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Assessing Economic Impact of Disaster-Induced Transportation Disruptions Using A University Community Partnership Framework

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ASSESSING ECONOMIC IMPACT OF DISASTER-INDUCED TRANSPORTATION DISRUPTIONS USING A UNIVERSITY-COMMUNITY PARTNERSHIP FRAMEWORK

Final Report

NITC-RR-1405

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16. Abstract

Transportation systems play a critical role in maintaining supply chains for effective post-disaster recovery. Modeling the potential economic impact of transportation-related disruptions, therefore, is an important step to promoting pre-event communitywide recovery and resilience planning. But existing supply chain and economic impact models are cost prohibitive and overly sophisticated for use by public sector entities with limited resources. There is also limited understanding of how small and medium enterprises (SMEs) adjust to post-disaster transportation disruption and how this experience influences their future preparedness for similar events. This project had two objectives: (1) to analyze the economic impact due to transportation disruptions in earthquake country using a collaborative university-community partnership framework; and (2) to examine business-level preparedness to such managing such disruptions. In the first phase, the project used the scenario of an M7.0 earthquake in Utah's Wasatch Front and brought together a common set of public sector actors (namely, emergency management departments, metropolitan planning organizations, port authorities, and university research centers) and tools they already use (namely, HAZUS, travel demand modeling and REMI+) to help assess the potential impact of catastrophic earthquakes on the regional economy.

The study estimates a potential economic loss of $6 billion due to interruption of intermediate goods supply in the Wasatch Front. The second phase surveyed 130 Salt Lake City businesses within top 10 worst-affected industrial sectors identified in Phase 1 to understand how they are currently navigating supply disruptions due to COVID-19 and their future earthquake preparedness. The survey found that businesses reported significant impact to supply chain management and production cost due to the disasters. Businesses took a range of actions to manage these disruptions including adjusting capital expenditures and diversifying suppliers within and outside the city. While the disaster experience had raised awareness and confidence in preparation for the future, businesses reported taking few concrete actions in terms of mitigation and preparedness. The study highlights the need for high hazard risk communities to identify at-risk industrial sectors and do targeted disaster management outreach and awareness raising in these sectors.

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EXECUTIVE SUMMARY

Utah's Wasatch Front currently faces a 43% chance of experiencing a (magnitude) M6.75+ earthquake within the next 50 years. It is also one of the fastest growing regions in the country, which implies that an earthquake in the region could have a devastating effect on not only the regional economy, but also that of the state and the nation. While there have been recent efforts to estimate the potential impact of a catastrophic event on the region, these efforts have focused on direct losses from the disaster (such as extent of road damage). What is still required is an understanding of the indirect losses that may result from these direct impacts (such as economic loss due to road damage). Particularly missing are analytical techniques that can help public-sector organizations better understand the cascading effects of infrastructure loss on supply chains within their region. Existing supply chain analysis techniques commonly use complex stochastic models that are not easily accessible to planners and policymakers and are usually not directed at their use. What is needed are low-cost analytical techniques that can help public-sector organizations to assess the potential indirect losses emanating from damage to physical infrastructure, and that can help prioritize action in the face of limited resources.

Current literature on supply management also falls short on understanding and explaining behaviors of small businesses in response to supply chain disruptions. Small businesses are highly vulnerable to impact from disasters, but are also likely to be slowest to adopt mitigation and preparedness measures. There is a need for research that examines how small businesses prepare for and respond to disasters, and how they currently manage supply chain disruptions. Knowledge on both these issues, namely, the extent of economic impact on industrial sectors and the extent of disaster preparedness and resilience within these sectors, are likely to help Utah officials make better decisions about resilience-focused investments. The low-cost and replicable methodologies developed here also provide a framework for other at-risk communities to assess their own risk and make their own resilience investment decisions.

To this end, this study uses a collaborative university-community partnership model to answer these two questions: (i) what would be the local economic impact of transportation disruptions due to a potential earthquake in the Wasatch Front? and (ii) what actions were taken by local businesses to manage these economic impacts and how has it affected their preparedness for future earthquakes? The study framework prioritizes use of common public-sector organizations (namely, emergency management agencies, metropolitan planning organizations, local universities, and Associations of Business and Economic Research or AUBER organizations) and easily available data and software (namely, Hazus, Travel Demand Models & REMI PI+) to ensure that similar analysis can be done in high- as well as low-resource communities.

The first phase of this study combines disaster impact data on the roadways of the Wasatch Front with travel demand modeling to first estimate truck travel time delays, and then the annualized cost of this delay to various industries. The study estimates that disruptions to the road system in the event of an M7.0 earthquake in the Wasatch Front would likely result in approximately $6 billion damage to the economy through the loss of

production. The study also estimates that 10 out of the 20 NAICS industrial sectors will experience more than $100 million in damage individually, and that this accounts for over 70% of the regional economy. Four of the five industrial sectors with the largest share of the Wasatch Front economy also feature in the sectors of highest disaster impact. These findings paint a dire picture of indirect impact due to road system disruptions on the regional economy, if not the national.

These findings also raise questions about the state of disaster preparedness in the high-impact sectors, and whether the recent experiences with the 2020 March earthquake and pandemic have built disaster resilience capacity of local businesses. The second phase of the study used survey methods to record business recovery actions after the March 2020 disasters, with special focus on supply and production issues and institutional learning for the future. The survey found that businesses were most challenged by production issues after the disaster events and that they undertook multiple actions, including diversifying suppliers to within and outside the city, to manage supply disruptions. Importantly, the disaster experience, while increasing risk awareness among businesses, had not translated into concrete preparedness or mitigation actions. This points to broader structural issues that may pose as a barrier to adoption of resilience business practices within the Utah economy.

Based on the findings of this research, the study suggests the following actions as key to building future local economic resilience along the Wasatch Front:

- Increasing pre-disaster investment in resilient transportation infrastructure to reduce the cost of eventual recovery.
- Improving business resilience practices for high-impact industrial sectors through education and outreach.
- Identifying structural barriers to adoption of resilient business and promoting mitigation through recovery.
- Mainstreaming disaster resilience into economic development by breaking the siloed approach to emergency management and economic development.

1.0 BACKGROUND AND STUDY OBJECTIVES

In 2015, an earthquake scenario report developed for the Utah Seismic Safety Commission estimated that the Wasatch Front currently faces a 43% chance of experiencing a magnitude (M)6.75+ earthquake within the next 50 years. The report also indicted that the Salt Lake City segment of the Wasatch Fault is overdue for a “Big One” (an M7.0 event) which last occurred 1,400 years ago. An M7.0 earthquake can produce double the ground shaking produced by an M6.75 event, which significantly increases risk to the region.

The 2015 Scenario Report models the potential impact of such an M7.0 earthquake event in the Salt Lake City segment of the Wasatch Fault. The report estimates that the Wasatch Front will likely experience a short-term economic loss of $33 billion, including $24.9 billion in direct buildings-related (capital) loss, $6.9 billion in income loss, and $1.4 billion in lifeline-related loss which includes transportation facilities. With regards to highways, railway tracks, road and rail bridges, and the Salt Lake City International Airport—essential to the region’s supply chains and economic resilience—the report points out that damage and disruption will be inevitable despite good building practices. This is due to both natural reasons (lateral ground movement and failures of embankments) as well as the need for careful inspections of each such facility before it can be reopened to the public.

The recent March 2020 M5.7 Magna earthquake event (which occurred in the same region) illustrated this point very well—the airport and multiple highway bridges had to be closed for many hours owing to inspections and repairs. Such transportation disruptions have significant consequences for Utah’s economy, but also nationally. A 2020 report prepared for the Wasatch Front Regional Council states that Utah’s transportation system carried $279.2 billion worth of goods by all modes combined in 2017 alone. With the new Inland Port being established in the northwest quadrant of Salt Lake City, one can expect this number to only grow in the coming years.

The impact of transportation loss, both short- and long-term, could be devastating for an economy so concentrated in one place and so heavily dependent on our transportation network. Of particular concern is the impact on small businesses which, according to the U.S. Small Business Administration, made up around 99% of all businesses in Utah in 2018. Of concern are also minority-owned small businesses which are growing rapidly in the Wasatch Front (Todd & Voight, 2016), but which are also particularly vulnerable to disaster impact. The ability of these businesses to prepare for and respond to supply chain disruptions has direct and significant consequences for the economy of the Wasatch Front and the state as a whole.

The ongoing Coronavirus pandemic and the 2020 M5.7 Magna earthquake provide an opportunity to study some of these dynamics in real time. While the pandemic did not result in transportation loss per se, it has disrupted supply chains around the country and studying small business response to it can provide critical insights into potential post-earthquake responses, and through that, inform pre-earthquake disaster resilience planning for the region. To this end, this study asks two interrelated questions:

i. What would be the local economic impact of transportation disruptions due to a potential earthquake in the Wasatch Front?

ii. What actions were taken by local businesses to manage these economic impacts and how has it affected their preparedness for future earthquakes?

Apart from creating more generalizable knowledge on disaster resilience of small businesses, this study also develops a collaborative and affordable analytical framework for planners and policymakers in high hazard-risk areas to use to make data-driven decisions on transportation and economic resilience planning.

The study methodology consists of two phases. Phase I aims to measure the local economic impact of disaster-induced transportation disruptions (Q1), while Phase II aims to identify small business response to these types of disruptions (Q2).

1.1 LITERATURE REVIEW

While supply chain disruptions due to natural and other disasters is frequently studied in business administration and transportation planning, much less attention has been given to supply chain disruption as an economic recovery problem with greatest risk to small businesses. Knowledge on these aspects can help planners and policymakers to promote effective and equitable pre-event disaster mitigation and preparedness practices for economic resilience, but also to prioritize investments to mitigate small business impact.

Literature on supply chain disruption can be roughly divided into three categories: (i) studies that develop novel techniques to model supply chains at the firm-level (see Hosseini et al., 2019, for a comprehensive review); (ii) studies that examine supply chain disruption management within the firm (e.g., Wagner & Bode, 2009; Zhao et al., 2020); and (iii) studies that model supply chain linkages between the firm and its counterparts, including through transportation systems (e.g., Töyli et al., 2013; Albertzeth, 2020). Studies focused on supply chain analysis techniques commonly use complex stochastic models (Hosseini et al., 2019) that are not easily accessible to planners and policymakers, and, with few exceptions, (see for example, Albertzeth, 2020) are not directed at their use. Supply chain management studies also, by and large, use secondary data (Kull et al., 2018) which precludes a nuanced understanding of business-level behaviors. These are better assessed through primary data collection such as surveys. This literature is also "firm-focused" (Kull et al., 2018, p.28)—that is, focused on improving business practices—which diminishes its utility for planners and policymakers who must conceptualize supply chains within the broader economic context and whose interventions are policy-based, applied areawide, and largely strategic given financial constraints.

The current literature on supply management also falls short in another aspect: behaviors of small businesses in response to supply chain disruptions (Kull et al., 2018). Post-disaster supply chain disruptions are more likely to adversely impact small businesses because they are typically less resourced; have higher rates of minority ownership than other size businesses (Marshall & Shrank, 2014; SBA, 2019); are limited in their ability to develop alternative supply streams (Mesquita & Lazzarini, 2008); and have higher transaction costs due to lower bargaining power and reputation (e.g., Arend & Wisner, 2005). Disaster studies have also shown that small businesses take fewer mitigative actions against disasters and are generally less prepared for such events (Josephson et al., 2017). Lastly, small businesses not only have fewer programmatic options for post-disaster aid, but these programs often require significant and tedious paperwork that acts as a barrier to their participation (Xiao & Van Zandt, 2012; Furlong & Scheberle, 1998).

