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# Functionality Recovery of Steel Grain Bins in Rural Communities Following the August 2020 Iowa Derecho

Evi Troulis, Undergraduate Research Student
*California Polytechnic State University, San Luis Obispo*

Christine E. Wittich[1], Assistant Professor
*University of Nebraska-Lincoln*

## ABSTRACT

Agriculturally-dominated rural communities are critical to the United States national economy, however the resilience of these communities has been noted to be considerably lower compared to their more urban counterparts. In August 2020, a derecho windstorm swept over 750 miles of land in the rural Midwest of the United States, inflicting particularly significant damage in the state of Iowa. While damage was observed to buildings, transmission lines, and other typical infrastructure, agricultural structures such as steel grain bins dominated damage reports. As a result, this storm provided an opportunity to study the performance of these critical agricultural structures under high winds as well as to evaluate the recovery of their functionality over time, in an effort to understand the unique contributors to agricultural and rural resilience. To this end, over 160 agricultural sites and over 700 individual steel grain bins were surveyed immediately following the storm and after one year. The state was split into seven widespread regions, which were then separated based on business site. Each bin was recorded by their initial state of damage, followed by other characteristics, such as dimensions, county socioeconomic factors, and ownership types. It was found that high initial damage, large bin capacity, and high county-level unemployment rates positively correlated with a change in functionality. Of particular note is the relationship with ownership type, where agricultural cooperatives initially suffered more bin losses compared to private farms, but were able to recover at a much faster rate.

*Keywords: agriculture, wind, steel silo, community resilience*

## INTRODUCTION

Rural areas are primarily responsible for supporting nearly the entire agriculture industry in the United States (U.S.). Given that they mainly consist of agricultural fields, rural communities house the majority of U.S. crops, which contribute not only to the economy, but also to the growth and support of the population. Rural areas also house most of the transportation networks between cities and ports in the United States. According to the Federal Highway Administration (2020), 71.2% of highway miles, 69.4% of highway lane miles, and 72.4% of bridges are in rural areas. When rural areas are impacted by a natural disaster, the transportation systems in the U.S. often are too. Despite their importance, rural areas are vastly underrepresented in research and media. This can be seen when the House of Representatives set aside 81 billion dollars dedicated to natural disaster relief in 2017. While this is a large sum of money, only three percent of that amount, approximately 2.6 billion dollars, was reserved for the recovery of crops, trees, livestock losses, and other rural area disasters, some of which are hurricanes Harvey, Irma, Maria, and wildfires that year (Bloch, 2018).

Resilience is defined herein as the ability to resist or absorb systemic shocks and to rapidly recover from impacts. There are numerous definitions for community resilience that have been developed by different

[1] Corresponding Author: Christine E. Wittich, Assistant Professor, Department of Civil and Environmental Engineering, University of Nebraska-Lincoln, Lincoln, NE. Email: cwittich@unl.edu.

disciplines (Koliou et al. 2018). In general, resilience has three main aspects: Reducing impacts or consequences, reducing recovery time, and reducing future vulnerabilities (Adger, Hughes, Folke, Carpenter, & Rockstrom, 2005; Cutter et al., 2008; Maguire and Hagen 2007; Resiliency Alliance 2007; UN/ISDR, 2005; Walter, 2004). After a natural disaster, a drop in functionality of physical, economic, and social systems tends to follow. Functionality recovery is the amount of time needed for a system to return to its fully functional state and is the driving factor for many resilience analyses.

Rural areas have shown to be less resilient than their more urban and suburban counterparts. According to Cutter et al. (2016), resilience in urban areas is primarily driven by economic capital, while in rural areas, resilience is primarily driven by community capital. This means that resilience cannot be approached the same way in every kind of community, and it will vary from area to area. Distinct areas should therefore be analyzed and modeled in a variety of ways, as they each have different strengths and criteria. It is also theorized by Cutter et al. (2016) that the reason for the lack of resilience in rural areas is due to their geographic remoteness and limited economic diversity. Another reason for lack of resilience in rural areas is due to their business and government operations struggling to be maintained under regular circumstances, therefore when facing a disaster, they lack the excess capacity and resources required to support the community (Cutter et al., 2016). This serves as an obstacle for resilience in rural communities, as they prevent rural areas from a quick recovery.

