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The Framework for Calculating the Measure of Resilience for Intermodal Transportation Systems

ABSTRACT

A literature review indicates no conforming approval on the measure of resilience (MOR) for intermodal

The Framework for Calculating the Measure of Resilience for Intermodal Transportation Systems

INTRODUCTION

System performance in response to unexpected disruptions or transportation resilience has always been a concern. In recent years, especially after the catastrophe of Hurricane Katrina in August 2005, transportation resilience has emerged as a timely issue. Researchers have paid much attention to resilience studies in an individual mode of transportation such as highway, rail, waterway, and air; however, intermodal transportation resilience has not received wide attention from transportation researchers. Therefore, appropriate methodology has not yet been developed for practicable evaluation of intermodal transportation resilience. Furthermore, regarding the lessons learned from Hurricane Katrina, it is necessary to study the long term effects of disasters to local and regional intermodal transportation and measure of resilience to the system.

In the state of Mississippi, the intermodal system was severely damaged by Hurricane Katrina. For example, the U.S. 90 Bridge between Bay St. Louis and Pass Christian was not repaired until more than two years after the storm. The railroad bridge of CSX Corporation in Bay St. Louis was reconstructed in 156 days after Hurricane Katrina. The port of Gulfport took approximately two and a half months to restore its operation to pre-Katrina levels.

The objective of this research is to develop a framework of calculating the measure of resilience (MOR) for intermodal transportation systems. To accomplish the objective, the following four goals will be achieved:

Define measures of resilience of intermodal transportation systems

Recreate the transportation system snapshots before and after Hurricane Katrina

Propose a framework to calculate the projected MORs, and

Perform a case study of MORs in the recovery of Mississippi Gulf Coast after Hurricane Katrina

The results from this research will not only provide a specific evaluation to the entire intermodal transportation resiliency of the Mississippi Gulf Coast but will also help the transportation planning agency identify the most vulnerable part of the intermodal network so that resources can be allocated effectively to mitigate the impact of future disasters. The Gulf Regional Planning Commission (GRPC) and Mississippi Department of Transportation (MDOT) are providing various levels of support for this work.

This report contains a relevant background and literature review about state-of-the-art transportation resilience research. The TransCAD modeling procedure used for this research is explained and the proposed MOR calculation framework is discussed in this report. The computational experience and analysis based on the Mississippi Gulf Coast after Hurricane Katrina is presented followed by a conclusion and recommendations for further study related to the scope of this report.

LITERATURE REVIEW

Transportation System Resilience

Resilience has been studied extensively over years. However, intermodal transportation resilience has been addressed to a limited degree (1). Transportation resilience is an inherent value measured by the performance of the transportation system in response to an unexpected situation. Resilience can be evaluated at the individual, community, design, economic, and strategic planning levels (3). Measure of Resilience is tentatively proposed as the percentage of deduction in intermodal transportation system performance indices.

So far, there is no widely accepted MOR in particular for intermodal transportation systems. Li (4) defined resilience as the ratio of recovered system performance resulting from a certain strategy with respect to the system performance reduction without the strategy. Four strategies were proposed to mitigate the road congestion caused by incidents. Four criteria (network performance, average travel speed, Origin-Destination (OD) travel time, and maximum queue length) were employed to evaluate the effectiveness of resilience and anticipated level of resilience after a disaster. Several key parameters in terms of road accessibility were considered when measuring the resilience gap.

Dalziell et al. (6) established the concept of resilience as the possibility that a system would continue to function at the expected level in the face of a disaster. A Key Perform discussed. Results revealed that the Port of Kobe would suffer a long term loss of market due to the competition among ports.

$$T = \frac{\sum_{i \in O, j \in D} v_{i,j} \cdot t_{i,j}}{\sum_{i \in O, j \in D} v_{i,j} \cdot l_{i,j}} \quad (1)$$

Where:
T = average travel time per mile (*min/mi*),
O = set of origin,
D = set of destination,
i,j = origin and destination,
$v_{i,j}$ = average daily truck volume between origin *i* and destination *j* (*veh*), ,
$t_{i,j}$ = average travel time between origin *i* and destination *j* (*min*), ,
$l_{i,j}$ = link length between origin *i* and destination *j* (*mi*), .

Average truck trip length is defined as,

(2)

Where:
L = average truck trip lengd

Table 1: LOS Criteria for Intermodal Road Network

Criteria	LOS					
	A	B	C	D	E	F

In the study area, the entire intermodal network consists of two components: road network and intermodal terminals. The road network comprises over four thousand highways while the intermodal terminals include seaports, rail stations, and airports. Since the operations between road network and intermodal terminals are different, it is necessary to develop a specific set of indicators to evaluate intermodal terminal performances. Considering the data availability, intermodal terminal LOS has been measured by a number of performance indicators in terms of mobility, reliability, flexibility, security, and accessibility. These measures of criteria shown in Table 2 are from the Ballis (19) proposed set of LOS standards for intermodal terminals.

