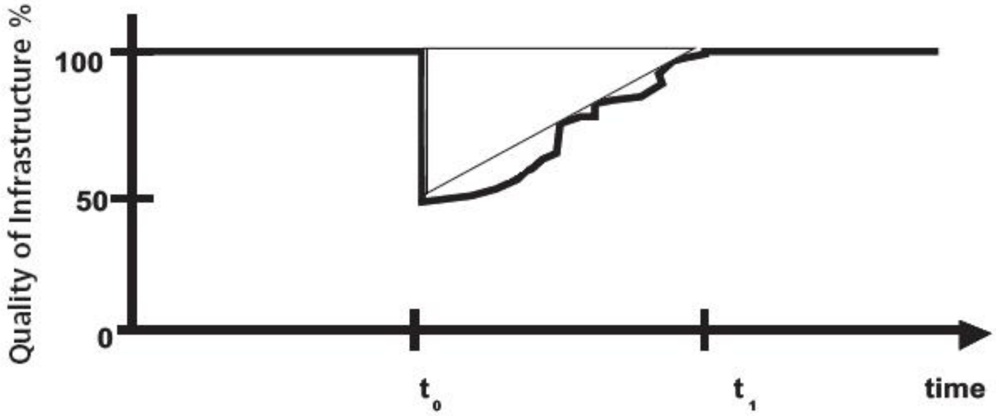


Figure 1: Conceptualized resiliency triangle from disaster research

The resiliency triangles derived using the ATRI geospatial truck location data differ from the concept shown in Figure 1. Rather than a sudden abrupt loss of function, the impact of significant weather events was more gradual, as conceptualized in Figure 2.

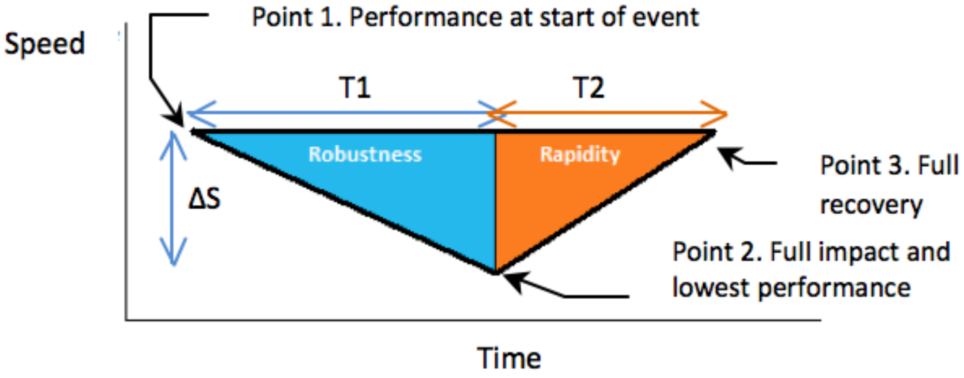


Figure 2: Conceptualized resiliency triangle observed during significant weather events

The shape and areas of the resiliency triangle provide information about two of the four resiliency measures. *Robustness* is the ability of the highway system network and system elements to withstand disaster forces without significant degradation or loss of performance. *Rapidity* is the capacity to restore functionality in a timely way by containing losses and avoiding disruptions. Two other measures, *redundancy* and *resourcefulness*, deal with the infrastructure network and policy. These measures could not be represented with the data set provided by ATRI and therefore could not be quantified in this study. Additional research would be needed to quantify these other two measures.

The Test Corridor

The researchers used truck count and speed data along the I-90/94 corridor from Hudson to Beloit in Wisconsin. The corridor runs along Interstate 94 from Hudson to Tomah, Wisconsin and continues along Interstate 90 to Beloit.

The Hudson to Beloit Corridor was segmented using the 59 intersections as limits to define 58 segments along the corridor (Figure 3). The segment numbering started in Hudson and increased to the east. Segment 58 is adjacent to the Wisconsin-Illinois border near Beloit.

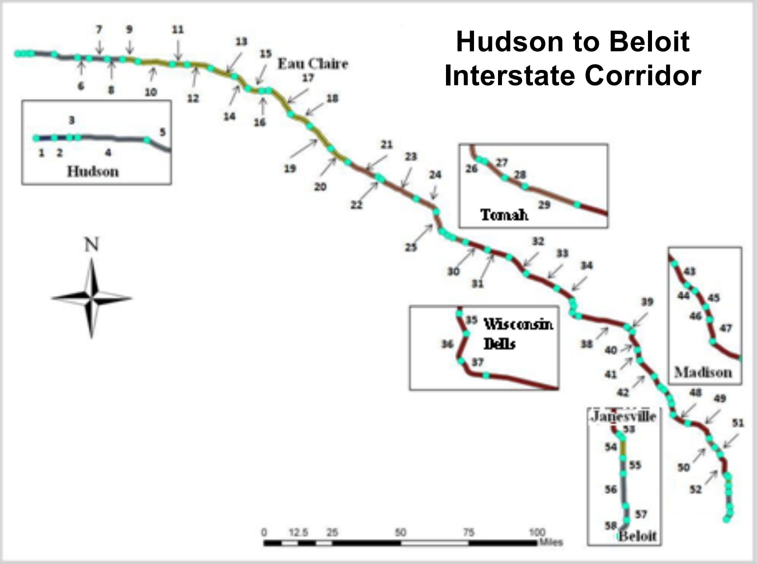


Figure 3: Hudson to Beloit Interstate Corridor shown with numbered segments and major cities

The corridor is the critical backbone for freight and passenger mobility and accessibility in Wisconsin. The corridor also supports significant pass-through freight and passenger travel between Chicago and Minneapolis and beyond. Using ATRI data, researchers were able to analyze resiliency by tracing truck entries and exits along the corridor and travel speed through the corridor.

During 2008, two major weather events caused road closures and significant delays on the corridor. These severe weather events demonstrated how fragile some sections of the corridor could be. The analysis particularly focused on four sections of the corridor listed in Table 1.