Rural areas are characterized by various agricultural systems outstretched over a large area, such as irrigation systems, barns, and storage bins. These agricultural systems are not designed to the same standards as the houses and buildings in urban areas, therefore during a natural disaster, the rural areas may face higher catastrophes than the urban communities. This is largely due to the structural design of the buildings in these different areas (Loken et al., 2020). An example of these rural-area-structures are steel grain bins, which are used to store harvested crops. Steel grain bins are cylindrical structures consisting of corrugated steel walls. These walls are made of corrugated steel plates that are approximately three-and-a-half feet tall. They are bolted together to fabricate the circumference of the bin and are connected to the ground through various anchorage types. Some bins include vertical stiffeners and wind hoops, which help to reinforce the structure, as shown in Fig. 1.

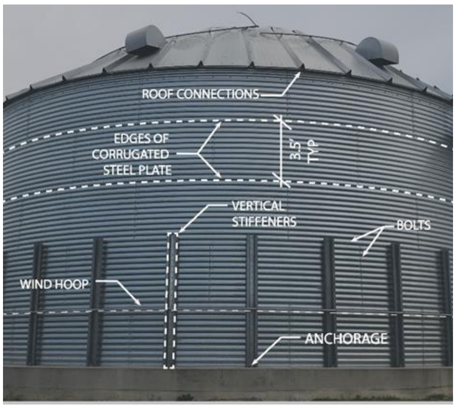



***Figure 1.*** *Standard steel grain bin with annotations for key structural components*

In August of 2020, a derecho, or windstorm of long-lasting straight-line winds, devastated over 750 miles of land in rural areas, including Nebraska, Iowa, Illinois, and Indiana. This caused substantial damage to the agricultural community, most particularly the steel grain bins. Approximately 57 million bushels of grain was lost, resulting in $11 billion in damage. Twenty percent of Iowa's farmland, an estimated 6 million acres of corn and soybeans, were lost. While planted crops and steel grain bins can often be covered by some insurance policies, the stored grain is not (Wittich et al., 2021). This significantly impacts individual farmers and also the entire regional agricultural economy. Depending on their structure and materials, grain bins have shown to perform unpredictably under wind forces (H.V. Kebeli et al., 2001). When subjected to wind, steel grain bins may experience several damage and failure mechanisms including: roof buckling, wall buckling, roof tear-off, and anchorage failure. (Wittich et al., 2021). In this paper, the performance of steel grain bins in rural areas following the 2020 derecho is presented and compared to the 12-month functionality of the bins. By interpreting these functionality changes based on different variables, trends that predict the functionality recovery of grain bins are preliminarily proposed.

## INITIAL RECONNAISSANCE: AUGUST 2020

### Methodology

In August of 2020, a derecho, a windstorm consisting of long duration straight-line winds, took place in Iowa, United States, and moved towards the east, devastating 750 miles of land in the Midwest. While both cities and rural areas were affected by this, the windstorm mainly passed through agricultural areas. (Wittich et al., 2021 (in press)). A subset of the authors commenced the initial reconnaissance by selecting 7 regions across the damaged area in Iowa that were characterized by wide ranges in estimated and measured wind speeds. These regions are shown overlaid on a map in Fig. 2 and every other property that included at least one steel grain bin prior to the storm was selected along drivable and accessible paths within the region (Wittich et al., 2021 (in press)). To properly analyze the bins, the authors created a questionnaire to document various characteristics of each bin, such as ownership type (cooperative vs. private), location of site (county), initial state of damage, and general dimensions (height and diameter). Some additional variables that were collected were the manufacturer of the bin, estimated condition of the structure prior to the event, anchorage details, and wall and base dimensions. In addition to the questionnaire, nearby damage to non-bin structures was also documented to help better constrain the wind field.