Adverse disaster impact on small and locally owned businesses, in turn, has lasting consequences for the post-disaster recovery of the broader community at large (Xiao & Van Zandt, 2012; Xiao et al., 2018). Small businesses are key social actors in their community, not just economic ones, and often play a role in placemaking at the neighborhood level as well as overall neighborhood recovery (Xiao et al, 2018). Despite their significance to community-level resilience, empirical research on small businesses recovery is lacking in both disaster studies literature (Marshall & Shrank, 2014) and that on supply management (Krull et al., 2018).

This study addresses existing literature gaps by: (i) using easily accessible and primary data methods to assess potential local economic impact of transportation-dependent small businesses in the event of an earthquake; and (ii) overall preparedness of small and medium enterprises in managing such disruptions in the future. In contrast to other studies that focus only on disaster vulnerability, this study also focuses on coping and adaptation behaviors of small businesses, which accounts for their own agency in supply management and is a generally more empowering perspective on resilience planning. This type of nuanced approach can provide planners and policymakers with a clearer understanding of where resilience-building policy, planning and infrastructural interventions are needed the most, to what extent, and to what effect.

1.2 METHODOLOGICAL OVERVIEW

The study was conducted in two interlinked phases using a mixed method approach. Phase I involved integrating results from three popularly used models (Hazus, the Wasatch Front Travel Demand Model, and REMI PI+) to identify industrial sectors expected to be most impacted by transportation loss in a M7.0 earthquake scenario within the Wasatch Front (i.e., Box Elder, Davis, Morgan, Salt Lake, Tooele, and Weber counties). The study obtained results of a 2019 Hazus analysis of an M7.0 earthquake event in the Wasatch Front from the Utah Division of Emergency Management and used it to identify recovery status of road and bridge networks at Days 1, 14 and 30. These results were then inputted into the Wasatch Front Travel Demand Model to estimate travel delays caused by these for Day 30 and, finally, the REMI PI+ model was used to estimate the annualized economic impact

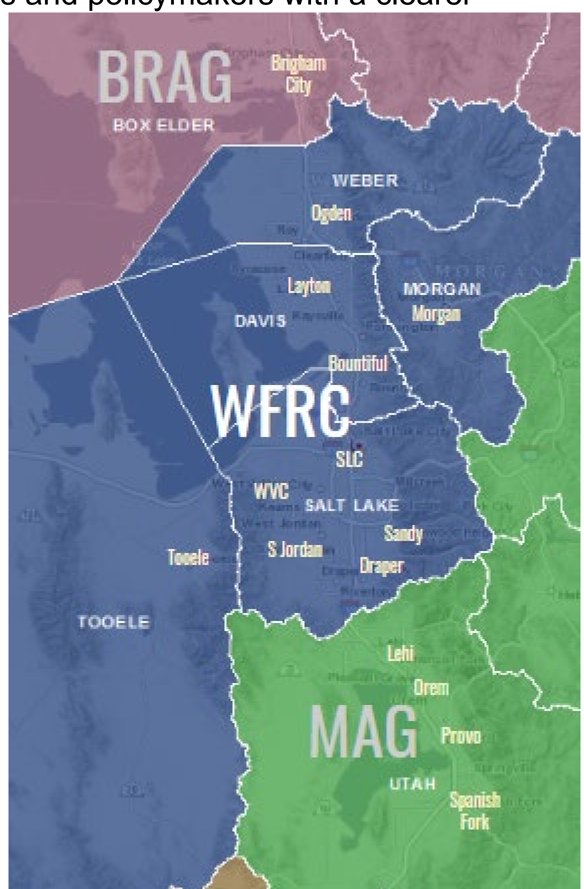


Figure 1.1. Map of Study Area for Phase I (five county area, marked in dark blue)

of these travel disruptions to industrial sectors. Chapter 2 presents each of these analytical stages in detail.

Phase II of the study involved a random sample telephone and online survey of 130 Salt Lake City businesses from within the high-impact sectors identified during Phase I. Businesses were sampled using the Mergent Intellect database, available through the University of Utah library system, and stratified for the North American Industry Classification Manual-United States (NAICS) industrial sector and size. Only the top 10 worst-affected industrial sectors identified through Phase I were surveyed. The survey assessed the impact of the Coronavirus pandemic and M5.7 Magna earthquake on business operations; actions taken to manage supply and service disruptions and other recovery actions; recovery status; level of awareness of earthquake risk in the region; and their interactions with disaster preparedness and planning resources at the county, state and federal level. Survey methods and results are described in Chapter 3.

2.0 PHASE I: ECONOMIC IMPACT OF DISASTER-INDUCED TRANSPORTATION DISRUPTIONS

2.1 EXPLANATION OF SOFTWARES AND MODELS

The study used three specific software to conduct this exercise, namely, Hazus, Wasatch Front Travel Demand Model (WF-TDM), and REMI PI+. Hazus, developed by the Federal Emergency Management Agency and the National Institute of Building Sciences, is a natural hazards loss estimation software developed at the national level. The model is commonly used by state and local governments to estimate regional-level economic, life, building, and lifeline losses and to model shelter, debris removal, and essential service needs after multiple types of disasters (including earthquakes). The program uses multiple default databases for general building stock (including construction type and occupancy classes); facility information for select lifeline and essential facilities (including transportation facilities); and, in the case of earthquakes, fault structures and ways to predict ground motion. Hazus contains baseline inventories for the entire country available to download through the FEMA Map Center Service website. The program can be customized to include region-specific data to improve accuracy of loss estimation.

Wasatch Front Travel Demand Model (WF-TDM), developed by the Wasatch Front Regional Council, is a modified four-step travel model that uses a travel time feedback loop to evaluate roadway congestion costs. Travel demand models are commonly used by regional governments to assess and predict travel behaviors within the region. The WF-TDM calculates roadway volumes, travel speed indicators, transit route boardings, and regional statistics including vehicle miles traveled (VMT), vehicle hours traveled (VHT), transit/auto/non-motorized mode shares, and trip length costs. The model includes current regional roadway and transit projects listed in the Regional Transportation Plan (RTP) and the official traffic analysis zone (TAZ)-level socioeconomic forecasts for the Wasatch Front Region. The model's parameters are calibrated to reflect local travel behavior patterns reported in the Utah Travel Study household survey and the model's results are validated with observed travel conditions for the model's base year, 2015.

REMI PI+, developed by Regional Economic Models, Inc., is a dynamic, multiregional simulation model that forecasts economic, population and labor market impacts for many years into the future. The REMI PI+ is similar to many economic analysis models used by states and regions across the nation for their own economic development planning. REMI provides year-by-year estimates of the regional effects of specific economic or policy changes. The model incorporates input-output relationships, general equilibrium effects, econometric relationships, and economic geography effects. Although REMI has many complex, interrelated submodels and features, the essential logic of the model derives from the economic base, input-output, and cohort component submodels. The REMI model connects these submodels through labor, capital, financial, and product markets. It simulates the size and composition of the economy and population over time. For example, if there is an increase in the production of an export base industry to the region, the region's employment and income increase as well.

2.2 TASKS AND METHODOLOGY (PHASE I)

Phase I of this study assesses potential economic impact of an M7.0 earthquake event in the Wasatch Front. The phase involved three main research tasks: (1) assessing potential damage state and recovery functions for roadways and bridges using Hazus; (2) analyzing travel time delay for trucks based on estimated damage level; and (3) annualizing economic cost to various industrial sectors based on estimated truck travel time delay. Each of these stages of analysis are described below.

The analytical framework presented here was carefully designed to be replicable and transferable to other communities. Since much of mitigation funding is disbursed *post*-event (to mitigate against future events), this puts communities which are at risk but have not yet experienced the event at a major disadvantage. The university-community partnership model that this study is based on provides a relatively inexpensive path for at-risk communities to create the planning support needed for mitigation action at the regional and business-level. While this study and framework were focused on transportation-related impacts, such a university-community partnership, with appropriate selection of team members and models, could easily be applied to topics such as post-disaster impacts on housing, power or water infrastructure, or population displacement.

2.2.1 Assessing damage state and recovery function

This study uses results from a 2020 Hazus analysis of an M7.0 earthquake for the Salt Lake City segment of the Wasatch Fault provided by the Utah Division of Emergency Management (DEM). The Hazus analysis required updating baseline inventory for highway segments (see Appendix A) because roadways (unlike railroads) are not typically included in the Homeland Infrastructure Foundation Level Data (HIFLD), which is the traditional source for baseline data in Hazus. Updated data on bridge fragility assessment could have improved the Hazus analysis further; however. it was unavailable for this study.

Hazus produces two types of data that are relevant to this study. First is damage state, which is classified into five categories (None, Slight, Moderate, Extensive, and Complete), and the second is a discrete restoration function (Functional Percentage) for days 1, 3, 7, 14, 30 and 90 past the disaster event. These are produced for every road, rail and air segment, bridge, and facility and are produced as GIS datasets (GIS shapefiles). This study uses the functionality/restoration function to represent system impact instead of the damage function because recovery function better indicates a system's ability to continue operations in the event of a disaster and because of easier fit with WF-TDM model, which can more readily interpret and integrate reduced system functionality.

For non-highway bridges, functionality of the road links going through it or under it were assumed to be the same as the bridge. For highway bridges, functionality of the road link going through the bridge was assumed to be the same as the bridge, but the road link going under the bridge was assumed to remain unaffected due to the possibility of re-routing that traffic and the priority given to highways for debris clearance.

Based on these assumptions, we extracted Hazus results data for highway (roads) segments and bridges for the six-county region under jurisdiction of the Wasatch Front Regional Council (Box Elder, Davis, Morgan, Salt Lake, Tooele, and Weber). This step ensured that the Hazus analysis was coterminous with the second stage WF-TDM analysis. This study did not analyze the impact of rail and air transportation disruptions because the WF-TDM does not support traffic demand analysis for the railway or air systems, which limits the study's ability to estimate travel delays by these modes. This data was then reconciled with and inputted into the WF-TDM in the next step.

2.2.2 Forecasting delay in vehicle hours traveled

For this study, the Wasatch Front Regional Council calculated travel time delays using the WF-TDM based on the restoration function for Days 1 and 30. These specific timelines were chosen based on typical definitions of response and recovery phases as used by the Federal Emergency Management Agency (FEMA). According to the 2019 National Response Framework, "short-term response" begins immediately after a disaster event and lasts for "a few weeks." On the other hand, FEMA's 2017 Pre-Disaster Recovery Planning Guide for Local Governments and the 2015 Planning for Post-Disaster Recovery: Next Generation (PAS Report 576) of the American Planning Association both cite "recovery" as starting approximately one month (30 days) after the disaster.

The study analyzed two scenarios using the Wasatch Front Travel Demand Model (WF-TDM), Version 8.3.1 released August 2020. The model was run for the year 2019. The first run assumed the network functionality and accompanying decrease in allowable road capacity (based on Hazus-generated functionality/restoration function) that would occur on Day 1 after a 7.0 magnitude earthquake. The second run assumed the same but for 30 days out from the event. Table 2.1 shows the forecasted delay in vehicle hours traveled for Day 1 and Day 30 scenarios for all vehicle modes and trucks, specifically because these are common modes of road-based transportation of supply goods.