Table 1: Study sections along the Hudson to Beloit Interstate Corridor

Section	Segments	Length
Hudson to Eau Claire	1 to 13	58.2 miles
Mauston to Portage	33 to 39	39.1 miles
Portage to Madison	40 to 43	22.0 miles
Janesville to Beloit	54 to 58	16.0 miles

The Hudson to Eau Claire section was least affected by the weather events. The Janesville to Beloit section was directly affected by the snow event in February 2008, particularly in the westbound direction. The eastbound Mauston to Portage section was closed due to flooding during the June 2008 event. The June 2008 floods also heavily affected the Portage to Madison segment.

Resiliency of the Corridor

February 2008 Blizzard

On February 6, 2008, a severe winter storm hit Wisconsin, leaving more than 13 inches of snow and ice. Difficult travel conditions caused two tractor-trailers to lose traction and block westbound traffic along the corridor in Southwest Wisconsin. As the weather conditions deteriorated, some travelers experienced standstill conditions for more than 8 hours. To evaluate the impact on travel conditions before, during, and after the event, we analyzed truck counts and speed data for February 5–7, 2008.

Figures 4–7 show truck counts and the speed resiliency triangles for the February 2008 snow event on the Beloit to Janesville and the Portage to Mauston sections of the corridor, respectively. The figures show hourly average truck counts and speed in both directions on the days before, during, and after the event. At this scale of resolution, there is little evidence of a significant change in truck counts on the day of the event (February 6) compared to the previous day (February 5). Figure 4 shows evidence of the standstill conditions—a constant truck count of about 300—that occurred in the westbound direction starting at approximately 5pm on February 6 and continuing through the night. On the day after the event (February 7), there was a significant increase in the truck count. One possible explanation is that drivers of stranded vehicles exited to refuel and refresh and then re-entered the corridor. Figure 5 shows a significant decrease in truck counts for the same period on the downstream, westbound Mauston to Portage section. One reason for the drop in truck traffic on the Mauston to Portage section is that those trucks were otherwise stranded on the Janesville to Beloit section. Figure 5 also shows a significant increase in westbound truck counts on the day after the event. Again many trucks may be double counted because they exited to refuel and refresh, and then re-entered the corridor.

Figures 6 and 7 show the speed resiliency triangles for the February 2008 snow event on two sections of the corridor, Janesville to Beloit and Mauston to Portage, respectively. For the Janesville to Beloit section, the travel speed was severely affected in both directions—most notably in the westbound direction, where the average speed dropped to 15 mph. The average deceleration rate is the downward slope of the resiliency triangle and a measure of robustness. For this analysis, we assumed a normal average truck speed of 46 mph in the westbound direction and 49 mph in the eastbound direction. During the 27-hour snow event from 12:00 am on February 5 to 3:00 am on February 7, the westbound direction suffered a 31 mph speed loss (46-15=31), which is equivalent to an average deceleration rate of 1.15 mph/hour. In the eastbound direction, the travel speed dropped by approximately 18 mph (49-31=18). Over the course of the 27-hour storm, the average deceleration rate in the eastbound direction was 0.667 mph/hour.

Even with this difference in deceleration rates for the east- and westbound directions on the Janesville to Beloit section, we cannot automatically conclude that the eastbound roadway is more robust than the westbound unless they both experienced the same event. Both directions experienced heavy snow and high winds but the westbound traffic was brought to a standstill because of disabled vehicles. The vertical alignment of the westbound highway requires vehicles to ascend a grade change while vehicles on the eastbound lanes are required to descend the grade change. Since the response in the east- and westbound directions is due to differences in the physical infrastructure and not differences in the weather event, we can conclude that the eastbound lanes are more robust in a snowstorm than the westbound lanes.

Similarly, Figure 7 shows the speed resiliency triangles for the east- and westbound directions of the Mauston to Portage section. Both directions experienced the same storm event and similar traffic loads (see Figure 5) but the westbound direction suffered a speed loss of 22 mph over a 39-hour period—equivalent to an average deceleration rate of 0.564 mph/hour. The difference in the robustness between the two directions of this section may be attributed to the alignment or condition of the physical infrastructure.

Table 2 summarizes the resiliency measures for the February 2008 winter storm event. The angles α and β are described in the Summary and Conclusion section of this report.

Table 2: Computed robustness and rapidity resiliency measures for the February 2008 winter storm event

		Avg. speed	Min. speed	ΔS	T1	Robustness (ΔS/T1)		T2	Rapidity (ΔS/T2)	
Corridor Section	**Direction**	**mph**	**mph**	**mph**	**hrs**	**mph/hr**	α	**hrs**	**mph/hr**	β
Mauston to Portage	West	50	28	22	39	0.564	27.2°	20	1.100	47.7°
Janesville to Beloit	East	49	31	18	27	0.667	33.7°	26	0.692	34.7°
	West	46	15	31	27	1.148	48.9°	12	2.583	68.8°