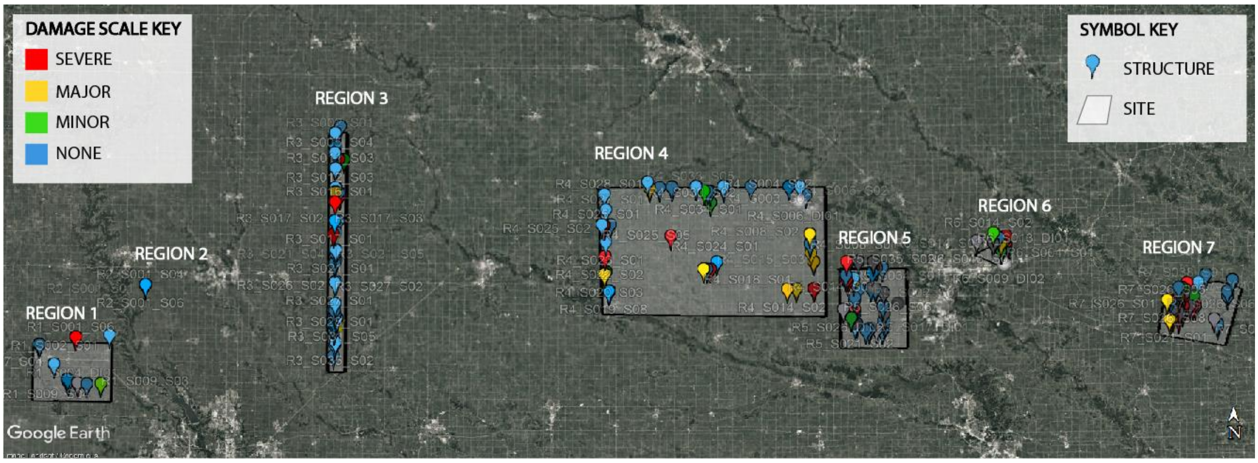



***Figure 2.*** *Map of regions and sites included in reconnaissance.*

At each site and for each bin, the damage was rated. Severe damage was characterized by complete collapse of the bin. Major damage was characterized by a significant breach of the roof, sidewall, or base that could be a result of roof tear-off, roof buckling, wall buckling, or anchorage pullout. Minorly damaged bins were those that sustained minor buckling or non-structural damages, such as staircase failure, but that were not characterized by a breach (i.e., moisture intrusion not occurring). The damage rating of each site surveyed is overlaid in Fig. 2. Bins that underwent severe and major damage were labeled as 0% functional, while bins that had only minor, or no damage, were 100% functional. Site functionality was calculated by taking the average functionality of the site, which was done by dividing the total number of functional bins by the total number of bins. While it is possible that an individual farm could remain functional in the absence of bins, this is expected to have a negligible impact. This is justified by considering that storage capacity typically matches expected harvest. However, an individual farm could elect to store cooperatively for the season. In this case, the reported functionality in this paper would be underreported. The number of cases for which this situation is applicable is expected to be low based upon the increased storage demand as well as informal reports from individual farmers. Alternatives to maintain functionality and farmer decision processes in that regard is outside the scope of this paper, but is the focus of ongoing research.

### Results

Out of all the bins that were damaged, 119 of them experienced severe damage, 74 experienced major damage, and 40 experienced minor damage. 484 bins were left undamaged. Of these 717 bins, 307 were less than or equal to 25 feet in diameter, 330 were between 25 and 50 feet, 37 were between 50 and 75 feet, and 36 were over 75 feet tall. In total, 11 counties were involved in this study: Benton, Boone, Cedar, Clinton, Dallas, Hardin, Jasper, Jones, Linn, Story, and Tama. Boone, Clinton, Jasper, and Jones had to be eliminated due to having an insufficient number of bins and sites being part of the study. The number of bins and sites studied on each county can be seen in Figure 3.

