

Construction Capacity and Residential Roofing Reconstruction after Hurricanes in Texas and Puerto Rico

Dr. Erin Arneson, PhD.
Colorado State University
Fort Collins, CO

Over the past decade, the U.S. has experienced an increasing number of billion-dollar hurricane events. The 2017 hurricane season was particularly devastating to the residential housing stock, which is susceptible to damages from high wind speeds. For example, over 465,000 residential houses were damaged or destroyed after Hurricanes Irma and Maria struck Puerto Rico and an additional 370,000 houses were damaged or destroyed following Hurricane Harvey in Texas. The strong winds associated with these hurricanes caused over $38 million dollars in direct damages to the roofs of residential houses. The residential roofing sub-sector of the broader U.S. construction industry plays a critical role in meeting the increased demand for roofing repairs and reconstruction after disaster events. *Construction capacity*, defined here as the maximum building volume a construction industry can supply with available resources, may determine how efficiently residential roofs are rebuilt following a disaster. To better prepare for post-disaster reconstruction, this study addresses the question: *how does pre-disaster construction capacity for the U.S. residential roofing sector influence post-disaster demand surge for construction services?* This research analyzed this question for residential house roofing repairs and replacement in Texas and Puerto Rico following Hurricanes Irma, Maria, and Harvey in 2017. Building on literature from construction supply chain management theory, we: (a) identified construction wholesale trade (material) and residential roofing contractor (labor) establishments within Texas and Puerto Rico; (b) measured pre-disaster construction capacity as the net value of residential construction that can be performed in a given year; (c) calculated post-disaster roofing losses for single-family residential housing based on FEMA damage inspections; and (d) compared pre-disaster construction capacity and post-disaster roofing damages, using a cross case comparison. Results highlight the extent to which the U.S. roofing sub-sector within Texas and Puerto Rico was capable of meeting post-disaster demand for residential roofing construction.

Key Words: Construction Capacity, Residential Roofing, Reconstruction

Introduction

The U.S. ranks in the top five countries most hard hit by disasters, both in terms of frequency of events and economic losses (FEMA 2013). Economic losses from individual disasters now often exceed one billion dollars, especially for large-scale natural hazard events such as hurricanes. Due to steady population growth and expanding residential housing development along the coastal U.S., residential houses are increasingly exposed to damages caused by high wind speeds associated with hurricanes. In fact, the overwhelming majority of residential roofs in the U.S. are built with asphalt shingles, which can become severely damaged and destroyed from wind speeds produced by even the lowest Category 1 classification of hurricane (Standohar-Alfano and van de Lindt 2015). Therefore, strong hurricane wind shears often result in widespread damages to the residential housing stock, requiring rapid mobilization of construction industry resources to quickly repair disaster damaged roofing. To meet post-disaster demand for the repair and reconstruction of residential housing, the construction industry must be capable of supplying adequate labor and material resources (Hwang et al. 2015). However, the U.S. residential construction industry is highly susceptible to unexpected disruptions in normal operating conditions such as disaster events (Halman and Voordijk 2012), which often result in a sudden demand surge for residential construction services. Rapid reconstruction of residential housing is critical for post-disaster recovery (Nejat and Damnjanovic 2012), but is hampered by the widespread damage caused by hurricanes and a lack of available construction industry resources (Cantrell et al. 2012). According to the U.S.

National Disaster Housing Strategy, post-disaster reconstruction efforts must focus on state-level recovery efforts, which in turn, are determined by pre-disaster construction industry resource availability within individual U.S. states (FEMA 2013).