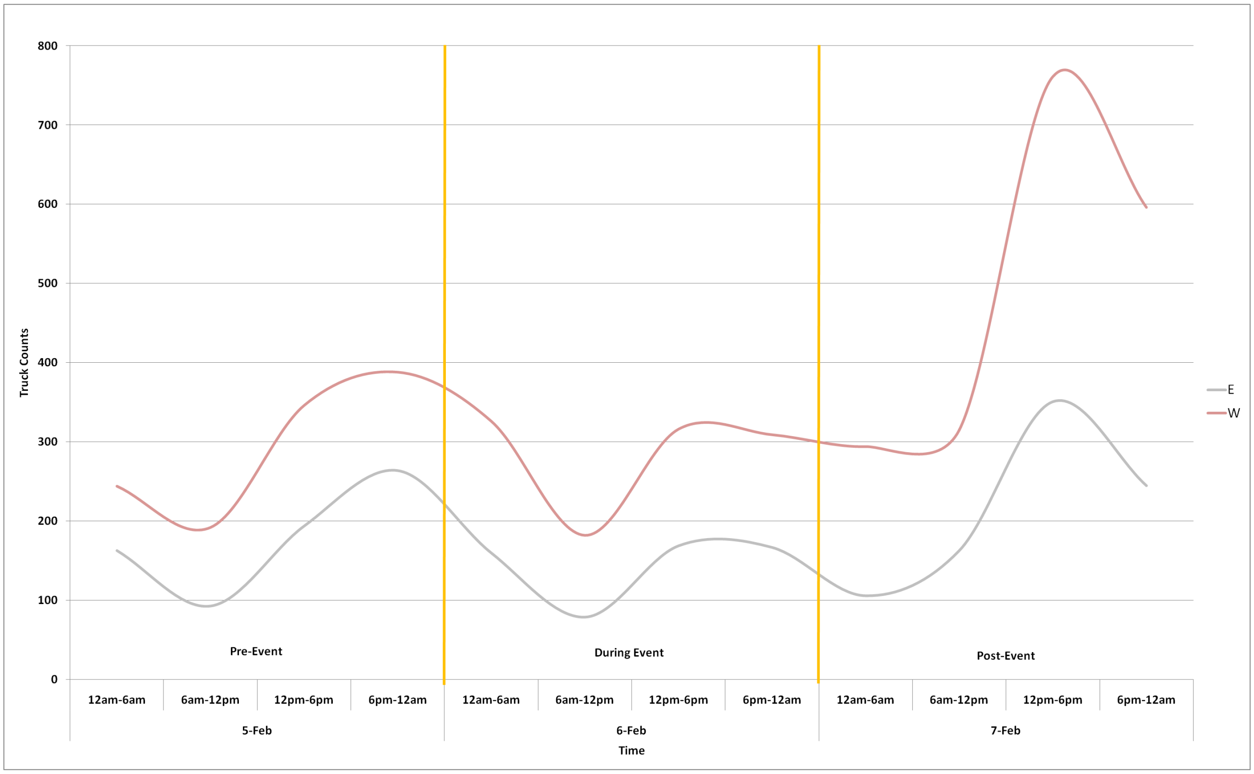


Figure 4: Truck counts on the Janesville to Beloit section affected by the February 2008 snow event

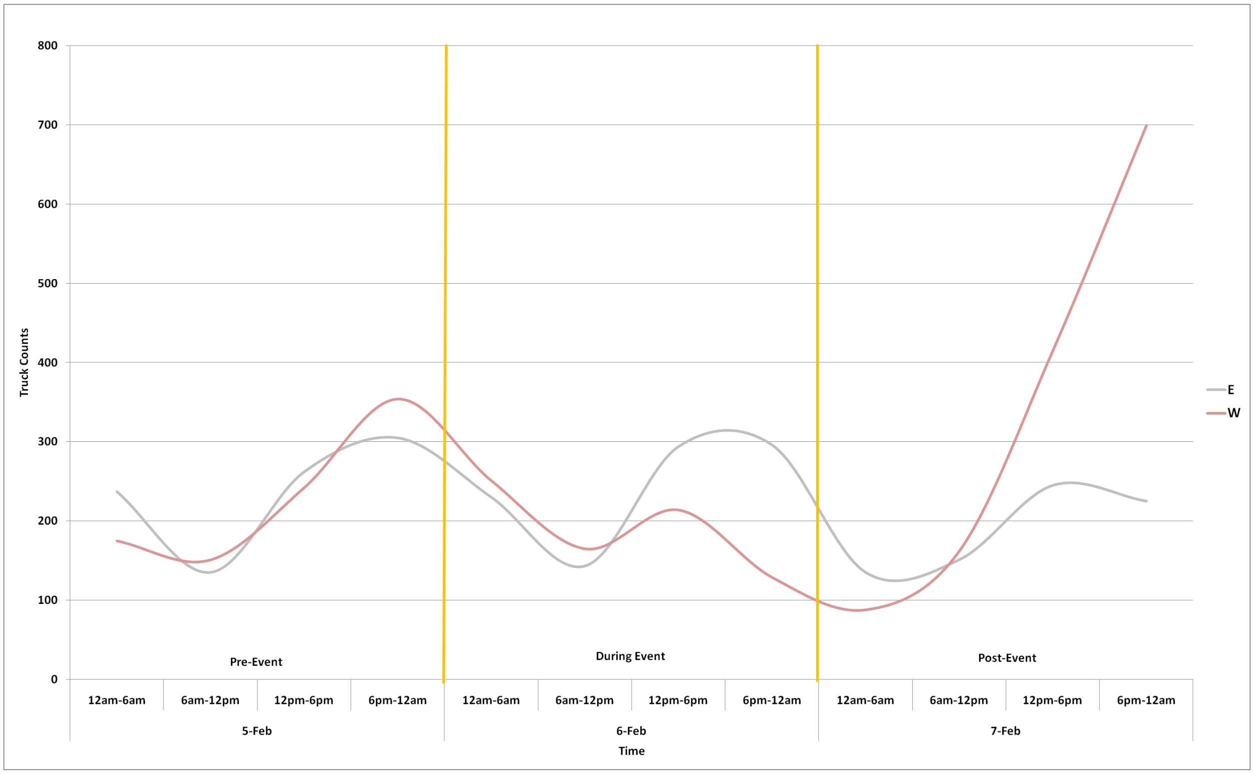


Figure 5: Truck counts on the Mauston to Portage section downstream of the February 2008 snow event