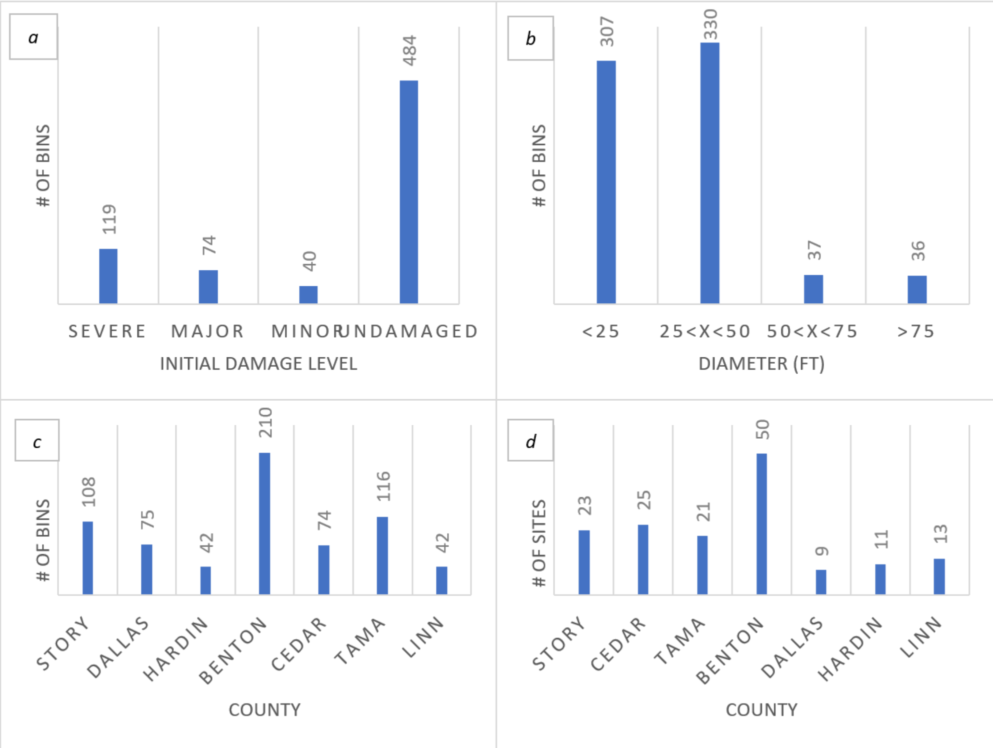


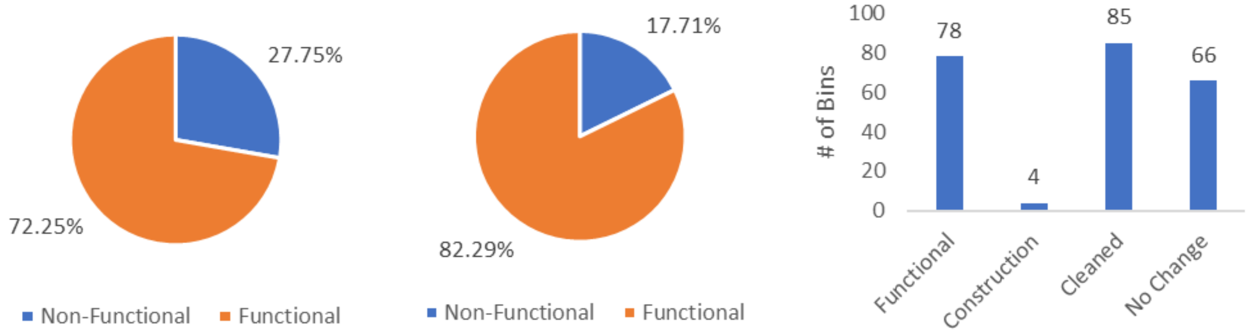

***Figure 3.*** *Initial reconnaissance results.*

**1-YEAR RECONNAISSANCE: JULY 2021**

In July 2021, a second reconnaissance took place where a team led by the authors revisited the sites that were studied during the initial reconnaissance. The goal of the second research group was to evaluate the current state of the farms and determine the recovery of the sites 12-months after the storm. To accomplish this, each bin was recorded with one of four recovery states: fully functional, under construction, debris cleaned up, and no change. Immediately following the storm, the overall functionality of the bins was 72.25%, leaving 27.75% of the bins as non-functional (Fig. 4a). The 12-month follow-up reconnaissance yielded an overall bin functionality of 82.29% (Fig. 4b). While this is a modest increase in functionality, this represents a fairly large reduction in overall grain storage capacity at a critical time of year – that is, the 1-year follow-up reconnaissance occurred just a few weeks before harvest. To further interpret this, the recovery state of the bins at 12-months is shown graphically in Fig. 4c. Note that this data only represents those bins that were initially non-functional immediately after the storm. It can be seen that the number of bins that were repaired or replaced and now fully functional is 78. Only 4 bins were observed to be actively under construction. Therefore, the majority of bins rendered non-functional by the storm in 2020 would still be non-functional in 2021 resulting in 2 years of potentially lost harvests.

