Agricultural Equipment Management and Natural Disasters: A Hurricane Irma Case Study

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Background

Hurricane Irma History

Irma made its first landfall as a Category 5 storm on Barbuda with sustained winds above 178 mph and gusts over 184 mph, and a minimum pressure of 918 mb on 6 September; Irma reached peak strength the day before (Cangialosi et al, 2018). Irma made landfall on St. Martin and the British Virgin Islands with similar wind surface speeds. By 8 September, Irma crossed the Bahamas with 155 mph winds and moved towards Cayo Romano, Cuba where it made landfall the next day with an increased 167 mph estimated windspeed (Cangialosi et al, 2018). As Irma crossed parts of Cuba it weakened down to a Category 2 storm, before re-intensifying to a Category 4 storm before landing in Florida on 10 September; it first landed on Cudjoe Key with windspeeds estimated at 132 mph and a minimum pressure of 931 mb, later landing near Marco Island with sustained surface winds of 112 mph and a minimum pressure of 936 mb (Cangialosi et al, 2018). Irma traversed peninsular Florida: by midnight as a Category 2 storm tracking east of Fort Myers; by 6:00 a.m. as a Category 1 hurricane located between Tampa and Orlando; by noon it was downgraded to tropical storm 20 miles west of Gainesville; as Irma traversed the Georgia-Alabama border at 6:00 a.m. the next day (12 September) it remained a depression until it dissipated over Southern Missouri the next day (Cangialosi et al, 2018).

Despite Southwest Florida's inherent lack of topography, and the dire predictions of storm surge prior to landfall, the peak USGS storm tide sensor with a wave-filtered water level of 8.31 ft NAVD88 (converting to 7.5 ft Mean High, High Watermark) at Everglades City, did not equate to excessive in-land storm surge related flooding (Cangialosi et al, 2018). The surge did keep estuaries and rivers at their respective high watermarks, and thus the drainage and feeder cannels that remove much of the surface as subsurface waters of Southwest were also at peak depth.

Rainfall across peninsular Florida averaged between 10 to 15 inches as Irma moved northward (Cangialosi et al, 2018). The Florida Automated Weather Network (FAWN) reported that in the 4-days prior to landfall (September 6, 7, 8, 9) there was a cumulative 3.18-inches of rain reported in Immokalee, FL (N 26.46225, W 81.44033; FAWN, 2017). On the day of landfall and as the Eye of Hurricane Irma passed by (September 10) Immokalee recorded 12.16-inches of rainfall (FAWN, 2017). This exceeds the 24-hour 100-year storm event of 11.0-inches and approaches the 24-hour 200-year storm event 12.5-inches (HDSC, 2017). For the three days Hurricane Irma directly impacted the Immokalee area (September 9, 10, 11), the total rainfall recorded was 14.53-inches (FAWN, 2017). The total rainfall for the three-day period (September 9, 10, 11) exceeds the three-day 100-year storm event of 13.4-inches, while it is below the three-day 200-year storm event 15.2-inches (HDSC, 2017).

Purvis Farms and Farmers Alliance Packing

At the time of the storm, Wade Purvis grew peppers, tomatoes, and green beans along with other vegetables on two fields, one East of, and the other West of Immokalee, FL. Immokalee is the heart of South-West Florida’s vegetable production and the region is one of the major national leaders in vegetables for the winter market. Prior to Irma, Purvis Farms employed 31 fulltime workers of various skill levels, and hundreds of temporary migrant workers during tomato and pepper harvests. Wade Purvis also manages Farmers Alliance Packing in Immokalee, a vegetable packing house serving four local farms and is branded as a consortium of seven farmers and other growers that serve the restaurants along US Eastern seaboard with fresh fruit and vegetables.

Preparations Before the Storm

Wade Purvis developed his hurricane preparedness plan, just in time for the 2004 Hurricane Season, that year the Major Hurricane Charlie (Category 4) went through the region. Between the preparation and a little luck, no damage occurred. Maybe with a little overconfidence, Purvis admits, the farm dealt with Major Hurricane Wilma (Category 3) the following year. The aftermath of Wilma was devastating to crops Purvis had in the field. Between 2005 and 2017, the region was spared all but Tropical Storms Ernesto, in 2006, and Fay, in 2008.
In the days prior to the storm preparations were well underway. All potential debris at both the fields and packaging plant were removed from outside locations and secured. Equipment was arranged to minimize damage, as an example, tractors were surrounded with vegetable wagons to block flying debris. Purvis had purchased several generators over the years, for use at the farm and packaging facility. Purvis’ plan includes loaning generators and providing meals to partners and staff, with the intent to free them from homebound worries allowing a focus on timely repairs to both the farm and packaging operations. Meals were also prepared and made available to the staff immediately after the storm. Aid was also given to the local greenhouse nursery that supplied transplants sets to Purvis Farms and Alliance partners, including storing transplant sets in the refrigerated cold rooms and helping cut plastic openings high tunnel greenhouses so that the greenhouse frames would not be destroyed.