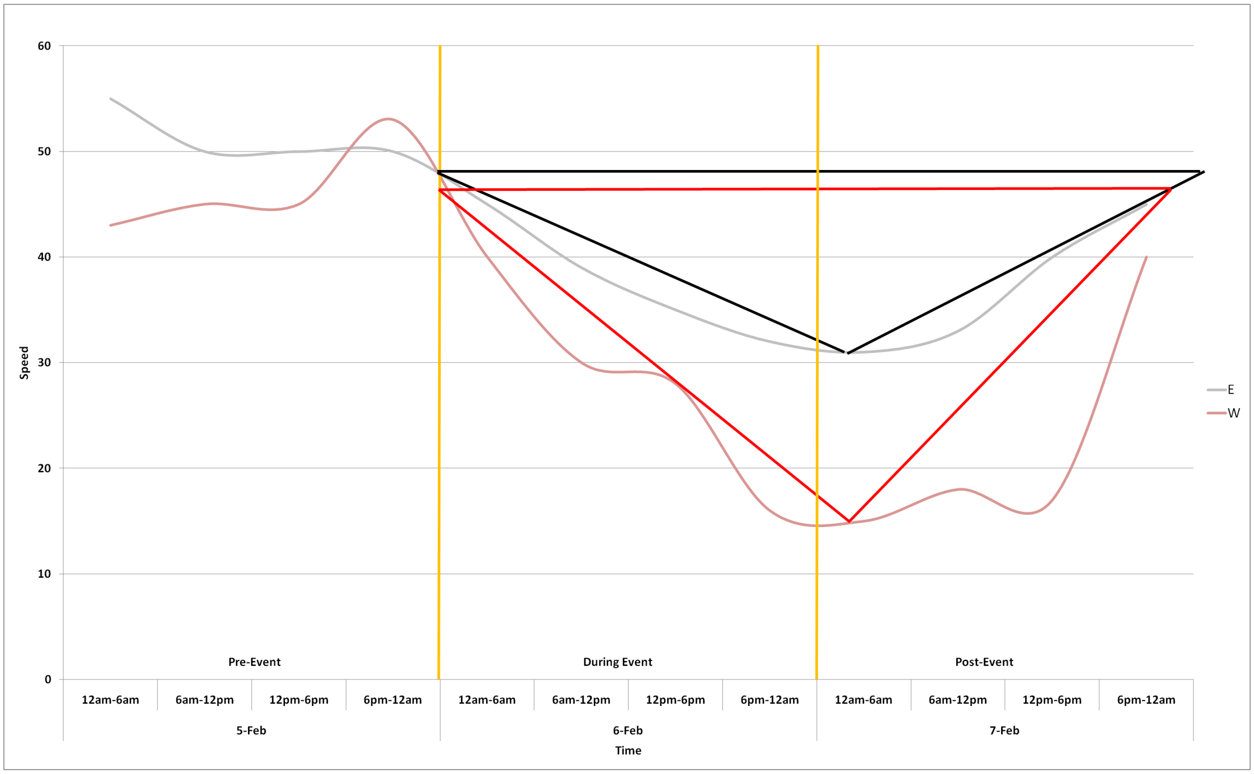


Figure 6: Speed resiliency on the Janesville to Beloit section affected by the February 2008 snow event

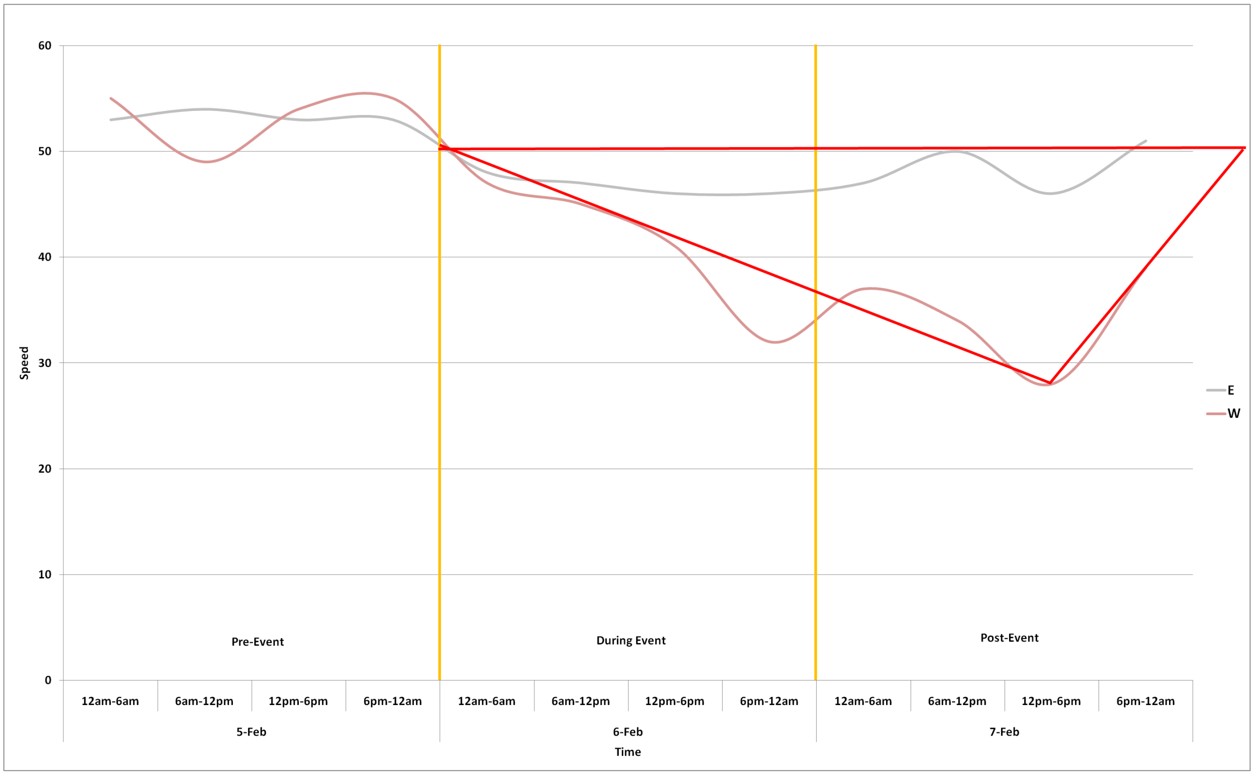


Figure 7: Speed resiliency on the Mauston to Portage section downstream of the February 2008 snow event.

June 2008 Flooding

In June of 2008, Wisconsin and other Midwest states experienced an unprecedented amount of rainfall. A series of storms during the period of June 5–12 caused widespread flooding that resulted in damage to thousands of homes, business, and roads. On June 9, heavy rain in Wisconsin Dells led to failure of the Lake Delton dam. Rushing water eroded a section of County Highway A, washed away three homes, and tore apart several others. Many local precipitation records were broken; some parts of Wisconsin received up to 17 inches of rain. The Governor declared a state of emergency on June 9.

Data for June 1–16, 2008, were used to evaluate the resiliency of the corridor during the heavy rain and flooding. Figures 8–13 show the truck count and speed resiliency triangles for three sections of the corridor during the sixteen days prior, during, and after the June 2008 flood event. The graphs are divided into day intervals per direction.