**ANALYSIS**

The results of the 1-year reconnaissance indicated that there was a relatively modest increase in bin functionality and that there would still be a significant economic impact for the second year in a row. Specifically, it was seen that the percentage of functional bins went from 72.25% after the storm to 82.29% after 1 year for an increase of 10.04%. It is noted that similar trends were observed when the data is analyzed by the number of sites, rather than the number of bins. In this case, the total increase in site functionality is 9.23%. In order to further explore what made one agricultural site more likely to recover than another, a parametric study is presented in this section. Since sites represent the storage capacity for an individual farm or business, the functionality recovery is analyzed in both bin and site contexts in the following sections.




(a) (b) (c)

***Figure 4**. Functionality of grain bins: (a) immediately after storm and (b) after 12 months. (c) Recovery state for bins at 12 months.*

**Ownership Type**

Farm ownership can largely be classified as private or cooperative. Cooperatives often consist of several independent farmers sharing storage capacity. As these cooperatives can represent large numbers of farms, the site and bins sizes tend to be considerably larger than those at an individual private or family farm. The functionality recovery of private and cooperative bins and sites can be seen in Figure 8, which plots the percentage of functional bins as a function of time after the storm. Both site and bin functionality are plotted in this, separated by square and "x" markers (representing the sites and bins respectively) and blue and yellow colors (representing cooperatives and private farms respectively). When comparing the change in functionality between these two types of farms, it was found that the bins owned by cooperatives experienced higher rates of destruction following the derecho, however they were able to recover at a faster rate. This is likely due to their increased access to resources, which enables them to recover their bins at a faster rate than individual farmers. When looking at site functionality, however, the opposite trend is observed. Since cooperative organizations are typically larger than private organizations, they often own a larger number of bins on each site. Due to this, even if cooperatives lose more bins than private farms do, they have more bins on their sites that remain functional, therefore preventing the site functionality from dropping to a crucially low number. On the contrary, if a private farm with two bins were to lose as little as just one bin, its functionality would immediately drop to 50%. For the same reason, private site functionality recovers faster due to the reduced number of bins that must be replaced.

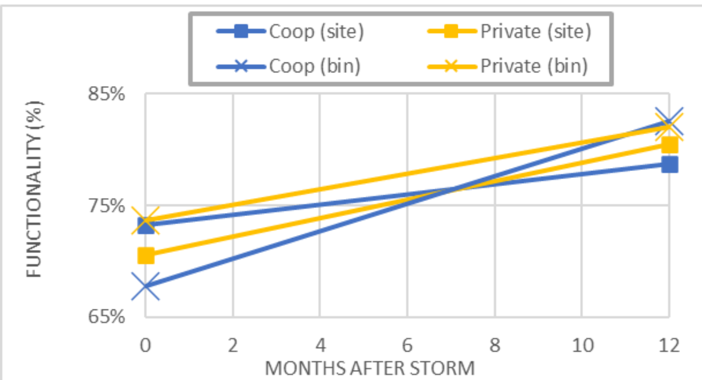
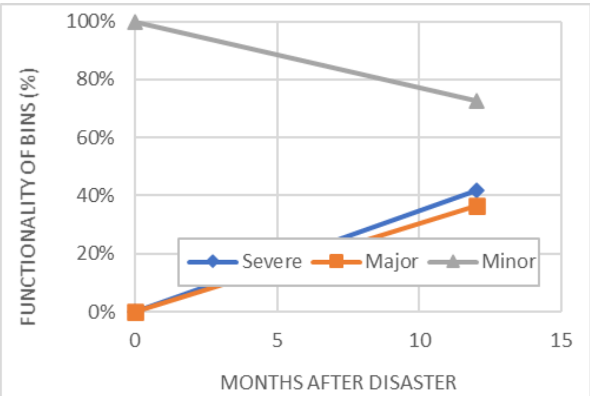