Table 2: Level of Service Criteria for Intermodal Terminals

	A	B	C	D	E	F
Mobility						

MOR Definition

In this document, the intermodal network resilience is defined as the ratio of the reduction of the intermodal system performance after a disaster with respect to the system performance before a disaster. The proposed methodology for MOR is based on the calculation of the performance indicators.

MOR can be calculated by:

(5)

Where:
t = total time required to restore the capacity (year), and
α = system parameter, used $\alpha = 0.5$ in case study

The parameter α is related with network size, socioeconomic status, government policy, etc. In this piece, α is designated as an average value of 0.5. Specific calibration will be performed in the future to obtain a more accurate value of α. It is important to note that resilience comes with a specific system disruption. The lower value of MOR means the system is more resilient to the disruption.

INTERMODAL OD FLOW ESTIMATION

TransCAD was employed to model the intermodal network and generate data in order to calculate the system's performance. Detailed discussion about data collection and process methods was provided to characteristics in some outlying rural area. Moreover, parts of census TAZs inside the urbanized area boundary were also split in order to achieve a more realistic and accurate distribution of traffic. Therefore, the total 473 census TAZs in the study area have been divided up to 570 TAZs including 16 external stations in the TransCAD model. The TAZs distribution in the study area can be viewed from Figure 1.

Figure 1: TAZs Distribution Map

Since the base year (2002) socioeconomic data is available at TAZ level and the target year (2005 and 2006) socioeconomic data can be obtained at the county level from the US census website, a disaggregation procedure has been applied to estimate the socioeconomic data associated with the TAZs using the county-level data. In this report, because th

CASE STUDY OF GULF COAST INTERMODAL TRANSPORTATION SYSTEM RESILIENCY

In this section, a case study is conducted for the Gulf Coast intermodal network which suffered severe

February 2006 with at least one lane operating (eastbound) and in December 2006 with all lanes opened, minus the bridges.

Other disruptions include the bridge between Bay St. Louis and Pass Christian and the Biloxi-Ocean Springs Bridge. The U.S. 90 Bridge between Bay St. Louis and Pass Christian reopened to two lanes of traffic on May 17, 2007 and four lanes in January, 2008. The Biloxi-Ocean Springs Bridge opened two lanes traffic in November, 2007. There is no estimated opening date for the new bridge (10).

Additionally, I-10 over the Pascagoula River Basin (eastbound) also underwent damage during the height of Katrina. MDOT restored one lane of traffic in each direction of Interstate 10 by using the undamaged westbound span for a distance of three miles. By October 1st 2005, MDOT reopened the bridge and restored four-lane traffic on I-10. Some spans of the Popps Ferry Bridge were damaged by Katrina. The repair work was completed at December 23, 2005.

For the sea ports, the port of Gulfport bore the brunt of the hit to a ruinous degree and lost almost 700,000 square feet of space (27). The port's rail system was destroyed in whole and seven tenths of berths were demolished. The port's capacity was returned by October 2005 and returned to its pre-Katrina level in November 2005 except for frozen cargo exports. The port of Bienville lost the rail service and administrative facilities after Katrina hit but recovered very quickly, resuming operations in December 2005.

For the rail system, the CSX rail line sustained devastation under the storm surge. The company's rail line along the coast was almost closed for the first few months and was then rerouted due to the destruction of the railroad bridge across the Bay of Saint Louis. The truck volume reduced from 37201 carloads per month before Katrina to 26968 carloads per month after Katrina. The Port of Bienville Railroad closed approximately 80% of its 14.5 mile track after Katrina; its connection with CSX was completely destroyed.

For the airports, Gulfport-Biloxi airport reported that the current air cargo building suffered extensive damage during Hurricane Katrina and was in need of substantial repair and renovation. It was expected to move all air cargo activity into a new facility by the end of August 2008. Another airport, Stennis International airport, did not suffered significant damage during Katrina according to a telephone survey.

All the disruptions listed above will be revealed on the TransCAD network. The impacts on the network performance due to reduction of the network capacity will be discussed in the next subsection.

Performance Measure Calculation

Based on the forecasted socioeconomic data for each TAZ, the intermodal OD flow before and after Katrina among TAZs was generated by TransCAD. A total of 135,555 truck trips were generated for year 2005 and 105,213 trips were generated for year 2006. Then, the intermodal OD flow was divided and distributed to the intermodal network using the TransCAD Trip Assignment Module.