Damage and Repairs to Purvis Farms

At Purvis Farms, primary damage to field operation was due to field flooding, in part to a failed field embankment and rainfall. The was minor damage to poll-barns, and lightweight pump station structures were all blown away. There was minor damage to tractors and to several pump stations. Pepper transplants were set to begin for the Fall season, and between the wind and flooding all field work including the laid black plastic mulch was a loss. Initially nearby waterways were over capacity limiting field drainage. Tractor damage was limited to soft components, like belts and hoses, Pierced and abraded by flying debris. Tractors were repaired with a supply of replacement belts and hoses maintained on site. Likewise, some of the damage to the pump stations was mostly focused on the soft components of the prime movers (hoses, belts, plastic caps and coverings, etc.), though some more significant damage occurred when covering structures were blown off. Utilizing replacement and spare parts, along with sacrificing components of nearby irrigation pump stations, all drainage pump stations were fixed and fields were dewatered within three days. Fields were prepped and crops were planted for the Fall season. Unfortunately, minor damage to the to the pole barn roofs or pump station shelters have been repaired or replaced (or even located).

Damage and Repairs to Farmers Alliance Packing

The Farmers Alliance Packing experienced damage to windward side of the roof, and at its crest, four condenser and heat exchange units where blown off. The damage to the roof and outer support was limited to an area that provides cover over a loading/unloading area. The damage is not critical and as such has not yet been repaired. The loss of condensers and heat exchangers reduced the refrigeration capacity by 45% and were replaced during the next few growing seasons.

Other Changes

At the end, even though the farm and packaging operations were ensured, the total cost of the damages were just over the insurance deductibles, thus seeking payments off insurance became too onerous and provided too little value in Purvis' estimation. Citing the market prices for peppers and tomatoes, just after the Fall growing season, Purvis switched his farm operations to edamame, lima beans, green beans, cranberry beans, black eyed peas and other pulses for the restaurant market. This reduced competition within the alliance, and with the purchase of, and loan of bean harvesters (both green and shelled), Purvis was able to consolidate his work force to five highly skilled workers and was no longer in need of migrant labor.

Management/Leadership Considerations

Technical Aspects of Reliability and Life Cycle Costs

Many of the terms used in this section are defined for the agricultural sector by ASABE Standard 495.1 NOV2005 (R2015) “Uniform Terminology for Agricultural Machinery Management.” A deeper dive into both the reliability and machinery costs are available in ASABE Engineering Practice 456 DEC1986 (R2015) “Test and Reliability Guidelines” and ASABE Data 497.7 MAR2011 (R2015) “Agricultural Machinery Management Data.”

Reliability

Instantaneous reliability of a given piece of equipment, or any component of a system to be measured is, R, and is determined from

$$R = \frac{n_t - n_f}{n_t} \tag{1}$$

where n_t is the number of operation attempts, and n_f is the number of operation failures. It is important to remember that failure is not necessarily defined as a catastrophic end of an operation event, it is defined in total by acceptable limits on performance as defined by the operations/equipment manager. Failures can be defined as: decrease in quantity or quality of the output produced, increase in the waste product stream, decrease in operating speeds, increase in contamination, decreases in efficiencies, increase in power consumed, increase loads or other inputs, or the redirection of labor. ASABE Standard 495.1 NOV2005 (R2015) defines failure simply as "The inability of a machine to perform its function under specified field and crop conditions."

The instantaneous unreliability of a given piece of equipment, or any component of a system to be measured, Q, is defined as one minus the reliability or by

$$Q = \frac{n_f}{n_t} = 1 - R \tag{2}$$

where both the reliability and the unreliability are expressed as decimal values less than or equal to one.

The long-term reliability of a given piece of equipment, or any component of a system to be measured, R_c, is related to time by the following exponential decay function

$$R_c = \exp(-\lambda t) \tag{3}$$

where, t is time, often expressed in hours of operation, and λ is the failure rate, expressed in units of number of failures per hours. Note that this reliability equation is exponential decay, where the reliability is never better than when new, in fact, it assumes that new component is 100% reliable. The failure rate (exponential rate coefficient) should be much, much less than 1, as 1 would indicate 1 failure per hour of operation. This negates the exist of an infant mortality or wear-out periods and focuses only on the equipment/component's useful life (ASABE 2015a).