The truck count graphs generally show the lowest counts on June 1, 8, and 15, which were Sundays. The exceptions occur during times when lanes were closed because of flooding. The Wisconsin Department of Transportation shut down one of the eastbound lanes of the corridor starting at Mauston and closed the section from Portage to Madison at 10 pm on Thursday, June 12. The lanes remained closed until Sunday, June 15. The westbound lanes from Portage to Madison were also closed but re-opened on Saturday, June 14. The effects of the lane closures can be seen in the truck counts on Figures 8 and 10, respectively.

On June 7, at least six confirmed tornadoes touched down in Wisconsin. The truck count graphs show no reduction in truck counts along these sections of the corridor on that day.

The resiliency triangles in Figures 9, 11, and 13 are shown to start on June 12 when the interstate lanes or segments were closed because of the rising water in the area. However for the Janesville to Beloit eastbound section in Figure 13, the resiliency triangle corresponds to the observed speed reduction, which began before June 12. Table 3 summarizes the robustness and rapidity measures derived from the speed resiliency triangles. The angles α and β are described in the Summary and Conclusion section of this report.

Table 3: Computed robustness and rapidity resiliency measures for the June 2008 flooding event

Corridor Section	Direction	Avg. speed June 1-7 mph	Min. speed mph	ΔS mph	T1 hrs	Robustness (ΔS/T1)		T2 hrs	Rapidity (ΔS/T2)	
						mph/hr	α		mph/hr	β
Mauston to Portage	East	52	40	12	27	0.444	24.0°	54	0.222	12.5°
Portage to Madison	East	52	24	28	48	0.583	30.3°	24	1.167	49.4°
	West	53	44	9	48	0.188	10.6°	24	0.375	20.6°
Janesville to Beloit	East	48	38	10	58	0.172	9.8°	60	0.167	9.5°
	West	47	39	8	48	0.167	9.5°	46	0.174	9.9°