Table 2.1. Delay in Vehicle Hours Traveled based on Day 1 and Day 30 Functionality

2019	Delay in Vehicle Hours Traveled (All Vehicles)			Delay in Vehicle Hours Traveled (Trucks)		
	Base	**Day 1**	**Day 30**	**Base**	**Day 1**	**Day 30**
Region	136,500	234,100	192,300	21,100	39,300	32,000
Box Elder	100	100	100	<100	<100	<100
Davis	20,000	26,400	22,600	3,000	3,800	3,400
Salt Lake	86,900	174,400	138,000	13,500	29,900	23,400
Weber	8,000	8,800	8,400	1,300	1,500	1,400
Utah	21,400	24,300	23,000	3,300	4,000	3,700

Source: Wasatch Front Regional Council analysis using the WF-TDM

2.2.2.1 Geoprocessing in preparation for modeling

To evaluate the traffic delay costs, it was necessary to transfer the Hazus Day 1 and Day 30 damage-level estimates onto the road network links that represent the transportation system in the TDM (TDM Master Network). Both data are represented as GIS features, but geometry and attribute structures are quite different. Hazus damage estimates were provided in a highway segments file while the WF-TDM master network is exported as a geodatabase file. These two files did not have a common unique identifier that could be used to match geographic features and relate their attribute values across the respective datasets. To transfer the Hazus Days 1 and 30 fields and values from the Hazus Highway Segment file to the TDM Master Network file required some data preparation work using spatial and table joins on query-based subsets of the datasets. This work is detailed below.

Roadways: Since there was no field available to join the highway segment shapefile with the master network, a series of spatial joins needed to take place. To do so, we utilized a custom tool called "Transfer Fields" separately for freeways, arterials, and ramps utilizing queries shown in Appendix A Figure 1 and Table 1. These geo-processed files were transferred back to the TDM Master Network file, which also transferred the needed attribute values for most of the road links. However, there were still several links that were in the WF-TDM master network that were not represented in the Hazus highway segment file, but which also needed a restoration function for Days 1 and 30. We used the query shown in Appendix A Table 2 to first flag these roadway links. Then, we used the Thiessen Polygon tool to spatially join the two road feature layers. This involved creating midpoints on the remaining links utilizing the Feature Vertices To Points tool and using those midpoints to run the Create Thiessen Polygon tool. Then, we spatially joined the Thiessen Polygons with the remaining links and assigned them functionality values for Days 1 and 30. This concluded the work necessary to transfer the Days 1 and 30 restoration function fields from the Hazus Highway Segments to the WF-TDM Master Network.

Bridges: Bridges overpassing other roadways presented an additional challenge as there is no standard way to differentiate a road link in the TDM master network that is a bridge versus one that runs under a bridge. For this, we needed to manually transfer the Days 1 and 30 restoration function values from the Hazus Highway Bridge shapefile to the TDM Master Network file. Attempts to separate out the arterials from the freeways and use the attribute transfer tool to transfer this data proved to be ineffective. The manual transfer process was extremely time consuming, which severely limited the study's ability to conduct more TDM runs for other restoration timelines provided by Hazus (Days 3, 7, 14 and 90), which, in turn, affects the accuracy of the annualization of truck delays as described in Section 2.2.3.1.

2.2.3 Estimating supply chain impact due to truck travel delays

2.2.3.1 Annualizing truck delays

We confined our analysis to truck transportation. On average, industries use about one-fifth as much air transportation as truck transportation and about one-seventh as much rail transportation.

Using the Hazus-produced functionality/restoration function for Days 1, 3, 7, 14, 30, and 90, we calculated the average functionality across all segments in a given county for each day. This was then subtracted from 100 to obtain the average percent nonfunctional, then plotted in Excel. We then added trendlines using the functional form with the highest R^2, and projected them out to 365 days (see Appendix A Figures 2-6). We weighted road and bridge segments equally, assuming that traffic would be routed around nonfunctional bridges until they were repaired.

The Wasatch Front travel demand model (WF-TDM) produced the delay vehicle hours of travel (VHT) for trucks by county on Day 1 and Day 30 of the earthquake. Since REMI PI+ works in annual increments, we needed to annualize the delays in each county. To do this, we set the intercept of each county's recovery curve equation (provided by Excel) to the Day 1 delay VHT for that county, then used the equation to estimate the delay VHT on Days 2 through 365. Summing these provided the total delay for one year (see Appendix A, A.1, 1.1 for technical note). Having TDM outputs for more than two points would, of course, provide a more accurate trendline for annualization purposes; but converting HAZUS model outputs to TDM inputs was time consuming and labor intensive.

In Box Elder and Weber counties, while the damage to roads and bridges is minor—the average percent nonfunctional on Day 1 is 0.0064% in Box Elder and 0.12% in Weber—the recovery curves never approach zero over the course of the year. This leads to unreasonably large annual hours of delay, for example, 106% of average annual VHT in Box Elder. To produce more reasonable results, we forced the recovery curves for these two counties to go to zero on Day 180, assuming that roads and bridges would be fully functional by six months after the earthquake (see Appendix A, A.1, 1.2 for technical note). We then used these modified recovery curves to annualize the delays in the same manner as the other counties.

The WF-TDM provided average weekday truck VHT, without an earthquake, for each county. Determining the average work week for truck drivers can be difficult. There are complex rules governing the number of hours truck drivers may work in a seven- or eight-day period. However, according to the U.S. Bureau of Labor Statistics' Current Population Survey (U.S. Bureau of Labor Statistics, 2020), transportation and material moving occupations work an average of 39.9 hours per week. This implies a 260-day work year, which we used to calculate the average annual truck VHTs for each county.

We then calculated the annualized truck travel delay hours by county as a share of average annual truck VHT without the effects of an earthquake (see Table 2.2). This share of normal annual VHT was distributed among industries in each county according to an industry's use of truck transportation. The U.S. Bureau of Transportation Statistics compiles a series of Transportation Satellite Accounts (TSAs). The direct requirements table in these accounts shows the amount of in-house and for-hire air, rail, water, and truck transportation services required by each industry to produce a dollar of output (see Table 2.3).

Table 2.2 Truck VHT Before and After Magnitude 7.0 Earthquake

	No Earthquake		After Earthquake		
County	Average Weekday VHT	Average Annual VHT	Day 1 Delay VHT	Annual Delay VHT	Delay Share of Average Year
Box Elder	22	5,724	42	1,298	22.7%
Davis	3,067	797,352	3,848	215,406	27.0%
Salt Lake	13,458	3,498,988	29,909	1,674,258	47.8%
Utah	3,279	852,566	3,969	304,622	35.7%
Weber	1,266	329,234	1,509	38,209	11.6%
Region	21,092	5,483,863	39,276	2,233,792	40.7%

Note: VHT = vehicle hours of travel
Source: Wasatch Front Regional Council travel demand modeling and Kem C. Gardner Policy Institute analysis of Utah Department of Emergency Management Hazus modeling outputs

Regional Economic Models, Inc.'s 29-county PI+ model for Utah contains baseline estimates of output by industry in each county. We multiplied baseline industry output by that industry's in-house, for-hire, and total trucking direct requirements to estimate the baseline value of trucking required for each industry in each county—essentially the demand for or use of trucking by businesses in each county. In a few cases, REMI industries and TSA industries did not match exactly. We used national industry output data from the U.S. Bureau of Economic Analysis to apportion transportation requirements from the more aggregated TSA sectors to the less aggregated REMI industries (see Appendix A, A.1, 1.3 for technical note). To estimate each industry's share of delays in each county, we multiplied each county's total trucking delay (share of normal annual VHT) by each industry's in-house trucking requirement as a share of county total baseline trucking requirements. All for-hire trucking delays were assigned to the transportation industry, as the provider of for-hire trucking to all other industries. These delay shares were entered into the REMI PI+ model as a percentage reduction in output for 19 private, nonfarm industries in each county. The following equation summarizes the process:

$$\Delta Y_{ic} = \frac{D_c}{N_c} \times U_{ic} \qquad [2-1]$$

where ΔY_{ic} is the percentage reduction in output by industry *i* in county *c*, D_c is the annualized truck delay VHT in county *c*, N_c is the normal annual truck VHT in county *c*, and U_{ic} is industry *i*'s share of total truck transportation usage in county *c*.

The REMI PI+ model allocates the transportation sector's additional delays based on an input-output matrix that indicates how much for-hire transportation each industry uses.

We did not try to account for demurrage costs—costs related to the time sensitivity of the goods being transported. There does not appear to be standard, publicly available data on these types of costs. Including these would also require analysis of what types of goods are being delivered to which local businesses. While statewide data on the flow of commodities by mode are available from the U.S. Department of Transportation's Freight Analysis Framework, county-level data are not. In addition, assigning commodities to the local industries that use them, as well as the amounts used, may be beyond the capacity of most local governmental and planning organizations.

Table 2.3 Use of Truck Transportation by Industry, 2019
(Value of transportation used as a share of industry output)

Industry	In-House	For-Hire	Total
Transportation and warehousing	0.00%	3.75%	3.75%
Construction	1.96%	1.50%	3.46%
Wholesale trade	2.42%	0.20%	2.62%
Manufacturing	0.87%	1.70%	2.57%
Retail trade	2.26%	0.18%	2.45%
Other services, except public administration	2.01%	0.25%	2.26%
Accommodation and food services	1.61%	0.22%	1.83%
Mining	0.75%	0.66%	1.41%
Professional and technical services	1.01%	0.09%	1.10%
Utilities	0.24%	0.79%	1.03%
Health care and social assistance	0.45%	0.17%	0.62%
Arts, entertainment, and recreation	0.51%	0.07%	0.58%
Information	0.31%	0.23%	0.54%
Administrative and waste management services	0.48%	0.04%	0.52%
Management of companies and enterprises	0.28%	0.03%	0.30%
Forestry, fishing, and hunting	0.07%	0.06%	0.13%
Real estate and rental and leasing	0.07%	0.02%	0.10%
Educational services	0.07%	0.02%	0.09%
Finance and insurance	0.06%	0.02%	0.07%

Note: The amounts shown are the dollars of truck transportation services used by a given industry per dollar of that industry's output, displayed as percentages.
Source: U.S. Department of Transportation, Bureau of Transportation Statistics, Transportation Satellite Accounts

2.2.3.2 Supply Chain Impacts

The Gardner Institute used the REMI PI+ model to estimate the negative economic impacts of a transportation shock caused by a 7.0 magnitude earthquake in Salt Lake City. REMI is a dynamic model incorporating input-output, economic geography, econometric, general equilibrium, and demographic components. The REMI inputs and results were for the 2019 calendar year. Economic loss was modeled by assigning a percentage reduction in output for 19 private, nonfarm industries in each county of the region of study, as described above. The study region consists of five counties: Box Elder, Davis, Salt Lake, Utah, and Weber.

Table 2.4 Economic Impacts of Transportation Shock, 2019 (Millions of Dollars)

Category	Total Impact
Total Employment	-109,517
Personal Income	-$5,982.5
Intermediate Demand*	-$5,327.8
Gross Domestic Product (GDP)	-$10,423.3

*Intermediate demand is multiplied by each respective industry's regional purchase coefficient to constrain it to impacts within the study region.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model

Table 2.4 summarizes the total loss of employment, personal income, and gross domestic product (GDP) within the five counties of study. A transportation shock to Utah's economy in 2019 would have resulted in about 110,000 fewer jobs, a reduction of $6.0 billion in personal income, and a $10.4 billion reduction in Utah's economic activity. Note that this analysis includes only losses due to transportation delays. There are other components to consider when estimating the overall loss of an earthquake, such as structural damage, displaced households, other production losses not related to transportation, and much more.

Using metrics such as employment, personal income, and GDP gives an overall view of the total economic impact of a transportation shock. However, these impacts are insufficient in identifying which industries are most vulnerable to supply chain disruptions. To do this, we look at the effects of a transportation shock to intermediate demand, which isolates inter-industry transactions of goods and services purchased by firms from other firms and used to produce final products. For example, a manufacturing company may buy copper extracted by the mining industry and use it to build wind turbines. The output from mining is an input for manufacturing, which leads to a finished product. While the inputs and outputs between firms are counted in intermediate demand, final goods and services that reach the final buyer are counted in final demand. The intermediate business-to-business transactions create complex networks that make up the supply chain.