As with the instantaneous unreliability of a given piece of equipment, or any component of a system to be measured, Q, the long-term unreliability, Q_c, is defined as one minus the reliability

$$Q_c = 1 - R_c = 1 - \exp(-\lambda t). \tag{4}$$

Equation (4) represents exponential rate limited growth to a maximum of one. This relationship is also referred to as the "Law of Diminishing Returns," however in this case is it says that each step forward in time increases the unreliability by a diminished fraction.

The reliability of a system, or several pieces of equipment operating in ***SERIES***, R_{series}, is the product of all of the reliabilities of the system components, thus

$$R_{series} = R_1 \cdot R_2 \cdot \ldots \cdot R_n \tag{5}$$

where R_n is the reliability of the last element in the series process.

The reliability of system, or several pieces of equipment operating in ***PARALLEL***, $R_{parallel}$, is found from subtracting the product of unreliabilities of all the redundant/backup equipment/components from one, thus

$$R_{parallel} = 1 - Q_1 \cdot Q_2 \cdot \ldots \cdot Q_n \tag{6}$$

where Q_n is the unreliability of the last element in the parallel process.
The mean time between failures, $MTBF$, is the basic measures of the reliability, and is determined from

$$MTBF = \frac{1}{n}\sum_{i=1}^{n} T_i \tag{7}$$

where n is the number of failures and T is measured time between individual failures. Since most customers are unfamiliar with the concept of the $MTBF$, most purchase based solely of initial costs, but not how often repairs will need to be made. The $MTBF$ should not be confused with the ultimate measure of reliability is the mean time to failure, $MTTF$, and represents the time from inception to irreparable failure. Ultimately the inverse of the $MTBF$ is the failure rate, λ, thus

$$\lambda = \frac{1}{MTBF}. \tag{8}$$

The mean time to repair, $MTTR$, represents the amount of time it takes to repair a component. While, a slightly larger value is the maximum down time, MDT, and represents the extreme value of the repair time. The MDT is useful in calculating the Availability, A, of a piece of equipment or measured device, which can be found from

$$A = \frac{MTBF}{MTBF + MDT}. \tag{9}$$

Note that as $MTBF$ becomes much larger than MDT, A tends to one, as $MTBF$ approaches MDT, A tends to one half, and as $MTBF$ approaches zero, so does A.

Life Cycle Costs

Life cycle costs are a sum of the fixed and variable costs. Fixed costs are all the cost associated with the purchase of machinery or equipment. The sum of fixed costs goes beyond just the initial cost of the equipment purchase to include:

- Interest (if there was borrowed capital)
- Deprecation
- Insurance
- Taxation
- Structures (if the equipment is stored when not in used, or requires a repair/maintenance facility)
- Infrastructure (if the equipment requires infrastructure, fuel or chemical storage tanks, external power, and the like)

Fixed costs are also referred to as the Total Cost of Ownership (ASABE, 2015b).
The variable costs are all the costs associated with the use of the machinery/equipment in question, and include:

- Energy Costs (fuel or electricity)
- Production Resources (seed, fertilizer, or other chemicals)

- Maintenance and Repair (including soft, wearable and fatigued components, lubrication, costs for adjustment)
- Transportation
- Incidentals
- Labor (for both maintenance and operation)

They are referred to as variable costs because as a piece of equipment's use increases, so do its costs; as use decrease, these costs also decrease. Variable costs are also known as Cost of Operation or operating costs (ASABE, 2015b).

In the most simplistic analysis, the cost of a storage structure on a per area basis, C_s, should be less than difference between the salvage value of equipment that has been properly stored when not in use, S_s, and its salvage value when left exposed to the elements, S_o, all divided by the necessary footprint to store the equipment, A_s, written as

$$C_s \leq \frac{S_s - S_o}{A_s} \tag{10}$$

while this inequality does not yield an expression for the ultimate value for proper storage, it does allow maximization of its benefit.

Leadership Aspects: The Lenses

Bolman and Deal (2013) describe four distinct leadership frames to help both better understand (model) how an organization works, and then to target specific actions providing improvements in leadership, and thus improvements to the organization. They consist of the symbolic, political, human resource, and structural frames.

The symbolic frame or lens is defined as the analysis of the definition of the organization's brand, its culture. The symbolic lens focuses on the "inspirational" requirements of leadership, and the creation (or even validation) of the organizational "meanings" or "beliefs (Bolman and Deal, 2013).