Specifically, this study examines the role of pre-disaster construction resource availability, including both labor and materials, for the residential roofing sub-sector. Here, the research introduces and defines the term *construction capacity* as the maximum building volume a construction industry can supply with available resources at a given time. The author hypothesizes that existing pre-disaster construction capacity either facilitates or hinders post-disaster residential roofing repair and reconstruction. Residential roofing material supply chains are particularly vulnerable to sudden demand surge associated with extreme weather events, where demand quickly outpaces the available material supply. Unexpected material demand surge makes it difficult for manufacturers to anticipate demand, often resulting in severe regional and statewide shortages of asphalt shingles (Olsen and Porter 2011). In addition, the residential roofing sector has experienced significant craft labor shortages (AGC 2017) and decreased manufacturing and production of roofing materials since the start of the Great Recession in 2007 (U.S. Census Bureau 2002a; b, 2007). Therefore, in order to better understand the role construction capacity plays in post-disaster rebuilding, we seek to address the research question: ***how does pre-disaster construction capacity for the U.S. residential roofing sector influence post-disaster demand surge for construction services?***

Research Context: Hurricanes Irma, Maria, and Harvey

According to the National Oceanic and Atmospheric Administration (NOAA), the 2017 hurricane season was the costliest year for disaster related damages in U.S. history (NOAA 2017). Three major hurricanes – Harvey, Irma, and Maria – impacted both Texas in mainland U.S. and the territory of Puerto Rico. The Federal Emergency Management Agency (FEMA) estimates that Hurricane Harvey caused over $2.1 billion dollars of total damages to residential houses, while Hurricanes Irma and Maria resulted in nearly $1.8 billion dollars of residential housing damages (FEMA 2018). All three hurricanes were classified as a Category 4 or higher, producing sustained wind speeds of at least 130 miles per hour (NOAA 2017). Since over 90% of residential houses in the U.S. are built with wood-framed construction and asphalt shingles, which can lose structural integrity and experience roof failure with sustained wind speeds as low as 100 mph (Standohar-Alfano and van de Lindt 2015), wind events such as hurricanes can cause severe roofing damages across widespread geographical areas. Accordingly, there were high levels of wind-related roofing damages to houses in both Texas and Puerto Rico after these three hurricanes.

Literature Review

This research builds upon theory and methods originally developed in the manufacturing industry to quantitatively measure material and labor resource availability. The author measures pre-disaster construction capacity for the residential roofing sector using two concepts: *material capacity utilization* and *unit labor costs.* This literature review provides background context to understand how these indicators originally developed and how they can be applied to measure construction industry resource availability.

Material Capacity Utilization and Unit Labor Costs

As the modern American manufacturing sector matured, firms began to quantitatively measure resource supply and demand mechanisms. Early manufacturing firms used supply chain theory to try to establish a supply to demand ratio is 1:1, so that end consumers could always purchase needed products while avoiding overstocking store shelves (Gill 2015). Capacity utilization, the ratio of production demand to the maximum available supply (e.g., capacity) measures the effectiveness of supply and demand relationships for any given industry (Fevolden 2015), as shown in Equation 1. When production capacity for material goods (e.g., supply) outpaces production output (e.g., demand) capacity utilization is below 100%. Capacity utilization rates below 100% indicate excess material stock inventories and lower material costs. When demand outpaces supply, capacity utilization rates rise above 100%. Higher capacity utilization rates represent a lack of available material resources and often result in higher material pricing and longer lead times (Mulligan 2016). The national U.S. capacity utilization rate has been measured by the U.S. Federal Reserve since

1972, and has remained stable around 82% across all tracked industries (Board of Governors of the Federal Reserve System 2016). However, the Federal Reserve only tracks national level data, does not include the construction industry in these measurements, and does not break down results by industry sub-sectors. Although capacity utilization can be used to measure supply chain efficiency and typical material resource availability within a given industry, only minimal research has examined such processes for the U.S. construction industry (Gill 2015). Instead, the construction industry has typically relied on historical demand levels to anticipate and manage future material needs (Goodrum et al. 2009). This approach does not consider the impact of unexpected disruptions like disasters on industry supply chains, nor the sudden increased need for construction labor and materials (e.g., demand surge) after disasters (Mulligan 2016).