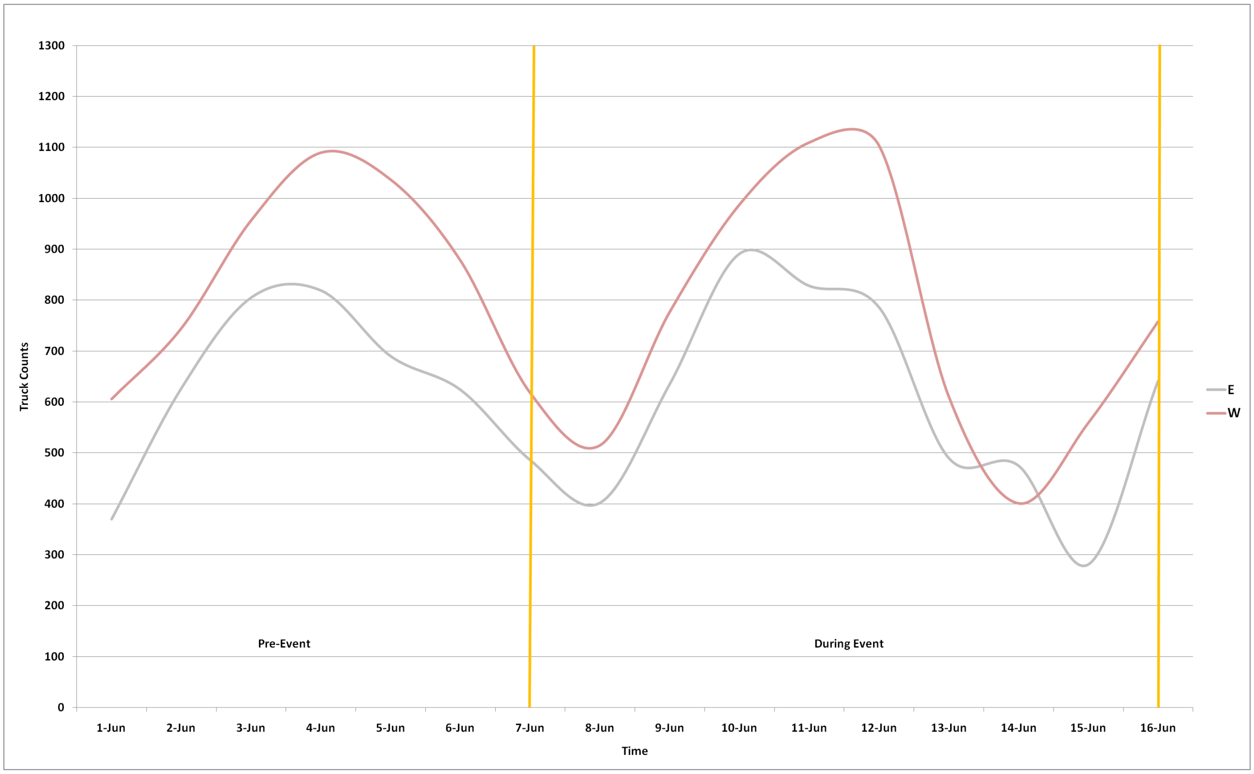


Figure 8: Truck counts on the Mauston to Portage section during June 1–16, 2008

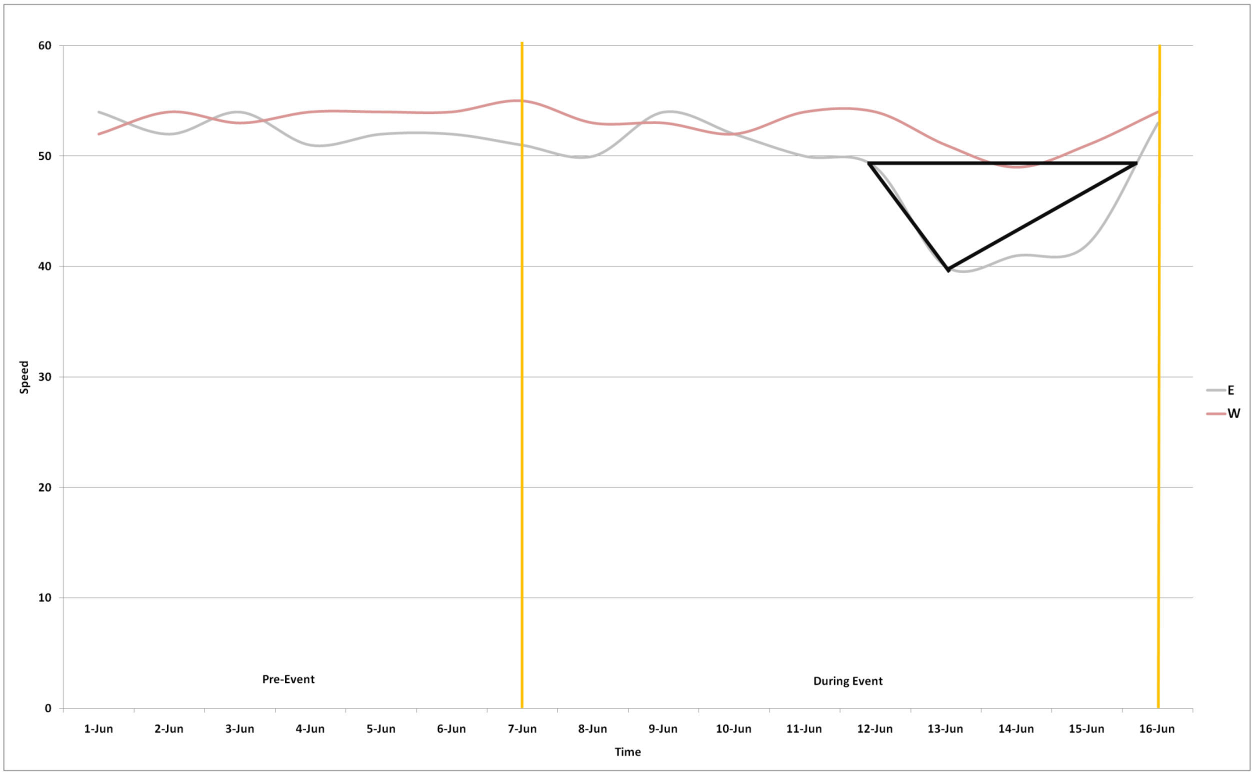


Figure 9: Speed resiliency on the Mauston to Portage section during June 1–16, 2008