A regional purchase coefficient is the proportion of local industry demand that is met by local industry supply. To constrain the supply chain impacts to activity within each county of study, we multiply intermediate demand in each county by each industry's regional purchase coefficient. This approach is conservative because we have no means to capture demand supplied from other counties in the study region. We obtained regional purchase coefficients by industry from the REMI PI+ model. The following equation summarizes the supply chain impact calculation:

$$SCI_{ic} = ID_{ic} \times RPC_{ic} \qquad [2-2]$$

where SCI_{ic} is the supply chain impact on industry *i* in county *c*, ID_{ic} is the intermediate demand by industry *i* in county *c*, and RPC_{ic} is the regional purchase coefficient for industry *i* in county *c*.

In the five-county study region, the loss in intermediate demand for all nonfarm private industries would have amounted to $5.3 billion (see Table 2.5) in 2019. Total loss for the top five industries—manufacturing, real estate and rental, professional and technical services, administrative and waste management services, and transportation and warehousing—accounted for $3.5 billion (66%) of the total loss from the simulated transportation shock.

The loss in three sectors—manufacturing, real estate and rental, and professional and technical services—amounted to nearly 50% of the total loss within the study region. Manufacturing's share of the loss was largest at 22.8%, followed by real estate and rental (13.7%), and professional and technical services (11.6%). Administrative and waste management services and transportation and warehousing rounded out the top five, taking a combined 18.4% share of the total.

Each county within the region of study has a unique economy. As such, total loss and industry sizes vary from county to county (see Appendix A Tables 3-7). Even with differences in local economies, manufacturing and real estate and rental are the two hardest-hit sectors for every county within the region of analysis. Professional and technical services ranks third in Davis, Salt Lake, and Utah counties, while transportation and warehousing and administrative and waste management services rank third for Box Elder and Weber counties, respectively.

Manufacturing was the most impacted sector for every county within the study region. The loss for all five counties was $1.2 billion, representing 23% of the total loss in intermediate demand. The manufacturing and transportation sectors are interdependent. The manufacturing industry consistently relies on transportation to provide its businesses with the raw materials to be transformed into useable products, and then to ship these intermediate and finished goods to their next or final destinations. In turn, manufactured goods are the most prominent industry input for the transportation sector. Manufacturing also has a significant footprint in every county of the study region. It is Box Elder County's largest and Weber County's second-largest sector.

It may come as a surprise that real estate and rental is second on the list, with regionwide losses of $730 million, a 14% share of the total loss. Transportation is not a vital input for the real estate and rental sector, nor is real estate and rental a very large industry in any of the counties within the study region. However, real estate and rental is a significant input for the transportation sector. Inputs from real estate and rental for transportation may include purchasing land for warehouses and the rental and leasing of storage facilities, vehicles, and commercial equipment. An earthquake's effect on reducing transportation's output, which uses real estate and rental as a significant input, also has an upstream impact on the real estate and rental sector itself. Another essential factor contributing to large losses in real estate and rental is this sector's regional purchase coefficient relative to other industries. Real estate and rental's regional purchase coefficient is relatively high compared with other sectors. Depending on the county, 76% to 98% of real estate and rental products and services are supplied within the local economy.

Table 2.5 Five-County Intermediate Demand Impacts by Industry, 2019 (Millions of Dollars)

Industry	Change in Intermediate Demand	Share of Total	Industry Size
Manufacturing	-$1,212.1	22.8%	8.1%
Real estate and rental and leasing	-$729.8	13.7%	6.3%
Professional and technical services	-$616.1	11.6%	9.5%
Administrative and waste management services	-$497.4	9.3%	7.0%
Transportation and warehousing	-$484.8	9.1%	4.8%
Finance and insurance	-$434.2	8.1%	7.9%
Wholesale trade	-$401.7	7.5%	3.5%
Information	-$237.2	4.5%	2.8%
Retail trade	-$153.0	2.9%	11.9%
Construction	-$146.2	2.7%	7.3%
Other services, except public administration	-$120.5	2.3%	5.5%
Accommodation and food services	-$92.5	1.7%	6.8%
Mining	-$64.9	1.2%	0.4%
Utilities	-$49.4	0.9%	0.2%
Health care and social assistance	-$27.5	0.5%	9.5%
Arts, entertainment, and recreation	-$26.7	0.5%	2.4%
Management of companies and enterprises	-$21.2	0.4%	1.8%
Educational services	-$10.6	0.2%	4.2%
Forestry, fishing, and hunting	-$1.8	0.0%	0.1%
Total	**-$5,327.8**	**100%**	**100%**

Note: Industry Size represents each industry's share of total employment in the region.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model

Professional and technical services would lose an estimated $616 million (11.6% of the total) in intermediate demand. The sector is the second largest of all within the five-county region. This, along with its relatively high regional purchase coefficients in Salt Lake, Utah, and Davis counties, are the driving factors for the sector reaching the third spot on the list. Administrative services would shrink by $497 million, 9.3% of the total. Like real estate, administrative services is another significant input for the transportation sector, and the sector also has a relatively high regional purchase coefficient.

Transportation and warehousing ranks fifth in terms of the total reduction in intermediate demand. While transportation is the fifth-largest sector in Box Elder County, it is less prominent in other study counties with significantly larger economies. The regional purchase coefficient of the transportation sector is comparatively lower than other sectors. While these two factors reduce the impacts on intermediate demand for transportation, the fact that it takes the largest initial hit (see Table 2.3, above) keeps it in the top five impacted industries.

The last piece of analysis compares the effects of a transportation shock with a "no-earthquake" baseline. The baseline represents Utah's industries operating as they normally would within the business cycle. This analysis shifts from comparing the absolute sizes of supply chain effects across industries, to considering changes within each sector relative to its size. Table 2.6 shows the percent changes in intermediate demand from industry baselines for each county in the study region. These changes do not account for regional purchase coefficients, but instead represent the change in total intermediate demand facing each industry relative to baseline levels.

When focusing on within-industry changes from a transportation shock, it is no surprise that the transportation and warehousing sector has the most considerable reduction. Several industries are heavily reliant on transportation for the movement of both inputs and outputs in their supply chains. Companies in retail and wholesale trade—such as grocery stores and construction equipment dealers—are heavily reliant on the goods they receive, delivered by the transportation sector. Transportation is likewise critical for moving raw materials from mining to manufacturing, and then intermediate and finished goods from manufacturing to their next destination.

The five industries most impacted by a transportation shock are transportation and warehousing (–12.3%), retail trade (–12.1%), management of companies and enterprises (–9.1%), wholesale trade (–9.0%), and mining (–8.8%). When focusing on within-industry changes from a transportation shock, it is no surprise that the transportation and warehousing sector has the most considerable reduction. Several industries are heavily reliant on transportation for the movement of both inputs and outputs in their supply chains. Companies in retail and wholesale trade—such as grocery stores and construction equipment dealers—are heavily reliant on the goods they receive, delivered by the transportation sector. Transportation is likewise critical for moving raw materials from mining to manufacturing, and then intermediate and finished goods from manufacturing to their next destination.

Table 2.6 Five-County and All-Region Percent Change in Intermediate Demand from Industry Baseline, 2019

NAICS Industrial Sector	Box Elder	Davis	Salt Lake	Utah	Weber	Total Region
Transportation and warehousing	-8.58%	-8.17%	-13.45%	-7.17%	-4.57%	-12.32%
Retail trade	-8.37%	-8.85%	-12.53%	-8.61%	-5.23%	-12.05%
Management of companies and enterprises	-7.22%	-7.03%	-9.42%	-6.63%	-4.18%	-9.08%
Wholesale trade	-7.64%	-7.33%	-9.80%	-6.71%	-4.39%	-9.04%
Mining	-8.07%	-8.25%	-9.10%	-6.86%	-4.65%	-8.79%
Manufacturing	-7.88%	-7.34%	-9.50%	-6.72%	-4.47%	-8.70%
Other services, except public administration	-6.75%	-6.16%	-9.34%	-6.14%	-3.71%	-8.67%
Utilities	-6.71%	-6.37%	-8.72%	-5.96%	-3.84%	-8.05%
Administrative and waste management services	-6.19%	-5.47%	-8.73%	-5.53%	-3.54%	-7.98%
Real estate and rental and leasing	-5.42%	-5.54%	-8.17%	-5.71%	-3.53%	-7.60%
Accommodation and food services	-5.40%	-5.06%	-7.72%	-5.11%	-3.26%	-7.07%
Professional and technical services	-6.10%	-4.76%	-7.31%	-5.53%	-3.40%	-6.87%
Forestry, fishing, and hunting	-6.70%	-7.72%	-8.25%	-4.93%	-4.10%	-6.86%
Information	-5.45%	-4.57%	-7.10%	-4.63%	-3.21%	-6.40%
Arts, entertainment, and recreation	-4.65%	-4.65%	-6.61%	-4.20%	-3.34%	-6.08%
Construction	-5.15%	-4.31%	-6.61%	-4.70%	-3.01%	-5.95%
Finance and insurance	-5.30%	-3.85%	-6.16%	-4.86%	-2.62%	-5.93%
Educational services	-4.21%	-3.94%	-6.39%	-4.41%	-2.81%	-5.67%
Health care and social assistance	-3.35%	-3.48%	-5.69%	-4.50%	-2.72%	-5.06%

Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model

3.0 ASSESSING BUSINESS-LEVEL DISASTER PREPAREDNESS & RECOVERY ACTIONS (PHASE II)

3.1 SURVEY SAMPLING & METHODOLOGY

The objective of Phase II is to identify impact of and response to the recent Coronavirus pandemic and March 2020 M5.7 Magna earthquake that occurred near Salt Lake City by the business community in the Wasatch Front, with a focus on the industrial sectors expected to be worst affected in an M7.0 earthquake scenario (identified through Phase I). Data was collected through a combination of telephone and online surveys of Salt Lake City businesses.

The survey sampling began with identifying the top 10 worst-affected industrial sectors identified in Phase I (see Table 2.6). Then, we downloaded business records for all Salt Lake City-based businesses within these sectors from the Mergent Intellect database, which is freely available through the Marriott Library system of the University of Utah. The Mergent Intellect database contains profile information of each business within the U.S. including complete contact information for each business. A total of 51,233 businesses were identified through the Mergent Intellect database (See Table 3.1, Column B). From this database, the team extracted a stratified sample (Table 3.1, Column C) to match the proportion of Salt Lake City businesses within the Phase-I top 10 industrial sectors as reported in the 2021 U.S. Census American Business Survey (Column A). This resulted in a sample of 3,820 businesses. A survey questionnaire was developed based on previous literature and studies conducted on the topic by the research team.

Following University of Utah Institutional Review Board requirements for study recruitment, the project team contacted all 3,280 businesses in the database by phone to gauge interest in survey participation. A total of 327 businesses agreed to participate in the survey and provided an email address for further contact. The team then sent an email to the business with a link to an online survey (administered through Qualtrics). The team placed reminder phone calls and sent follow-up emails for three consecutive weeks. The survey process was conducted over a four-month period between November 2021 and March 2022.

3.1.1 Respondent Business Profile

A total of 130 of the 327 businesses responded to the survey for a response rate of 39.7%. The survey was representative of the percentage distribution in four sectors (see Table 3.1, Columns D & E). It was overrepresented in the finance and insurance; administrative, support, waste management, and remediation services; and information sectors, and underrepresented in the retail trade and the professional, scientific, and technical services sectors. These over- and underrepresentation are likely to be related to the continued work-from-home policies in some sectors (such as professional, scientific and technical services) or to business closures in others (for example, finance and insurance), which may decrease the likelihood of making first contact for survey recruitment. Future regression analysis on this dataset will use sample weighting and other correction techniques to correct this sample response bias (Leeworth et al., 2001).