In order to present the case study more clearly, four scenarios were defined as follow:

Scenario 1: August, 2005 – Right before Hurricane Katrina occurred,

Scenario 2

Figure 3: Total Average Daily Truck Flow for all Scenarios in Gulf Coast

Highway Network

Performance indicators were calculated regarding network mobility, accessibility, and reliability. Because the truck tonnage data was not available, Truck Miles Traveled (TMT) was used as a basic parameter to

Percentage (%)	-	-	98.26	1.67	0.07	0.00
Minor Arterial	-	-	628	69	3	1
Percentage (%)	-	-	89.59	9.84	0.43	0.14
Principal Arterial	35	400	48	9	36	17
Percentage (%)	6.42	73.39	8.81	1.65	6.61	3.12
Freeway	118	113	53	11	2	6
Percentage (%)	38.94	37.29	17.49	3.63	0.66	1.98
Scenario 2	A	B	C	D	E	F
Local Street and Unclassified Road	1010	69	0	0	0	0
Percentage (%)	93.61	6.39	0.00	0.00	0.00	0.00
Collector	-	-	1382	48	0	5
Percentage (%)	-	-	96.31	3.34	0.00	0.35
Minor Arterial	-	-	604	74	12	10
Percentage (%)	-	-	86.29	10.57	1.71	1.43
Principal Arterial	26	346	49	2	5	117
Percentage (%)	4.77	63.49	8.99	0.37	0.92	21.47
Freeway	101	91	52	30	8	21
Percentage (%)	33.33	30.03	17.16	9.90	2.64	6.93
Scenario 3	A	B	C	D	E	F
Local Street and Unclassified Road	1064	15	0	0	0	0
Percentage (%)	98.61	1.39	0.00	0.00	0.00	0.00
Collector	-	-	1389	41	4	1
Percentage (%)	-	-	96.79	2.86	0.28	0.07
Minor Arterial	-	-	603	86	7	4
Percentage (%)	-	-	86.14	12.29	1.00	0.57
Principal Arterial	32	349	74	9	38	43
Percentage (%)	5.87	64.04	13.58	1.65	6.97	7.89
Freeway	101	104	46	31	9	12
Percentage (%)	33.33	34.32	15.18	10.23	2.97	3.96
Scenario 4	A	B	C	D	E	F
Local Street and Unclassified Road	1071	8	0	0	0	0
Percentage (%)	99.26	0.74	0.00	0.00	0.00	0.00
Collector	-	-	1400	34	1	0
Percentage (%)	-	-	97.56	2.37	0.07	0.00
Minor Arterial	-	-	632	63	2	3
Percentage (%)	-	-	90.29	9.00	0.29	0.43
Principal Arterial	33	382	74	4	36	16
Percentage (%)	6.06	70.09	13.58	0.73	6.61	2.94
Freeway	101	105	46	25	7	19
Percentage (%)	33.33	34.65	15.18	8.25	2.31	6.27

Intermodal Terminals

In this study, interviews were conducted with the Deputy Director of Trade Development at the Port of Gulfport, CSX Railroad Company, and GRPC to gather information with regard to the freight transportation statistics before and after Hurricane Katrina. The results are summarized in the Table 7.

Table 7: Intermodal Terminals Level of Service

Port of Gulfport LOS Survey - Before Katrina						
	A	B	C	D	E	F
Average waiting time of users (min)	UP to 19	20 – 30	31 – 40	41 – 60	61 – 120	> 120
Incidents of delay in departure (%)	UP to 2%	(3 – 5)%	(6 – 15)%	(16 – 30)%	(31 – 60)%	> 60%
Duration of delay in departure (min)	UP to 30	31 – 45	46 – 60	61 – 90	91 – 180	> 180

Table 8: MOR Calculation

	Scenario 1	Scenario 2	MOR
Mobility			
Average Travel Time per Mile (min)	2.129	2.275	18.7%
Mobility Performance Index	0.727	0.693	12.8%
Accessibility			
Percentage of Open Highway (%)	100.0%	91.12%	24.3%
Percentage of Truck Traveled under 85 Percentile of Limited Speed (%)	33.08%	38.76%	46.9%
Reliability			
Average Delay Per Truck Trip (hour)	0.150	0.166	29.1%

In this report, the MOR calculation for intermodal terminals was not provided for lack of information. That MOR calculation will proceed in the consecutive research.

Analysis of Case Study

In this report, the calculated system-wide resilience is corresponding to a specified disaster. With this lack of information, the level of intensity of the disaster was not accounted for in the MOR calculation; therefore, one cannot expect that the intermodal system will perform with the same resilience in another disaster. In the future, factors related to the level of intensity of the disaster should be considered in the framework. Another perspective of future activity is to

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