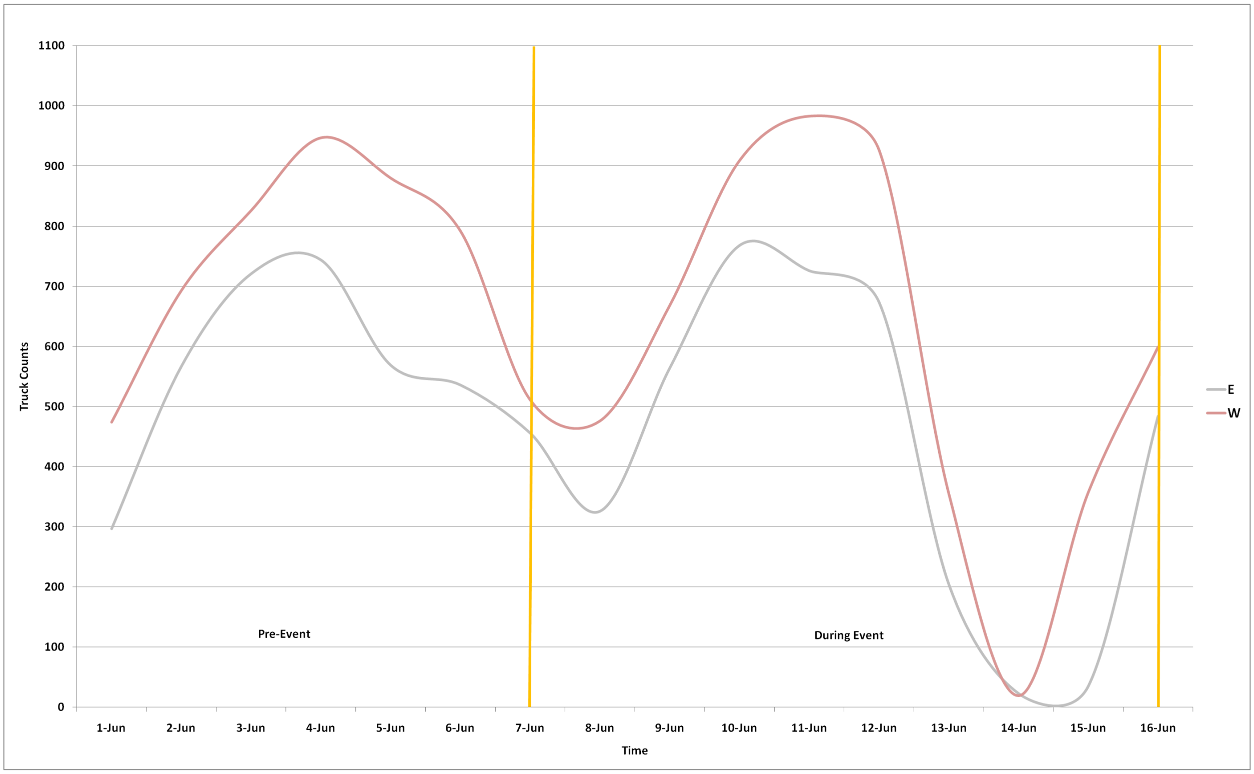


Figure 10: Truck counts on the Portage to Madison section during June 1–16, 2008

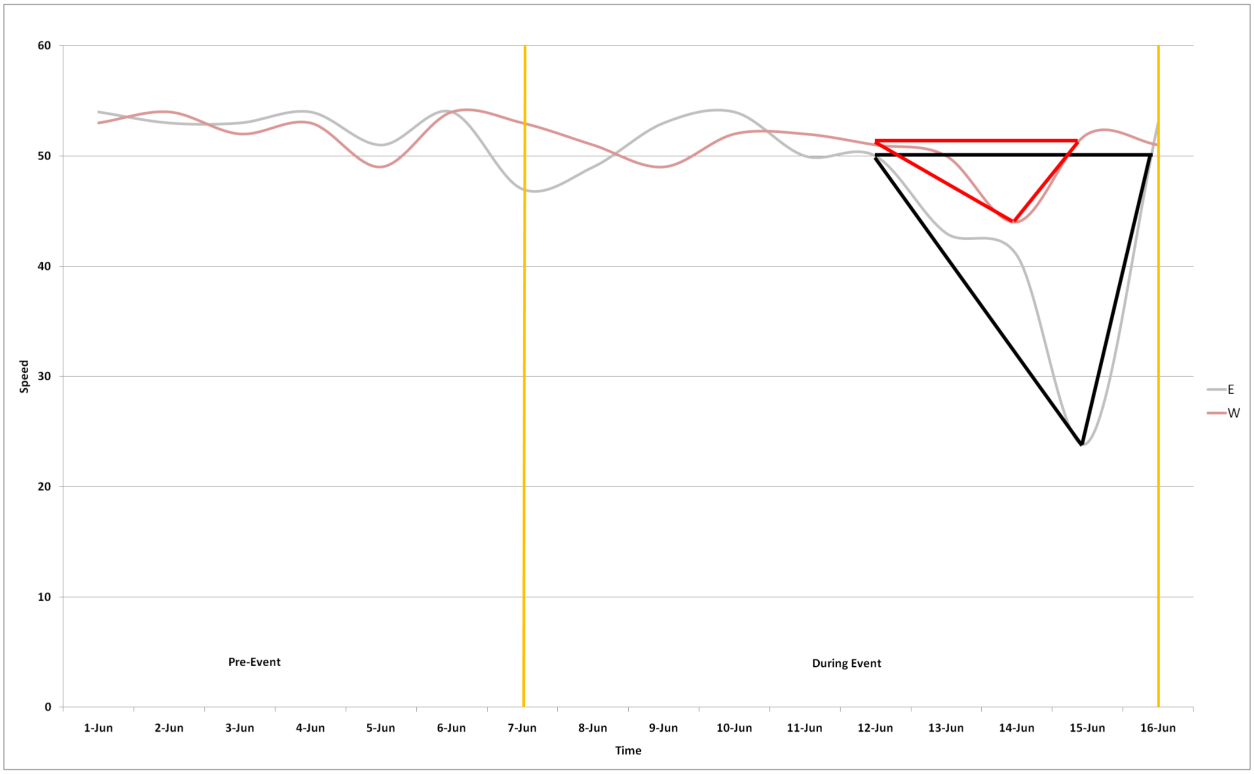


Figure 11: Speed resiliency on the Portage to Madison section during June 1–16, 2008

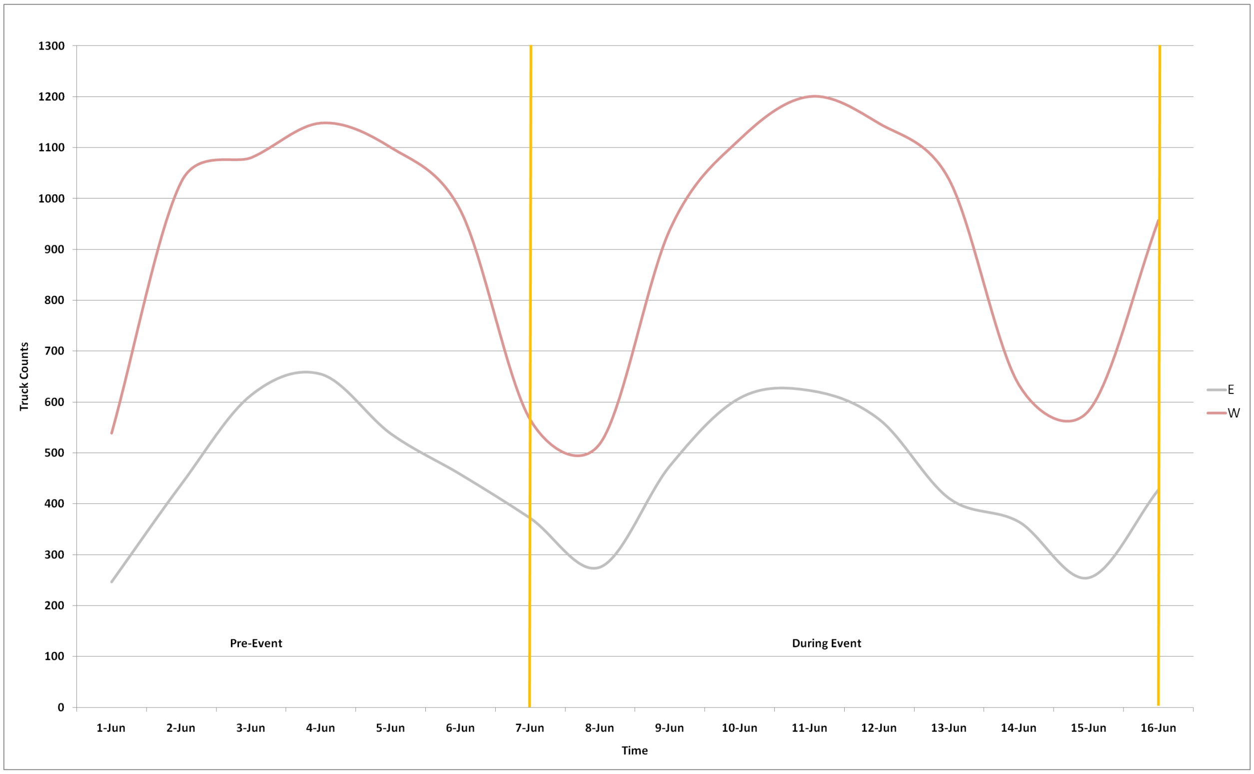


Figure 12: Truck counts on the Janesville to Beloit section during June 1–16, 2008