The Small Business Association (SBA) classifies small businesses differently for each NAICS sector, with threshold sizes ranging between 100 and 1,500. Respondent businesses in our survey had an average of 57.5 employees (median = 6) which implies that the majority of respondents were small businesses across all NAICS sectors. The respondents had been in business for an average of 27 years (median = 20.5 years) which implies they are well-established in the community. Approximately, 18% of respondents reported being minority-owned businesses and approximately 19% reported being women-owned.

Table 3.1 Industrial profiles of sampled and respondent businesses

NAICS Industrial Sector	No. of SLC businesses in sampling frame (A)	Composition of Phase-I Top 10 industrial sectors (%) (B)	Sample Size (C)	No. of survey responses (D)	Survey responses (%) (E)
Manufacturing	2925	8%	305	2	1.54%
Real estate and rental and leasing	4195	10%	382	12	9.23%
Professional, scientific, and technical services	10949	26%	993	8	6.15%
Transportation and warehousing	2026	5%	191	8	6.15%
Finance and insurance	4684	7%	267	13	10%
Administrative, support, waste management, and remediation services	10640	7%	267	37	28.46%
Wholesale trade	3105	12%	458	18	13.85%
Information	2060	4%	152	23	17.69%
Retail trade	6155	13%	496	2	1.54%
Construction	4494	7%	267	7	5.38%
Total	**51233**	**100%**	**3820**	**130**	**100**

Sources: (A) 2021 U.S. American Business Survey; (B) Mergent Intellect, 2021

3.1.2 Disaster Impact

Overall, most respondent businesses reported being impacted by the COVID-19 pandemic (90%), while about half reported being affected by the March 2020 earthquake (47%). Among COVID-19-affected business (n = 117), around 59% reported a negative effect, 23% of businesses reported a positive effect due to the pandemic, and 18% reported neither a positive nor negative effect. Among earthquake-affected businesses (n = 61), only 3% of businesses reported positive effects of the disaster on the business, 23% reported a negative effect, and a majority (74%) reported neither positive nor negative effects. The limited effect of the 2020 March earthquake may be related to its having occurred in a rural community outside the main urban core and having only impacted the westside neighborhoods of Salt Lake City and some parts of its downtown. Due to time and financial constraints, this survey did not cover other cities lying to the west of Salt Lake City (such as West Valley) where the earthquake had much higher impact.

Given the concurrency of both disaster events and the difficulty in isolating their individual impacts, questions on supply chain and other specific impacts were framed as impacts from “either COVID-19 or 2020 Earthquake”. A total of 93 out of 130 (71%) surveyed businesses reported some impact on supply chain management. Of these, 75% (70) SLC businesses reported having faced domestic or foreign supplier delays due to both disasters with 37% (34) reporting production delays at the business location, 40% (37) reporting difficulties in locating alternate suppliers (domestic or foreign), and 56% (52) reporting having experienced delays in delivery or shipping to customers (see Fig. 3.1).

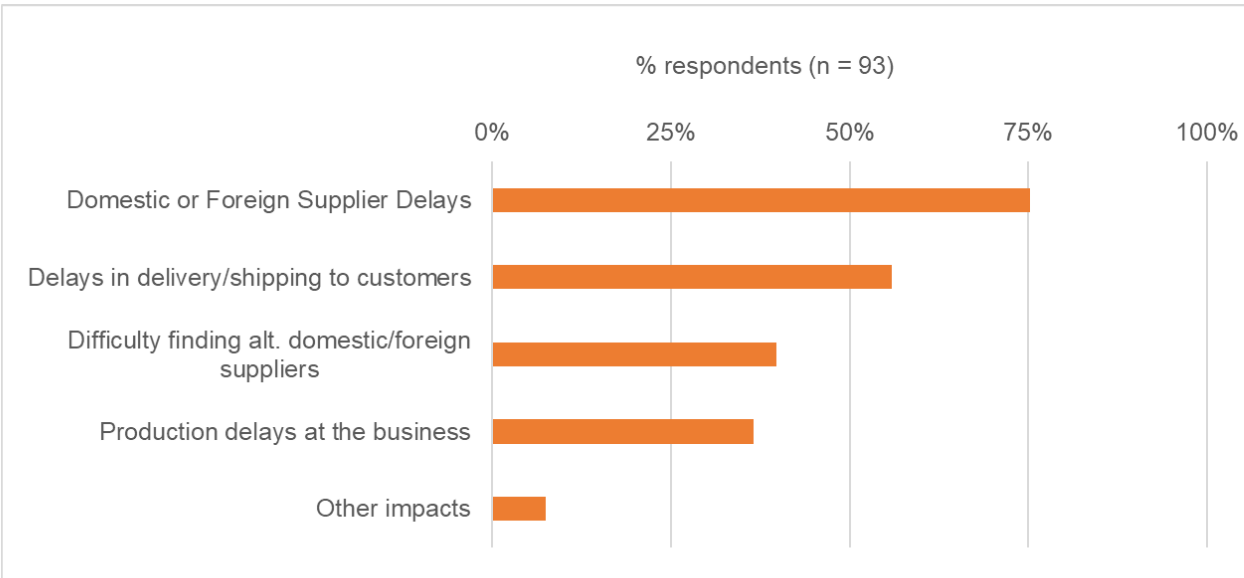


Figure 3.1. Impact of disasters on supply chain management.

In terms of operating capacity, which is defined as the ability to operate under realistic operating conditions, 77 of the 130 (59%) survey respondents reported an impact. Of these, 60% (46) of businesses reported impact on production costs which is in keeping with the predictions of production-level impact from Phase I of this study (Fig 3.2). In addition, 56% reported facing labor issues and 47% reported challenges in maintaining the health and safety of customers and employees. A small percentage of businesses reported damage to the building and contents due to the earthquake event (12%, 9).

In total, respondents reported having closed doors or remained inactive due to both disasters for an average of 12 weeks (n = 126), with the maximum reported closure of 72 weeks. About 35% of respondents reported that disasters had negatively affected business activity, while 23% reported a positive effect on the business (see Fig. 3.3). In addition, more businesses reported an increase in revenue since the disasters (approx. 50% or 65 respondents) than a decrease (31% or 41 total). This counterintuitive finding of positive effects from these concurrent disasters may be owed to the overrepresentation of finance and insurance; real estate, rental and leasing; and, administrative, support, waste management, and remediation service industries within the survey. These sectors are among the ones showing the fastest recovery from the pandemic (Breaux, Fernandez & Griffis, 2021; McKinsey & Company, 2020).

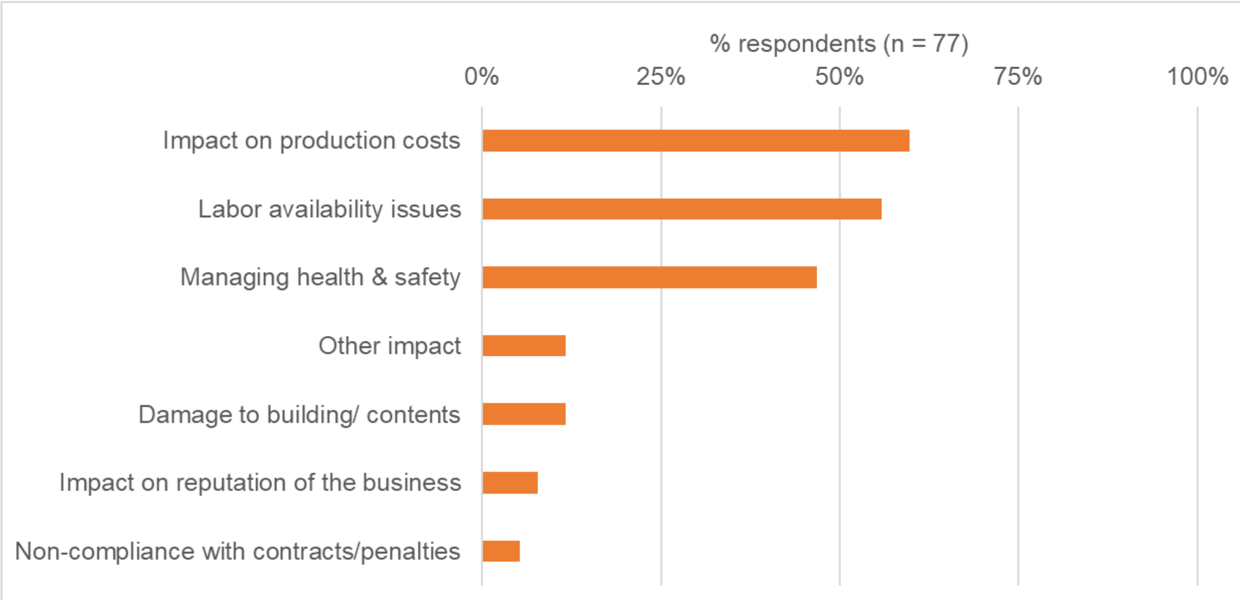
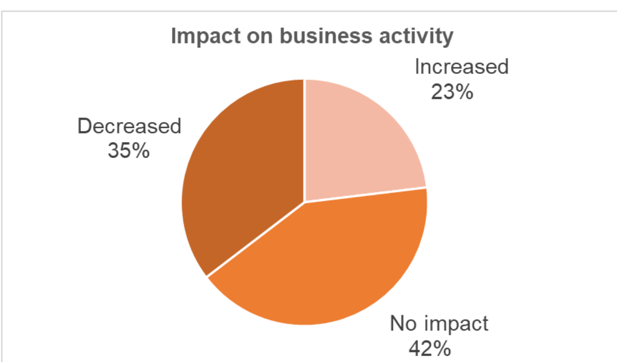


Figure 3.2. Impact of disasters on business operations

3.1.3 Supply Related Recovery Actions and Future Preparedness

Most surveyed businesses reported having either fully or mostly recovered (68%, 88 nos.) from the combined effects of the two disasters, which may also be an effect of the sample bias described in Section 3.1.2. Approximately 24% (32) businesses reported themselves as still recovering two years after the disasters. This slower recovery trajectory could be related to the nature of recovery, which typically unfolds over a long duration, and the nature of the COVID-19 pandemic, which is still ongoing and continues to affect global supply chains.



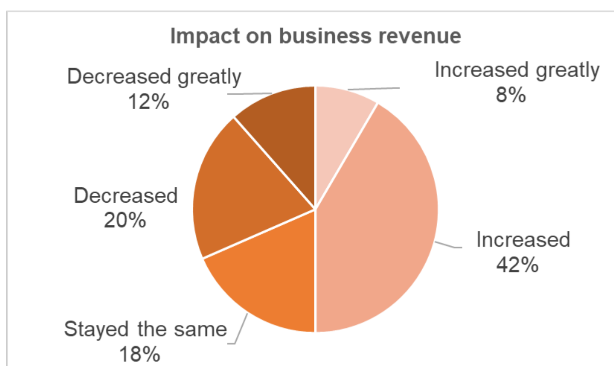


Figure 3.3 Impact of disaster on business activity and revenue (n =130)

Approximately 27% (35 total) of respondents reported having identified new suppliers, and another 14% (18 total) reported having changed their existing suppliers as a recovery action taken in response to the disasters (see Fig. 3.4). Businesses also reported having had to take other actions such as adjusting sales and marketing strategy (39%, 51); hiring new employees (32%, 42); adjusting capital expenditures for operation (30%, 39); creating work-from-home policies (29%, 38); and adjusting employee salaries (28%, 36). In specific reference to supply chain related actions, 14% (18) businesses said they had found new suppliers outside of their city and 13% (17) had found suppliers within their city. These results imply that businesses take a wide range of recovery actions, some with immediate effect (such as adjusting sales strategy or finding new suppliers) and some for which the effects may only be known in the long term (such as lowering capital expenditures). The results also suggest that finding alternative suppliers is challenging for impacted businesses.