The political frame or lens is defined around the analysis of how the organization interacts with other organizations and or agencies. The political lens centers on the "advocacy" or political acumen needed in leadership, and the ability to affect a political "agenda" or develop a "power base" on behalf of the organization (Bolman and Deal, 2013).

The human resource frame or lens is defined as the analysis of both the required and the accumulated skill sets and knowledge base of those within the organization. The human resource lens is aimed at leaderships ability to "empower" an organization by aligning both the "organizational and human needs (Bolman and Deal, 2013). It is by aligning…

The structural frame or lens is defined as the analysis of the hierarchal structure of the organization. The structural lens is targeted at the planning and design leadership must employ to address appropriate roles and responsibilities of individuals within the organization (Bolman and Deal, 2013).

The Structural Lens

In the aftermath of Hurricane Irma, Wade Purvis addressed many important issues before, during, and after the storm using the structural lens. Between the planning and allocating resources he is still in business today. While no plan is without its flaws, it is said that the oft keys to success are in the ability to plan and to adapt. After the many challenge before, during, an immediately after the storm, Purvis changed his farm business form a wide variety of vegetable, to a wide variety of beans, peas, and other pulses. While this cropping change was initiated by the storm, the cause was much more an underlying economic one of commodity prices and competition. But that change did involve a change in personnel from 31 moderately skilled field hands to 5 high skilled workers, and the need of migrant workers for the harvest was replaced with different bean harvesters. The change in the number of personnel, inherently changes the roles and responsibilities of what they were prior to Irma.

The Problem

Your firm is tasked to evaluate Purvis Farms and Farm Alliance Packing, and to ultimately propose changes to make the operations more attractive to future investors, or partners. Use the following questions to guide your team's proposal.

Technical Considerations: Reliability and Life Cycle Costs

- How would minor repairs to farm structures and to the packing house ultimately be beneficial to the overall operation? Would those repairs improve reliability of the equipment? Would they improve the Life Cycle Cost to Benefit ratio of the equipment in favor of the operation?
- How would replacing pump station shelters ultimately be beneficial to the overall operation? Would those shelters improve reliability of the pumps and prime movers? Would they improve the Life Cycle Cost to Benefit ratio of the equipment in favor of the pumps and prime movers?

Reliability

- How would the MTBF of field equipment change if minor repairs to farm structures are made?
- How would minor repairs to farm structures effect field equipment's availability? Its failure-rate? Its unreliability? Its reliability?
- How would the MTBF of pump stations change if protective structures are rebuilt?
- How would new pump station structures effect the pumping equipment's availability? Its failure-rate? Its unreliability? Its reliability?

- What further information do you need to gather?

Life Cycle Costs

- Which element(s) of the Total Cost of Ownership of the field equipment would change if minor repairs to the farm structures are made? Why would they increase or decrease?
- Which element(s) of the Operational Costs of the field equipment would change if minor repairs to the farm structures are made? Why would they increase or decrease?
- Which element(s) of the Total Cost of Ownership of the pump stations would change if new structures are installed? Why would they increase or decrease?
- Which element(s) of the Operational Costs of the pump stations would change if new structures are installed? Why would they increase or decrease?
- What further information do you need to gather?

Leadership Considerations

- How might Purvis Farms and/or Farmers Alliance Packing benefit from addressing any issues with a Symbolic leadership lens?
- How might Purvis Farms and/or Farmers Alliance Packing benefit from addressing any issues with a Political leadership lens?
- How might Purvis Farms and/or Farmers Alliance Packing benefit from addressing any issues with a Human Resource leadership lens?
- How might Purvis Farms and/or Farmers Alliance Packing benefit from addressing any issues with a Structural leadership lens?

The Structural Lens

- How would operations change if the minor repairs were made to both farm structures and to the packing house? Would there be any change to the responsibilities of the workers if repairs are made? Would be any increased need for special worker skills or responsibilities if repairs are made? Any decrease in those needs?
- How would operations change if pumping station structures were rebuilt? Would there be any change to the responsibilities of the worker if the pumping structures are replaced? Would be any increased need for special worker skills or responsibilities if structures are replaced? Any decrease in those needs?
- Is there any need for any other skills or responsibilities, especially if other changes were indicated through the other leadership lenses?

Combined

- How may a detailed reliability study of all equipment first benefit the operations at Purvis Farms and Farmers Alliance Packing? How may it change the operation itself?

- How may a detailed Life Cycle Cost Analysis of all equipment first benefit the operations at Purvis Farms and Farmers Alliance Packing? How may it change the operation itself?

Synthesis

- Based on the brainstorming and your team's responses to the above questions, develop and present your team's evaluation and proposed next steps.

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