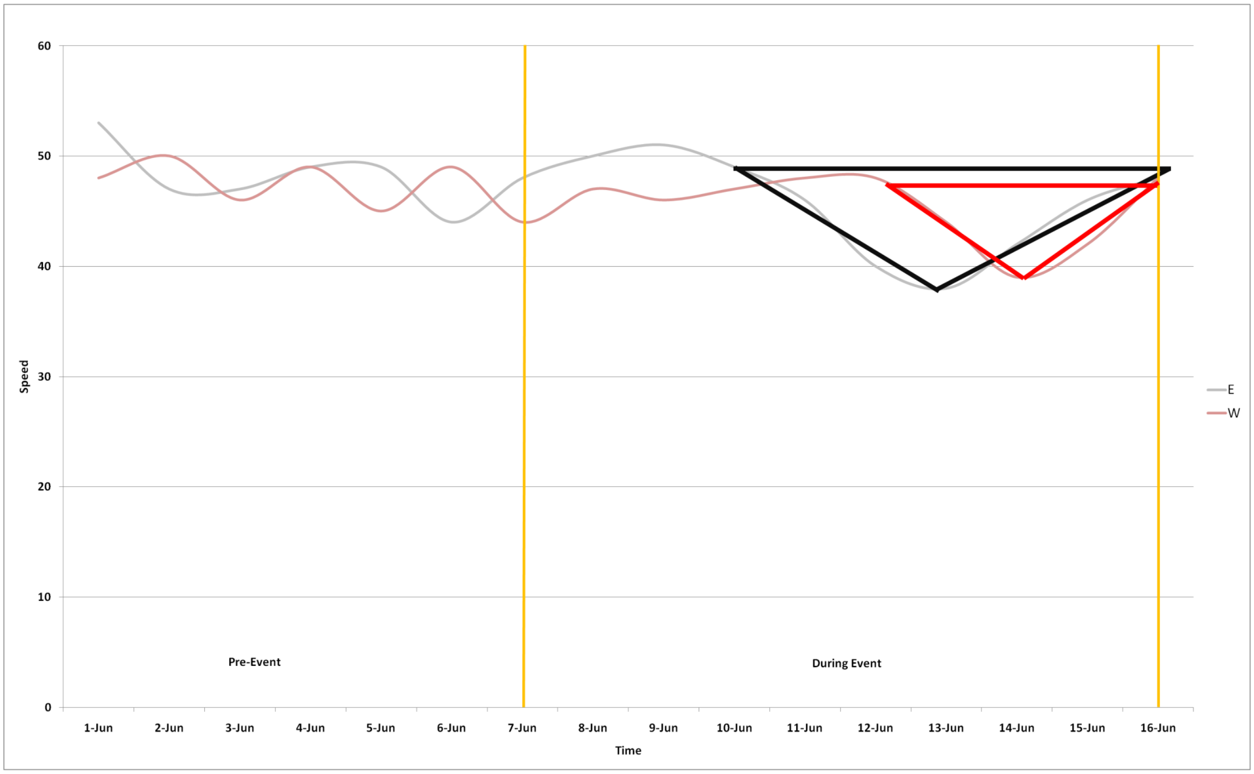


Figure 13: Speed resiliency on the Janesville to Beloit section during June 1–16, 2008

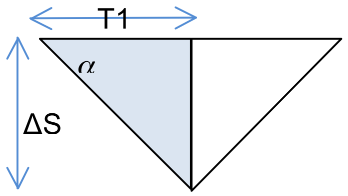
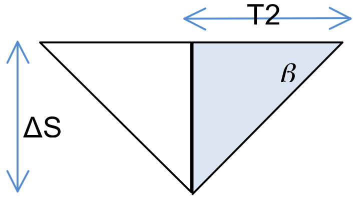
Summary and Conclusion

Current research on this topic does not present ways to numerically quantify the conceptual measures associated with the resiliency triangle. This research used ATRI data to attempt to fill this gap.

This study focused on estimating the resiliency measure using ATRI truck count and speed data for the Hudson to Beloit Interstate Corridor. Of the four resiliency measures—robustness, redundancy, resourcefulness, and rapidity—the first and the last were evaluated since they are related to truck counts and speeds.

The ATRI geospatial data is useful for computing the robustness and redundancy measures of resiliency. We propose a set of criteria to qualify the computed resiliency measures. These criteria reflect to corridor's observed behavior during the disruptive events. Table 4 summarizes the criteria with estimated threshold values. More research will be required to determine criteria for the threshold values.

Table 4: Criteria for Resiliency Measures of Robustness and Rapidity

Criteria	Figure
High Robustness: No loss or gradual minor loss of truck speed (ΔS) over the time period (T1). $\Delta S/T1 \leq 0.20$ mph/hr $\alpha \leq 11.3^{o}$ **Moderate Robustness:** Significant loss in truck speed (ΔS) occurs over a long period of time (T1). 0.20 mph/hr $< \Delta S/T1 < 0.50$ mph/hr $11.3^{o} < \alpha < 26.6^{o}$ **Low Robustness:** Rapid loss in truck speed (ΔS) occurs over a short time period (T1). $\Delta S/T1 \geq 0.50$ mph/hr $\alpha \geq 26.6^{o}$	
High Rapidity: Rapid increase in truck speed (ΔS) occurs over short time period (T2). $\Delta S/T2 \geq 0.50$ mph/hr $\beta \geq 26.6^{o}$ **Moderate Rapidity:** Significant increase in truck speed (ΔS) occurs over a long period of time (T2). 0.20 mph/hr $< \Delta S/T2 < 0.50$ mph/hr $11.3^{o} < \beta < 26.6^{o}$ **Low Rapidity:** Gradual increase in truck speed (ΔS) over a long time period (T2). $\Delta S/T2 \leq 0.20$ mph/hr $\beta \leq 11.3^{o}$	

The first portion of the resiliency triangle represents robustness, from the point where performance starts to deteriorate due to an event to the lowest performance point. If the triangle has a gentle downward slope then the system performance is deteriorating slowly because the system has the robustness to withstand the disaster forces. Conversely, a rapid loss in performance indicates low robustness because the disaster forces the system to deteriorate quickly. For the more robust sections of the Hudson to Beloit interstate corridor, we may posit that alternate routes provided redundancy for those sections. Our analysis did not evaluate use of alternate routes.

The second portion of the resiliency triangle represents rapidity, from the lowest performance point to the point where performance returns to the average pre-event level. If this closure angle has a steep slope, the system recovered quickly. If the slope is gradual, then the system did not recover quickly.

Resiliency triangles were created for truck speed during the February and June 2008 events. The triangle angles indicate the system performance loss, the duration of time until performance deteriorates to the poorest performance, and then the duration of time to recover. By plotting the resiliency triangles and analyzing the system performance during the disruptions we can conclude that the ATRI data is useful for measuring the robustness and rapidity of truck routes. These are important measures for evaluating overall freight route resiliency.

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