$$Capacity\ Utilization = \frac{Demand\ (\$)}{Supply\ (\$)} \quad (1)$$

Past research has shown that the ability of construction laborers to generate output (e.g., residential houses constructed) varies significantly across U.S. states (Vereen et al. 2016). Additionally, construction industry labor capabilities have been difficult to identify and measure because there is no single data source or definition for construction labor efficiency (Gill 2015). *Unit labor costs*, defined here as *the ratio of annual labor wages paid compared to the resulting production output value*, have been used in other industries as a metric for measuring labor efficiency and is shown in Equation 2 (Woodford 2001). Unit labor costs indicate the value of produced output ($USD) that can be generated for every $1 paid in total annual labor wages. Unit labor costs indicate the efficiency with which capital resources are transformed by an industry's labor force into a finished product. The U.S. Federal Reserve is the only governmental agency tracking and publicly posting unit labor costs in the U.S. (Board of Governors of the Federal Reserve System 2016). However, unit labor cost data is aggregated for multiple industries and only at the national level, and few researchers have examined unit labor cost data for the U.S. construction industry or sub-sectors (Vereen et al. 2016).

$$Unit\ Labor\ Costs = \frac{Labor\ Wages\ (\$)}{Value\ Produced\ Output\ \ (\$)} \quad (2)$$

Research Methods

To answer the research questions, the authors followed a multi-step process that: (a) measured pre-disaster construction capacity for baseline year 2012 (e.g., the most recent construction industry economic performance data); (b) calculated post-disaster FEMA verified roofing losses from Hurricanes Harvey, Irma, and Maria in Texas and Puerto Rico; and (c) compared pre-disaster construction capacity to post-disaster roofing demand surge.

Data Collection

This study relied on publicly-available state-level data sources to perform all analyses. Material and labor data were collected from the U.S. Bureau of Labor Statistics (BLS) and U.S. Census Bureau from years 2012-2016 (U.S. Bureau of Labor Statistics 2016; U.S. Census Bureau 2002b, 2012a; b). Hurricane roofing damages were collected from FEMA for the disaster year 2017 (FEMA 2018). Data was collected from the BLS and Census Bureau because they are the only U.S. governmental agencies that track and publish publicly available industry-level economic data. Pre-disaster state-level construction capacity data was collected from the baseline years 2012-2016, since that is the most recently published data that is publicly available from the U.S. government and includes economic data to measure both material capacity utilization rates and unit labor costs.

Material and labor data were used to measure pre-disaster construction capacity from the years 2012-2016 to form a baseline trend. Data were sourced from the U.S. Bureau of Labor Statistics (BLS) and the Census Bureau, which incorporate North American Industry Classification System (NAICS) codes to identify sub-sectors of the construction industry (e.g., residential construction roofers). First, the authors collected datasets from the BLS *Census of Employment and Wages*. This included the annual average number of employed residential roofers and the annual average wages paid to those residential roofers during 2012-2016 in Texas and Puerto Rico (e.g., NAICS 23816 – Residential roofers) (U.S. Bureau of Labor Statistics 2012).

Second, the researchers collected construction capacity metrics from the Census Bureau, namely the *2012 Economic Census program*. This involved identifying three state or territory level construction capacity metrics, including: the value ($USD) of annual residential roofing put in place by all residential roofing contractors and laborers within each state (e.g., NAICS 23816 – Residential roofers); the value ($USD) of all roofing materials, components, and supplies purchased annually by any building contractors within each state or territory (e.g., NAICS 236 – Building General Contractors); and the value ($USD) of all building materials sold annually by merchant wholesaler establishments within each state or territory (e.g., NAICS 4233 – Lumber and Other Construction Materials, using 'Products and Services code 10721 to identify roofing materials) (U.S. Census Bureau 2012a; c). The Economic Census is the only publicly available source of construction sub-sector economic performance but is only conducted every five years. The last published Economic Census is from 2012 and was thus used in this research.

Third, the author collected inflation index data from the Census Bureau's *Survey of Construction*, which provides a national price index for the value of residential construction work put into place annually (U.S. Census Bureau 2017a). Index data is based on physical characteristics and prices of new houses (excluding land or other non-construction values), as well as interviews with builders (U.S. Census Bureau 2017b). To explore how pre-disaster construction capacity may influence post-disaster reconstruction, the year 2016 was established as a baseline for the 2017 hurricane season. The inflation index was used to estimate the 2016 baseline from the most recent economic data in the 2012 Economic Census.