***Figure 5.** Functionality recovery for cooperative and private farms.*

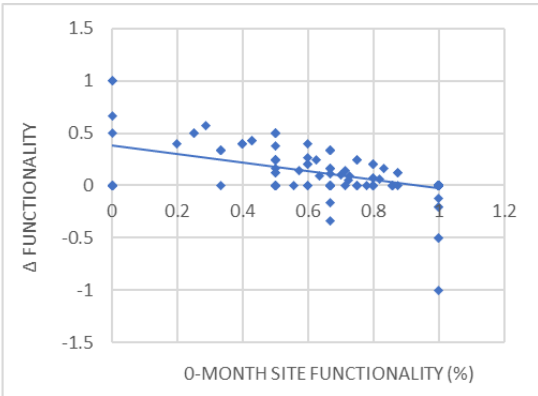
**Initial Damage State**

An additional variable that was explored was how quickly bins were able to recover based on their initial level of damage. Figure 6a plots the average functionality of bins based on their initial damage state as a function of the months after the 2020 derecho. Bins that were severely damaged in the storm increased to an average functionality of 42.02% within one year, while those that were majorly damaged reached a similar average functionality of 36.49% in the same time period. This shows that all bins with an initial functionality of 0% recovered at approximately the same rate. A more interesting finding from this chart is that the functionality of minorly damaged bins reduced from 100% to 72.5%. This can be explained by various reasons, some of them being farmers opting to have a full equipment upgrade, altering their method of storage (such as joining a coop), or entirely changing their business and removing all equipment as a likely response to other impacts such as damage to crops or other structures.

Site recovery was also analyzed based on initial site functionality. This was accomplished by plotting every site's change in average functionality based on its initial average functionality, which can be seen in Figure 6b. The average functionality of each site was calculated and subtracted from its 12-month functionality. A linear regression is overlaid on this plot to emphasize the general trend and account for overlaid data points that may be obscured. In general, it can be seen that there is a much higher increase in functionality for sites that were heavily damage (closer to 0% 0-month site functionality), which is plausible as there is more need for repair and replacement. As expected, the trend decreases with initial (0-month) site functionality. However, the spread of data highlights some interesting findings, particularly for those sites that were initially highly functional in the immediate aftermath of the storm. The change in functionality switches from increases in functionality to evidence several instances of decreases in functionality. This means that a site may have exhibited minor or no damage during the storm, however the total number of bins present after one year is less. This can be indicative of non-storm business decisions (e.g., leaving the agricultural industry, electing to join a cooperative, etc.). However, it can also be indicative of bin replacement when the bin was only minorly damaged. This would have been observed during the 1-year reconnaissance as "debris cleaned up". While it is not possible to differentiate these situations with the current data, it warrants further exploration as the dedication of resources to high functioning sites would be expected to have an overall negative impact on the region's agricultural economy.




(a)




(b)

***Figure 6.*** *(a) Bin functionality recovery as a function of initial damage, and (b) Change in site functionality as a function of initial site functionality.*

**Bin Structure**

The recovery of individual bins was further explored by looking at the diameter of the bins, ranging from as little as 9 feet to as much as 130 feet. The bins were separated into four categories: less than 25 ft, between 25 ft and 50 ft, between 50 ft and 75 ft, and over 75 ft. For each, the average functionality was calculated at 0 and 12 months after the storm. The results are presented in Figure 7. It can be seen that bins smaller than 25 feet in diameter had the highest functionality following the derecho and did not evidence any significant change in functionality after one year. Fig. 7 also shows that the bins that faced the most damage from the derecho were the bins larger than 75 feet, however they were also the ones that underwent the largest recovery. Their functionality increased from 33.3% to 80.04%, nearly a 50% increase. This trend follows that discussed with regard to cooperative and private farms. As mentioned previously, cooperatives tend to own larger bins due to having larger storage needs; however, their bins also tend to experience more damage after a windstorm. This is likely due to bins with larger diameter being taller, therefore being more exposed to wind and vulnerable to damage. Since large bins suffered more damages, it is likely that they were prioritized by their owners during recovery, therefore returning to their 100% functionality rate much more efficiently.