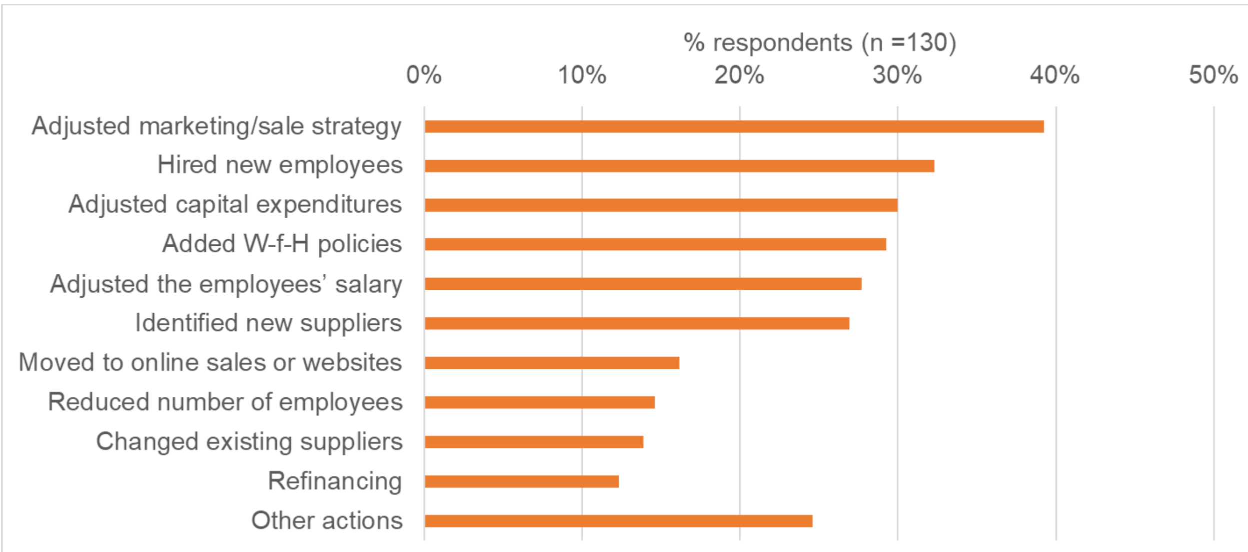


Figure 3.4 Recovery actions taken by businesses in response to concurrent disasters (n=130)

Recovery experience seemed to have a raised awareness of disasters within the business community but did not translate into concrete mitigation or preparedness action. Approximately 60% (78) of respondents agreed or strongly agreed that the disaster experience had prepared them for a future event (see Fig 3.5). However, only 36% (47 out of 130) reported having undertaken mitigation or preparedness actions and only 23% (30) reported having a disaster response plan in place before the March 2020 disasters.

The most frequent reported action was having received consultation on improvement of business resilience practice (11 out of 130 respondents) with another six businesses reporting having retrofitted their buildings to withstand earthquakes. This high awareness but low-action state indicates that there are more barriers to business level mitigation and preparedness than just risk awareness and these reasons must be investigated to ensure the success of business resilience programming.

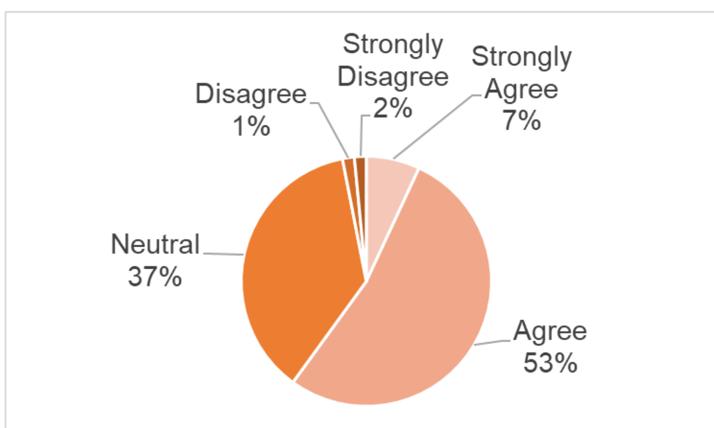


Figure 3.5 Agreement with whether disaster experience has helped with future preparedness

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study estimates that the Wasatch Front could experience an economic loss of $6 billion due to road disruption in the aftermath of an M7.0 earthquake on the Salt Lake City segment of the Wasatch Fault. The study also found that the industrial sectors comprising the largest share of the Wasatch Front economy (namely and in order, retail; professional, scientific, and technical services; manufacturing; and finance and insurance) feature in the top 10 list of worst-affected industries. This indicates a significant economic impact that will reverberate within Utah's economy as a whole, and which could influence economic growth and development for decades to come.

It is important to treat this estimate as a conservative figure since it only reflects effect on intermediate demand, which forms only one part of the supply chain (final demand being another). This estimate also does not include other aspects of economic impact, such as impact to the actual built environment, tax revenue, employment or demand for products (often calculated by Hazus as direct and indirect loss), nor does it reflect losses due to rail disruption which is also a mode of supply distribution to the state. Lastly, this estimate only includes impact supply disruption to the Wasatch Front and not the impact freight traffic traveling through the state. The latter is of significance because Utah lies at the hub if seven major freight routes in the country (Braceras and Kuhn, 2017). This implies that the $6 billion loss estimated by this study is likely to be far exceeded in the event of a high magnitude earthquake and could affect the entire national economy. This should act as a call for action to build infrastructure and business resilience in the local communities of the Wasatch Front. The current Biden-Harris Administration's emphasis on supply chain resilience and the 2021 Executive Order 14017 provide support to the need to understand and address supply chain resilience within the state and the country.

The results of the first phase also call for more inquiry into the current state of business-level preparedness and mitigation. To this end, this study conducted a survey of businesses in Salt Lake City to gauge what their level of preparedness has been and to understand their behaviors in response to recent disaster events. The study has found that businesses are impacted by production costs in the aftermath of disasters, which fits well with the predictions of the first phase of this study that estimates loss to industrial production due to transportation disruption. The survey also indicates that some businesses benefit from a disaster and that a likely explanation for this is that their industrial sectors are likely more resilient, if not direct beneficiaries of the post-disaster economy (construction or insurance, for instance). The study indicates that businesses are challenged by supply chain disruptions after disasters, both in terms of supplies needed to produce goads but also shipping of produced goods. Businesses in this study tried to diversify their suppliers in the face of concurrent disasters, although not everyone found suppliers within the local geography. Supply chain management issues combined with other employee management and lowered production capacity likely provide an explanation for why a significant proportion of surveyed businesses claim to have still not recovered from the 2020 disasters two years later. This finding adds to the importance of needing to focus on long-term community recovery and the role of infrastructure systems in driving (or inhibiting) this process.

Importantly, the study found that despite businesses claiming higher awareness of disaster preparedness and mitigation, few of them actually took concrete actions—to operations or to the building—to mitigate against future events. This finding points to the need to better understand and address the structural barriers to businesses adopting disaster mitigative and preparedness actions. It also points to a general disconnect between economic development and disaster management practice since there exist practices with each discipline that could promote business resilience to disasters, but they are rarely presented together to affected businesses. For example, in Utah, the Governor's Office of Economic Development provides help to small businesses to assess their supply chains, but these services are not automatically coupled with disaster aid provided to the same business through the Federal Emergency Management Agency (FEMA) or the U.S. Small Business Administration (SBA). At the same time, economic development institutions rarely emphasize hazard retrofits to business owners despite it being important to the continued or quick reopening of businesses after disasters.

The study makes the following key recommendations in order to improve infrastructure and economic resilience within the Wasatch Front:

Increase investment in resilient transportation infrastructure

This research makes a case for strengthening Utah's road infrastructure to better withstand a high impact, low probability earthquake—the cost of such improvements is far likely to be outweighed by the potential benefit in both, a monetary sense as well as in the sense of protecting Wasatch Front communities. The 2022 Infrastructure Investment and Jobs Act presents a significant opportunity for state and local transportation agencies to make disaster and climate resilience improvements to transportation infrastructure including bridges and roadways. Hazus scenario data for the Wasatch Region already identifies the roadway and bridges at highest risk of damage. These combined with social equity analysis and in keeping with the recent Justice40 Initiative, can act as a guide to transportation infrastructure improvements within the region. Pre-disaster engineering improvements to transportation infrastructures are likely to help protect the regional and Utah economies in the aftermath and allow Utah communities to recover faster.

Improve business resilience practices for high-impact industrial sectors

This study identifies the following industrial sectors as potentially experiencing greater than $100 million in individual economic loss due to post-earthquake supply disruption: manufacturing; real estate and rental and leasing; professional, scientific, and technical services; administrative, support, waste management, & remediation services; transportation and warehousing; finance and insurance; wholesale trade; information; retail trade; and construction. These sectors constitute approximately 70% of the Wasatch Front economy which indicates that impacts to these sectors carry serious repercussions for the economic growth in the region, if not the state. Additionally, according to the SBA, over 99% of Utah's economy comprises of small businesses which often do not have the knowledge or capacity to undertake preparedness and mitigation activities (SBA, 2021). These facts highlight the importance of state and local agencies to invest in disaster education and outreach to businesses in these high-impact sectors. Such outreach may include education on disaster risk, risk assessments, supply chain assessments, business interruption insurance, and business continuity planning. As discussed below, some of these strategies may already be in place, but disconnected from traditional disaster planning institutions.

Identify structural barriers to adoption of resilient business

As Phase 2 of this study shows, even when businesses become aware of disaster risk, they may be unable to undertake concrete disaster preparedness and mitigation actions. This points to the possibility that something other than risk awareness is at play when it comes to adoption of resilient practices by businesses, which also calls for further investigation and alleviating other capacity related such as financial constraints, aid and resource awareness, and social capital characteristics that could also determine disaster resilience actions of businesses (Xiao, et al, 2018; Kim & Chandrasekhar, forthcoming). State and local agencies may also consider including mitigation and preparedness goals into post-disaster recovery programs which are typically better funded than pre-disaster programs (Kim & Chandrasekhar, forthcoming). Such programming is more possible through state and local action because they operate with much greater flexibility than their federal counterparts Not utilizing the recovery moment to promote future mitigation represents a significant lost opportunity to promote resilience within the business community.

Mainstream disaster resilience into economic development

This research also calls for ways to mainstream disaster planning into economic development practices, particularly those aimed at business and industry development. Mainstreaming is defined as the process of “looking critically at each (development program) activity and project that is being planned, not only from the perspective of reducing the existing risks disaster disasters, but also from the perspective of minimizing its potential contribution to creation of new risks of disasters” (Chakrabarti, 2017: 7). In other words, mainstreaming is the act of considering mitigation hazard risk in the process of development planning and not as an ancillary activity. For economic development, this means carefully considering which business development strategies are adding to (or, in a positive sense, mitigating) a business’s disaster risk, and then promoting more resilient practices. The instruments for such mainstreaming arguably already exist—through tools for business planning and supply management offered by economic development institutions on the one hand, and through grant programs for disaster recovery and mitigation from emergency management institutions on the other. The way forward in this case is to break the silos within which these communities of practice operate and develop integrated approaches to resilient economic development, preferably implemented before disaster strikes.

4.1 STUDY LIMITATIONS

The study’s limitations in Phase 1 are owed mainly to assumptions and choices made during data translation and processing. Specific examples include the following:

- Non-inclusion of rail and air transportation disruptions, which limits the study’s ability to estimate travel delays by these modes.