Lastly, data needed to measure the demand for post-disaster repair and reconstruction of residential roofs were collected from FEMA's *Individual Assistance program* (FEMA 2014). When a large-scale disaster event such as a hurricane overwhelms resources available within a given U.S. state or territory, FEMA sends trained housing inspectors to assess the value ($USD) to repair damaged houses. The value of these assessed damages is tracked and reported by the inspectors while in the field, including a separate estimated value to replaced damaged roofing components. FEMA estimated roofing damages were collected for both Texas and Puerto Rico from the year 2017 (FEMA 2018).

Data Analysis

A model was developed to identify construction capacity based on material and labor resource availability. 2016 was used as a baseline for pre-disaster construction capacity in both Texas and Puerto Rico, based on inflation-adjusted economic performance data from the most recent Economic Census conducted by the U.S. Census Bureau. Model results were then compared with the FEMA roofing losses from Hurricanes Harvey, Irma, and Maria in the post-disaster phase. Building upon concepts from the manufacturing industry, the authors developed a model for measuring two metrics: capacity utilization and unit labor costs (Gill 2015; Woodford 2001).

First, the capacity utilization rates for both Texas and Puerto Rico were measured as the ratio of demand to supply for building materials, as shown in Equation 3. This study identified the cost of materials, components, and supplies ($USD) purchased by any residential building contractors or subcontractors (NAICS 236) within Texas, Puerto Rico, and for the total U.S. This value represents the typical annual demand for roofing materials. Next, the volume of wholesale trade sales ($USD) completed by merchant wholesalers (NAICS 4233) within each or territory was identified. This value represents the total supply of building materials within Texas, Puerto Rico, and for the total U.S. in the pre-disaster baseline year.

$$Capacity\ Utilization = \frac{Cost\ Materials\ Purchased - NAICS\ 236\ (\$USD)}{Wholesale\ Sales - NAICS\ 4233\ (\$USD)} \quad (3)$$

Second, the unit labor costs were calculated as the inverse ratio of annual wages to the value of roofing work put into place, as shown in Equation 4. Unit labor costs represent the annual value of residential roofing put in place ($USD) for every $1 of annual wages paid to residential contractors and is therefore a measure of labor efficiency. The total annual wages paid to residential roofers (NAICS 23816) in Texas and Puerto Rico in 2016 was identified. Next, the authors identified the value of construction put in place by those same residential contractors (NAICS

23816) during 2012. This value was multiplied by the Census Bureau's housing cost index to adjust for inflation, to estimate the 2016 baseline year value of roofing work put in place in Texas and Puerto Rico.

$$Unit\ Labor\ Costs\ = \frac{1}{\left[\frac{(WAGE^{2016})}{(CV^{2012})(HCI^{2016})}\right]} \quad (4)$$

Where:
$WAGE^t$ =total annual wages, in year t
CV^t = construction value put in place, in year t
HCI^t = national housing cost index construction inflation adjustment, in year

Results

Pre-disaster construction capacity was measured for both Texas and Puerto Rico using two specific metrics: material capacity utilization and unit labor costs, as shown in Table 1 and Table 2. Since material capacity utilization rates are calculated as a ratio, the study used data from 2012 with no inflation adjustment to estimate the 2016 baseline capacity utilization. Unit labor costs were calculated using roofer wage data from 2016 and inflation adjusted value of roofing work put in place. These pre-disaster capacity measurements were then compared against hurricane roofing damages, as shown in Table 3.

Results of this study indicate that pre-disaster capacity utilization rates for asphalt roofing materials vary significantly across different states or territories, such as Texas and Puerto Rico. The U.S. national capacity utilization (86%) for the roofing sub-sector of the construction industry was measured by the author based on national purchases and sales of shingle roofing materials. The national capacity utilization is well below 100% and therefore represents an excess of roofing materials available for purchase in wholesaler locations such as Home Depot, Lowes, or other privately owned wholesalers across the entire U.S. Therefore the national capacity utilization rate for the residential roofing sub-sector (86%) aligns closely with the national capacity utilization rate tracked across all industries (82%) by the Federal Reserve.