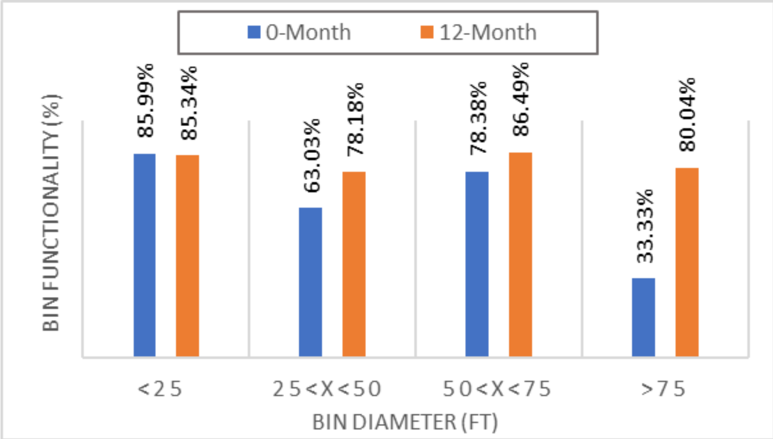



***Figure 7.*** *Functionality recovery as a function of bin diameter.*

**County-Level Socioeconomic Indicators**

Geographic location was also analyzed for potential correlation with functionality recovery, which was categorized at the county level and analyzed by county socioeconomic indicators including average household income and unemployment rate. The average change in functionality of each bin and site was calculated and placed in a table comparing it to the characteristics of each county, which can be seen in Table 1. For both bins and sites, Story County had the smallest recovery rate, and Linn County had the largest recovery rate. The median household income of both counties was very similar, approximately $64,000. The unemployment rate of the two counties, however, was vastly different. For Story County, it was 3.6, while for Linn County it was 6.4, nearly twice as high. This outcome gives reason to believe that a higher unemployment rate in an area allows the bins to recover at a faster rate. After plotting the recovery of both bins and sites compared to their associated county's unemployment rate, a positive correlation can be identified, which can be seen in Figure 8. A potential reason for this correlation could be that high unemployment meant a larger available labor pool to be leveraged in reconstruction efforts, however further analysis is required.

***Table 1.*** *County-level socioeconomic indicators and change in bin and site functionality.*

| | Change in Bin Functionality | Change in Site Functionality | Unemployment Rate | Median HH Income | # Silos | # Sites |
|---|---|---|---|---|---|---|
| *Story* | 2.78% | 3.78% | 3.6 | $64,151 | 108 | 23 |
| *Dallas* | 4.00% | 7.20% | 3.6 | $97,535 | 75 | 25 |
| *Hardin* | 4.76% | 7.88% | 4.6 | $57,103 | 42 | 21 |
| *Benton* | 9.05% | 10.09% | 5 | $70,023 | 210 | 50 |
| *Cedar* | 9.46% | 11.23% | 4.4 | $71,029 | 74 | 9 |
| *Tama* | 17.24% | 14.03% | 5.1 | $56,281 | 116 | 11 |
| *Linn* | 28.57% | 23.46% | 6.4 | $64,783 | 42 | 13 |


***Figure 8.*** *Change in functionality as a function of county-level unemployment rate.*

## CONCLUSIONS

The goal of the study was to elucidate what characteristics of steel grain bins and their associated businesses contributed to quicker functionality recovery within an impacted agricultural area. Positive correlations were found with initial damage after the event, bin capacity (size), and county-level unemployment rates. Initial level of damage is indicative of whether repair and replacement are necessary and is an expected indicator of recovery, however the precise degree of damage was not found to correlate. Bin capacity or bin size also positively correlated with recovery. This similarly agrees with initial damage since the majority of damage was observed for larger bins. The recovery of these larger or more damaged bins can be explained, in part, when considered ownership type. Cooperative farms have substantially larger storage needs and typically have much larger bins. These larger bins were more often damaged due to their high exposure and thin structure. Cooperative farms, however, tend to have significantly more resources at their disposal which likely contribute to their ability to recover quicker compared to private or family farms. At the county level, recovery of both bins and sites was found to correlate with unemployment rates. While the precise reasons are not able to be fully understood based on this study, it is hypothesized that this contributes to a larger available labor pool to aid in repair and replacement of structures after the storm. Further research is ongoing to understand functionality trends in more detail as well as to understand farmer decision processes regarding alternatives to maintaining functionality after a storm.

## ACKNOWLEDGMENTS

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