- Use of Hazus functionality/recovery function instead of damage function to better reflect the transportation system's ability to continue operations in the event of a disaster and because of better fit with link capacity measure in the WF-TDM model.
- Assuming that for non-highway bridges, functionality of the road links going through it or under it would be the same as the bridge. For highway bridges, functionality of the road link going through the bridge was assumed to be the same as the bridge, but the road link going under the bridge was assumed to remain unaffected due to the possibility of re-routing that traffic and the priority given to highways for debris clearance.
- Assuming the advent of recovery phase at Day 30 based on the National Response Framework, FEMA's 2017 Pre-Disaster Recovery Planning Guide for Local Governments and American Planning Association's 2015 Planning for Post-Disaster Recovery: Next Generation (PAS Report 576).
- Only including operational costs associated with trucking and not accounting for value of commodity in the cost of time delay.
- Annualizing of cost of delay over a calendar year regardless of date of earthquake.
- Trimming the annualized cost scenarios by remove the highest and lowest curves, which may reduce its accuracy.

The study's limitations in Phase 2 are owed mainly to survey overrepresentation by quick-recovery industrial sectors, which may have skewed study findings to be more positive than on ground. The Phase 2 survey was also constrained by time and monetary considerations, which affected its response rate and limited its geographic scope to one city in the Wasatch Region.

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APPENDIX A: TECHNICAL APPENDIX

TECHNICAL NOTES

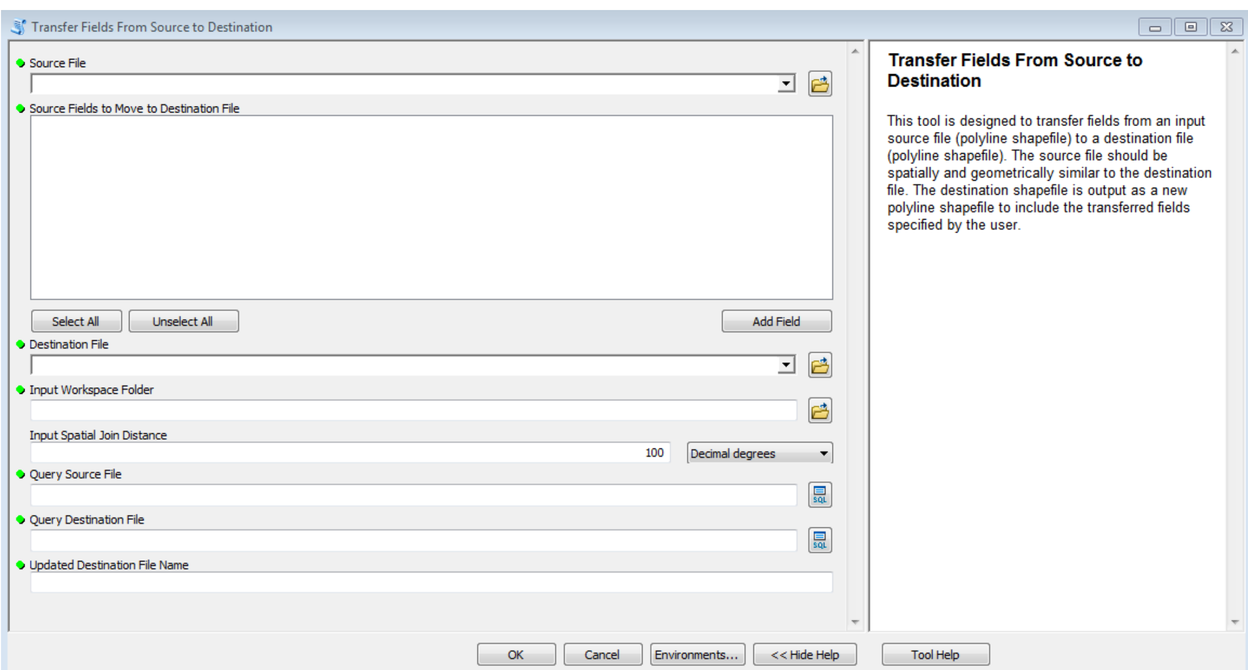
1.1 We also fit curves to the Day 1 and Day 30 delay VHTs, but in most cases the declines were not realistic, with significant delays still present one year after the earthquake.

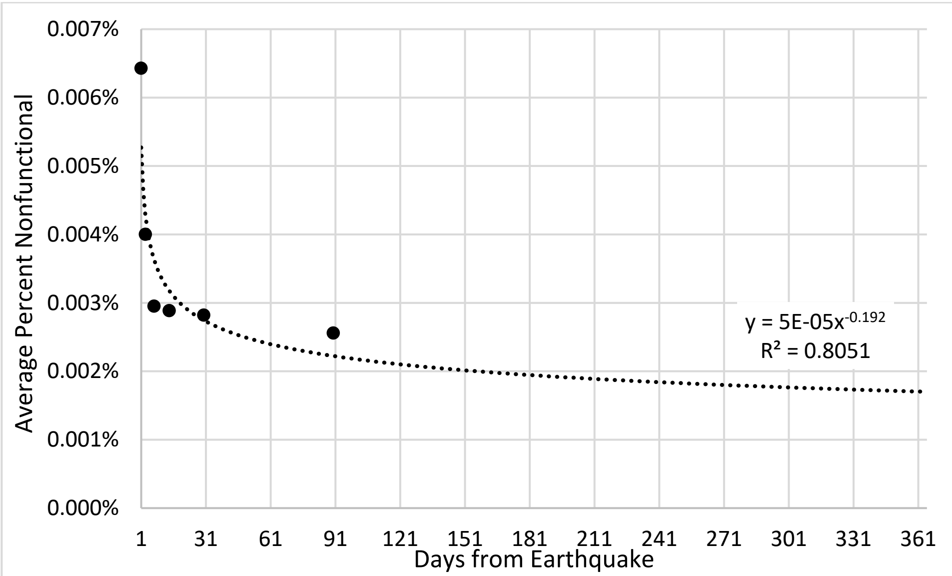
1.2 The equation of the trendline fitting the HAZUS average functionality data was of the form $f(x) = axb + c$, where $f(x)$ is the percent nonfunctional on day x and c is a constant. Setting $f(180) = 0$ implies $c = –a(180)b$. Therefore, $f(x) = axb – a(180)b$. This was run through the Solver in Excel with the functionality data for Days 1, 3, 7, 14, 30, and 90 to determine the parameters a and b that minimize the sum of squared errors. To scale to VHT, we used the exponent b and solved for a when $f(1)$ equals the Day 1 delay VHT produced by the travel demand model.

1.3 For example, the TSA sector-level direct requirements table has one industry for natural resources and mining. This is represented by three industries in the 23-sector REMI PI+ model: forestry, fishing, related activities, and other; mining; and farms. We used gross output data from the BEA for each of these industries to calculate their shares of a combined natural resources and mining industry, and used these shares to allocate the natural resources and mining trucking requirements to the three component industries.

FIGURES AND TABLES

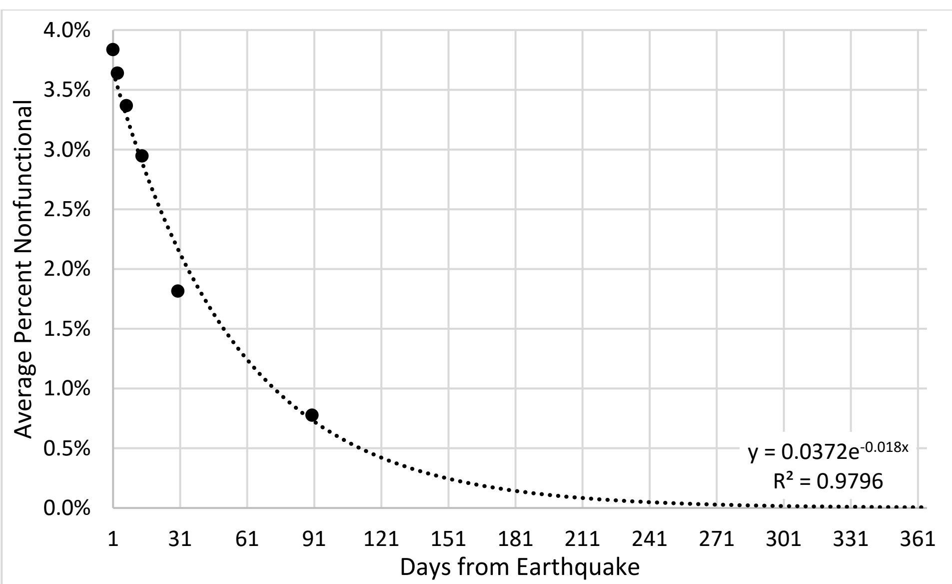
Figure 1: Custom "Transfer Fields" tool used in geoprocessing of roadways





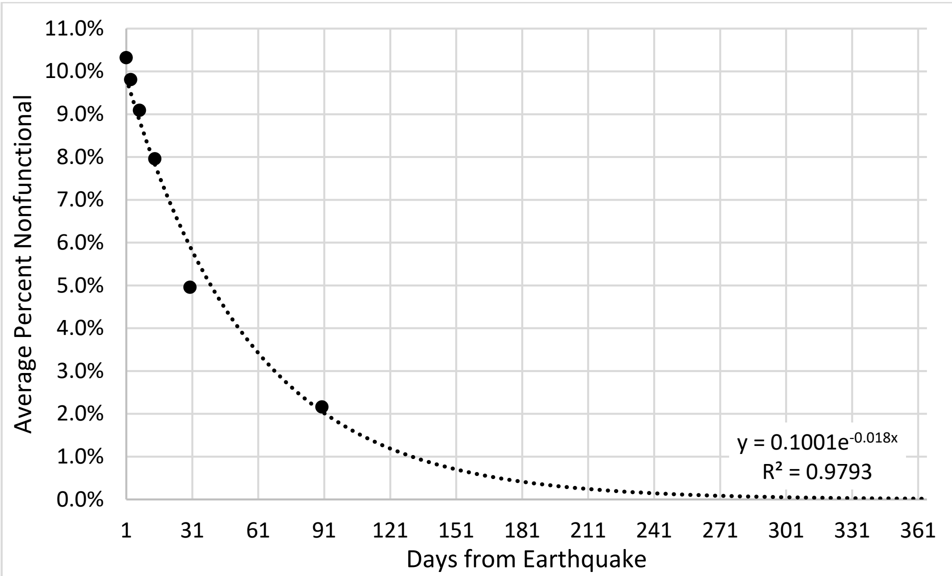
Note: Day 1 is the day of the earthquake.
Source: Kem C. Gardner Policy Institute analysis of Hazus model output provided by Utah Division of Emergency Management