However, the capacity utilization rates for both Texas (103%) and Puerto Rico (242%) represent varying degrees of roofing material shortages within smaller geographic areas. For example, in Texas the supply to demand ratio is close to 1:1, indicating that roofing materials are sold from stores very quickly and the supply is just barely keeping pace with demand throughout the state. Puerto Rico was already experiencing severe roofing material shortages even before Hurricanes Irma and Maria struck in 2017. A capacity utilization rate of 242% reflects a massive shortage of roofing materials available for purchase in local wholesaler store locations throughout Puerto Rico. Since all building contractors bought almost 2.5 times the available roofing supplies sold in the territory, this also indicates that contractors were forced to import roofing materials to keep up with project demand in the pre-disaster setting.

Table 1

2016 Construction Capacity Baseline – Capacity Utilization

Location	Cost of Materials Purchased ($USD)	Material Wholesale Sales ($USD)	Capacity Utilization % ($ Materials Purchased / $ Wholesales)
Texas	$1,195,033,000	$1,158,705,000	**103%**
Puerto Rico	$45,520,000	$18,788,000	**242%**
U.S. Total	$247,936,646,016	$286,438,419,278	**86%**

Unit labor costs for residential roofing contractors also varies across the U.S. (Table 2). While the U.S. average unit labor costs are $2.36, they are $11.79 for Texas and $17.65 for Puerto Rico. Since unit labor costs represent the value of roofing work put in place annually per dollar spent on labor wages annually, unit labor costs are a measure of labor efficiency (Woodford 2001). Higher unit labor costs seen in both Texas and Puerto Rico reflect high levels of efficiency in the pre-disaster baseline year and represent roofing labor workforces that can build and repair roofs more quickly than the national average. However, such efficiency is due to lower wage rates in Texas and Puerto Rico compared to the U.S. national average.

Table 2

2016 Construction Capacity Baseline – Unit Labor Costs			
Location	**Value Construction Installed[a] ($USD)**	**Annual Wages[a] ($USD)**	**Unit Labor Costs (Value Construction Installed / Annual Wages)**
Texas	$2,385,971,000	$202,444,360	**$11.79**
Puerto Rico	$83,863,000	$4,750,924	**$17.65**
U.S. Total	$62,210,863,826	$26,410,660,679	**$2.36**

a = includes residential construction index inflation adjustment

The demand for residential roofing construction services after a disaster event can also vary across geographic location, even for areas that experience the same type of hazard event such as a hurricane (Table 3). Results show that Texas experienced approximately $4.1 million dollars in residential roofing losses. To understand the magnitude of the demand surge for residential roofing services Hurricane Harvey created in Texas, the FEMA assessed roofing losses were compared against the typical pre-disaster baseline capabilities of Texas roofing contractors. Since Texas residential roofers typically installed over $2.3 billion dollars in roofing annually, the spike in demand for post-disaster roofing was almost negligible. However, Texas had much lower residential roofing damages than Puerto Rico. Puerto Rico experienced residential roofing losses of over $34.7 million dollars from Hurricanes Irma and Maria in 2017. Not only were the total roofing losses higher than those seen in Texas, but the demand surge was also much more pronounced. Since roofing contractors in Puerto Rico only installed about $83.9 million dollars in roofing work annually in the pre-disaster setting, the unexpected demand to repair and replace over $34.7 million dollars in hurricane damaged roofs resulted in a 41% demand surge.

Table 3

Post-Disaster Residential Roofing Demand Surge			
Location	**FEMA Assessed Roofing Losses ($USD)**	**Value Construction Installed[a] ($USD)**	**Demand Surge (Roofing Losses / Value Construction Installed)**
Texas	$4,104,616	$2,385,971,000	**0.17%**
Puerto Rico	$34,742,421	$83,863,000	**41.00%**

a = includes residential construction index inflation adjustment to reflect 2016 costs