Figure 2: Road and Bridge Recovery Curve for Box Elder County



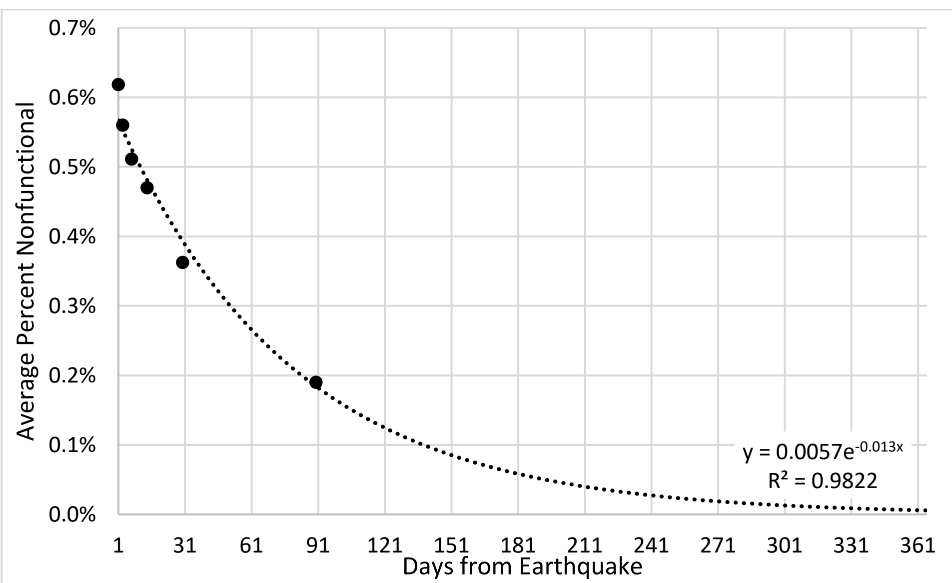
Note: Day 1 is the day of the earthquake.
Source: Kem C. Gardner Policy Institute analysis of Hazus model output provided by Utah Division of Emergency Management

Figure 3: Road and Bridge Recovery Curve for Davis County



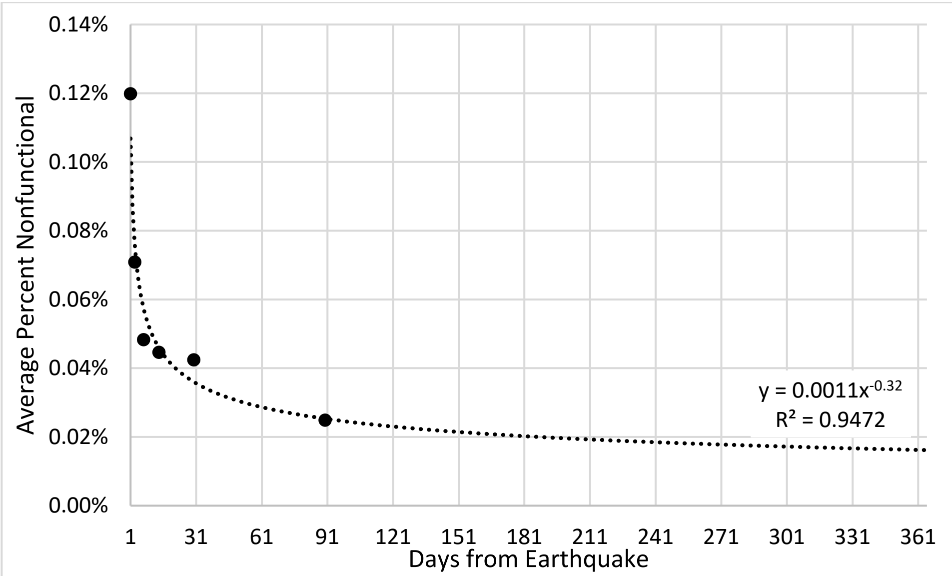
Note: Day 1 is the day of the earthquake.
Source: Kem C. Gardner Policy Institute analysis of Hazus model output provided by Utah Division of Emergency Management

Figure 4: Road and Bridge Recovery Curve for Salt Lake County



Note: Day 1 is the day of the earthquake.
Source: Kem C. Gardner Policy Institute analysis of Hazus model output provided by Utah Division of Emergency Management

Figure 5: Road and Bridge Recovery Curve for Utah County



Note: Day 1 is the day of the earthquake.
Source: Kem C. Gardner Policy Institute analysis of Hazus model output provided by Utah Division of Emergency Management

Figure 6: Road and Bridge Recovery Curve for Weber County

Table 1: Queries used in geoprocessing of roadways

File Name	Hazus Highway Segments Query	TDM Master Network Query
Master_Fwy	Comment = '1' OR Comment = '2' OR Comment = '4'	"FT_2019" > 31 AND "FT_2019" < 41 AND "LN_2019" > 0
Master_Art	Comment = '3' OR Comment = '5' OR Comment = '6' OR Comment = '8' OR Comment = '9'	"FT_2019" > 1 AND "FT_2019" < 20 AND "LN_2019" > 0
Master_Ramps	Comment = '7'	FT_2019 = 21 OR "FT_2019" = 30 OR "FT_2019" = 31 OR "FT_2019" = 41 OR "FT_2019" = 42

Table 2: Queries used to identify roadway links missing in Hazus highway segment inventory

File Name	Query
Master_2020-08-17	FT_2019 <> 1 AND "LN_2019" > 0 AND "FunctDay1" = 0 AND "Flag" < 1 (outside damage area)

Table 3: Box Elder County Intermediate Demand Impacts by Industry, 2019
(Millions of Dollars)

Industry	Change in Intermediate Demand	Share of Total	Industry Size
Manufacturing	-$49.3	64.2%	25.0%
Real estate and rental and leasing	-$6.2	8.0%	5.6%
Transportation and warehousing	-$6.2	8.0%	7.9%
Wholesale trade	-$3.4	4.5%	2.8%
Construction	-$2.8	3.7%	8.3%
Administrative and waste management services	-$2.4	3.1%	6.6%
Professional and technical services	-$1.7	2.2%	3.1%
Retail trade	-$1.6	2.1%	11.4%
Other services, except public administration	-$1.5	1.9%	5.7%
Accommodation and food services	-$0.8	1.0%	6.8%
Utilities	-$0.5	0.7%	0.2%
Mining	-$0.1	0.1%	0.4%
Health care and social assistance	-$0.1	0.1%	8.0%
Finance and insurance	-$0.1	0.1%	3.3%
Arts, entertainment, and recreation	$0.0	0.1%	1.9%
Information	$0.0	0.0%	0.6%
Forestry, fishing, and hunting	$0.0	0.0%	0.7%
Management of companies and enterprises	$0.0	0.0%	0.3%
Educational services	$0.0	0.0%	1.4%
Total	**-$76.8**	**100%**	**100%**

Note: Industry Size represents each industry's share of total employment in the county.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model.

Table 4: Davis County Intermediate Demand Impacts by Industry, 2019
(Millions of Dollars)

Industry	Change in Intermediate Demand	Share of Total	Indust ry Size
Manufacturing	-$175.7	46.1%	9.3%
Real estate and rental and leasing	-$48.2	12.7%	7.3%
Professional and technical services	-$35.7	9.4%	9.5%
Transportation and warehousing	-$25.8	6.8%	4.7%
Administrative and waste management services	-$24.8	6.5%	4.9%
Wholesale trade	-$18.4	4.8%	2.1%
Construction	-$13.4	3.5%	8.5%

Retail trade	-$10.4	2.7%	13.0%
Other services, except public administration	-$8.9	2.3%	6.6%
Accommodation and food services	-$4.6	1.2%	7.0%
Information	-$4.1	1.1%	1.1%
Finance and insurance	-$3.4	0.9%	6.7%
Utilities	-$2.4	0.6%	0.2%
Health care and social assistance	-$1.6	0.4%	9.7%
Arts, entertainment, and recreation	-$1.6	0.4%	3.3%
Mining	-$1.0	0.3%	0.3%
Educational services	-$0.6	0.2%	4.1%
Management of companies and enterprises	-$0.2	0.1%	1.5%
Forestry, fishing, and hunting	$0.0	0.0%	0.1%
Total	**-$381.0**	**100%**	**100%**

Note: Industry Size represents each industry's share of total employment in the county.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model.

Table 5: Salt Lake County Intermediate Demand Impacts by Industry, 2019
(Millions of Dollars)

Industry	**Change in Intermediate Demand**	**Share of Total**	**Industry Size**
Manufacturing	-$758.0	18.9%	7.3%
Real estate and rental and leasing	-$543.0	13.5%	6.2%
Professional and technical services	-$458.0	11.4%	9.7%
Transportation and warehousing	-$427.9	10.6%	6.0%
Finance and insurance	-$418.5	10.4%	9.3%
Administrative and waste management services	-$387.2	9.6%	7.7%
Wholesale trade	-$311.5	7.7%	4.2%
Information	-$179.2	4.5%	2.7%
Retail trade	-$110.2	2.7%	10.9%
Construction	-$100.5	2.5%	6.2%
Other services, except public administration	-$89.4	2.2%	5.2%
Accommodation and food services	-$72.6	1.8%	6.9%
Mining	-$63.0	1.6%	0.5%
Utilities	-$31.3	0.8%	0.2%
Arts, entertainment, and recreation	-$22.4	0.6%	2.3%
Management of companies and enterprises	-$20.6	0.5%	2.2%
Health care and social assistance	-$19.1	0.5%	9.0%
Educational services	-$7.5	0.2%	3.4%

Forestry, fishing, and hunting	-$0.5	0.0%	0.1%
Total	**-$4,020.5**	**100%**	**100%**

Note: Industry Size represents each industry's share of total employment in the county.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model.

Table 6: Utah County Intermediate Demand Impacts by Industry, 2019
(Millions of Dollars)

Industry	**Change in Intermediate Demand**	**Share of Total**	**Industry Size**
Manufacturing	-$156.2	23.3%	6.7%
Professional and technical services	-$107.8	16.1%	10.6%
Real estate and rental and leasing	-$106.2	15.8%	6.2%
Administrative and waste management services	-$66.8	9.9%	6.1%
Wholesale trade	-$57.3	8.5%	2.4%
Information	-$52.8	7.9%	4.6%
Retail trade	-$25.4	3.8%	13.5%
Construction	-$22.0	3.3%	9.2%
Other services, except public administration	-$16.5	2.5%	5.3%
Transportation and warehousing	-$15.5	2.3%	2.0%
Utilities	-$14.0	2.1%	0.2%
Accommodation and food services	-$11.7	1.7%	6.3%
Finance and insurance	-$8.9	1.3%	5.5%
Health care and social assistance	-$4.8	0.7%	9.7%
Educational services	-$2.4	0.4%	7.2%
Arts, entertainment, and recreation	-$2.0	0.3%	2.4%
Mining	-$0.6	0.1%	0.3%
Management of companies and enterprises	-$0.3	0.0%	1.5%
Forestry, fishing, and hunting	-$0.1	0.0%	0.2%
Total	**-$671.3**	**100%**	**100%**

Note: Industry Size represents each industry's share of total employment in the county.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model.

Table 7: Weber County Intermediate Demand Impacts by Industry, 2019
(Millions of Dollars)

Industry	**Change in Intermediate Demand**	**Share of Total**	**Industry Size**
Manufacturing	-$72.8	40.8%	12.4%
Real estate and rental and leasing	-$26.3	14.8%	5.7%

Administrative and waste management services	-$16.3	9.2%	8.3%
Professional and technical services	-$13.0	7.3%	6.3%
Wholesale trade	-$11.0	6.2%	3.2%
Transportation and warehousing	-$9.5	5.3%	3.4%
Construction	-$7.4	4.2%	7.4%
Retail trade	-$5.3	3.0%	13.4%
Other services, except public administration	-$4.3	2.4%	6.3%
Finance and insurance	-$3.3	1.9%	6.9%
Accommodation and food services	-$2.8	1.6%	7.1%
Health care and social assistance	-$1.9	1.0%	12.3%
Utilities	-$1.2	0.7%	0.2%
Forestry, fishing, and hunting	-$1.1	0.6%	0.3%
Information	-$1.0	0.6%	0.9%
Arts, entertainment, and recreation	-$0.7	0.4%	2.7%
Mining	-$0.2	0.1%	0.2%
Educational services	-$0.1	0.1%	2.1%
Management of companies and enterprises	$0.0	0.0%	0.7%
Total	**-$178.1**	**100%**	**100%**

Note: Industry Size represents each industry's share of total employment in the county.
Source: Kem C. Gardner Policy Institute analysis using the REMI PI+ model.