Discussion and Conclusion

The frequency of hurricane events and the severity of hurricane-related residential housing damages in the U.S. is increasing over time. High wind speeds associated with hurricanes are leading to growing post-disaster roofing damages and economic losses due to the prevalence and susceptibly of wood-framed asphalt roofs to wind damage. Although the residential roofing sub-sector of the U.S. construction industry is responsible for quickly repairing and replacing damaged roofing components after major disaster events, there are few strategies available for determining pre-disaster vulnerability to disasters due to construction material and labor resource availability. Despite the increase in billion-dollar disaster events, there is a lack of quantitative research that examines how the U.S. construction industry can better prepare for and respond to disasters. To address this gap, this research explores how existing pre-disaster construction capacity, measured in terms of material and labor resource availability, affects post-disaster demand surge for construction services. In other words, by quantitatively measuring the amount of roofing materials readily available for purchase at wholesaler locations and the value of work that can be installed by roofer laborers in a typical year, we can calculate the increased demand for construction services that is imposed on the surrounding construction industry after a disaster. The author hypothesizes that areas of the U.S. with readily available roofing materials and an efficient labor workforce will experience less pronounced demand surges for post-disaster roofing construction work, decreasing the burden on the local roofing construction industry. An examination of two case study locations, Texas and Puerto Rico after the 2017 hurricane season, reveal similar housing economic losses from hurricane damage. However, the impact of the hurricanes in these two locations was vastly different due to the pre-disaster construction resource availability and efficiency (e.g., construction capacity) and the demand surge imposed on the local roofing sub-sectors.

For example, at the aggregate national-level there is an adequate supply of roofing materials available to the construction industry. The national roofing capacity utilization rate of 86% calculated in this research reflects a surplus supply and is similar to the capacity utilization rate tracked by the Federal Reserve for all industries (82%). In contrast, both Texas and Puerto Rico were already experiencing roofing material shortages before Hurricanes Harvey, Irma, and Maria even made landfall. The capacity utilization rates above 100% in both Texas (103%) and Puerto Rico (242%) indicate that the demand for roofing materials outpaced the available supply. While Texas was nearly keeping up with roofing material demand, Puerto Rico's construction industry demand was nearly 2.5 times greater than supply. Such material shortages would likely only be exacerbated by unpredictable supply chains, transportation routes, and temporary flooding issues that typically arise after hurricanes.

In contrast, both Texas and Puerto Rico have very efficient roofer labor workforces, which can repair and replace damaged roofing much quicker than seen at the national level. Roofers nationally have a unit labor cost of $2.36, so for every $1 in annual wages paid out a roofer can install $2.36 in roofing materials. Higher unit labor costs were measured in Texas ($11.79) and Puerto Rico ($17.65), indicating they have lower roofer wages and are thus more efficient at installing roofing work from an economic standpoint.

Lastly, the true reflection of how difficult the post-disaster reconstruction phase will be can be seen in the demand surge in Texas (0.17%) and Puerto Rico (44.0%). When the demand for construction services after a disaster overwhelms the existing industry capabilities, labor must be imported from nearby regions and states in order to avoid delays in rebuilding. This is a particularly difficult problem for Puerto Rico, since it experienced an enormous post-disaster demand surge for residential roofing services and is geographically isolated from the mainland U.S.

In summary, this research is an early step in understanding how to quantitatively measure and assess post-disaster reconstruction challenges faced by both the U.S. construction industry and the communities the industry serves. This research adds to the literature regarding construction supply chain management theory, by identifying construction capacity as a key component of effective post-disaster supply chains for the residential roofing industry. Therefore, analysis of regional pre-disaster construction supply chain elements, such as merchant wholesaler and contractor labor establishments, can help downstream suppliers better anticipate and meet sudden post-disaster demand surge for construction services. Disasters tend to exacerbate existing conditions, including construction labor and material resource availability. States and territories with low construction capacity metrics could use such information to assess the risk posed by disasters to the existing residential building stock. By measuring pre-disaster construction capacity, both governmental agencies involved in pre-disaster preparedness and the roofing industry involved in post-disaster reconstruction work can begin to understand their vulnerability to future disaster events. The need for pre-disaster preparedness planning, to address the challenges communities and the U.S. construction industry face in replacing damaged roofing in a post-disaster setting, must become a priority for both communities and the regional construction industries that serve them.

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