# Is Power Outage Associated With Population Density?

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***Abstract*—The U.S. electric power infrastructure is in urgent need of renovation. Recent major power outages in California, New York, Texas, and Florida have drawn attention to the unreliability of the U.S. electric power system. The media discussed America's aging power infrastructure and the Public Utilities Commission called for a comprehensive review of the causes of recent power outages. This study explores geographic information systems to identify a correlation between population density and power outages in Georgia. Initial investigation using ArcMap software as a visualization tool revealed areas where this association emerged.**

***Keywords-Power Outages; Electric Power Infrastructure; ArcMap; GIS.***

## I. INTRODUCTION & PROBLEM DEFINITION

In a short time, electrical power has become a necessity of modern life. Our work, healthcare, leisure, economy, and livelihood depend on the constant supply of electrical power. Even a temporary power outage can lead to relative chaos, financial setbacks, and possible loss of life. U.S. cities dangle on electricity and without the constant supply from the power grid, pandemonium would ensue. Power outages can be especially tragic when they endanger life-support systems in hospitals and nursing homes or systems in synchronization facilities such as in airports, train stations, and traffic control. In 2004, the economic cost of power interruptions to U.S. electricity consumers was $79 billion annually in damages and lost economic activity [1]. In 2017, Lawrence Berkeley National Laboratory estimated power-interruption costs had increased more than 68% per year since their 2004 study [2].

Many reasons underlie current power failures. Among these reasons are severe weather, damage to electric transmission lines, shortage of circuits, and the aging of the power-grid infrastructure. Severe weather is the leading cause of power outages in the United States [3]. In 2018, weather events as a whole cost U.S. utilities $306 billion: the highest figure ever recorded by the federal government [4].

The aging of the grid infrastructure is another noteworthy reason for power failures. In 2008, the American Society of Civil Engineers gave the U.S. power-grid infrastructure an unsatisfactory grade [5]. They stated in a report that the power-transmission system in the United States required immediate attention. Furthermore, the report mentioned that the U.S. electric-power grid is similar to those of third-world countries. According to the Electric Power Research Institute, equipment such as transformers controlling power transmission need to be replaced, as they have exceeded their expected lifespan considering the materials' original design [6].

Electrical outages have three main causes: (1) hardware and technical failures, (2) the environment, and (3) human error [7]. Hardware and technical failures are due to equipment overload, short circuits, brownouts, and blackouts, to name a few [8]–[10]. These failures are often attributed to unmet peak usage, outdated equipment, and malfunctioning back-up power systems. Environment-related causes for power outages comprise weather, wildlife, and trees that come into contact with power lines. Lightning, high winds, and ice are common weather-related power interruptions. Also, squirrels, snakes, and birds that come in contact with equipment such as transformers and fuses can cause equipment to momentarily fail or shut down completely [8]. As for the third main cause for electrical outages, human error, the Uptime Institute estimated that human error causes roughly 70% of the problems that plague data centers. Hacking can be included in the human-error category [11].

Analytics have been a popular topic in research and practice, particularly in the energy field. The use of analytics can help advance Smart Grid reliability by, for example, elucidating a root cause of power failure, defining a solution for a blackout through data, or implementing a solution with continuous monitoring and management. In this research paper, we aim to unveil the novel use of location analytics to investigate power-failure events and their association with population density. In this manuscript, we use ArcMap software to investigate U.S. power concerns and to answer the research question, "Is power outage associated with population density?" The rest of this paper is organized as follows. Section II presents the literature review and the research importance. Section III describes the process of data selection and acquisition. Section IV addresses research tools and methodology. In Section V, we discuss our findings.

## II. LITERATURE REVIEW

The economic cost of power interruptions to U.S. electricity is $79 billion annually [1]. The year 2018 was particularly onerous for outages with wildfires in California and a number of hurricanes that plagued Texas, the Southeast, and Puerto Rico [12]. When Hurricane Harvey struck the Gulf Coast in August 2017, about 280,000 people were without electricity at one point [13]. The report

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specified that the storm took out six transmission lines, 91 circuits, and about 10,000 MW of generation.

When Hurricane Irma hit Florida in 2017, it impacted about 5 million customers in districts where Florida Power & Light operates [14]. Commenting on Hurricane Irma, energy journalist Peter Maloney stated, “Miami-Dade County was hit hardest. At one point, more than 815,000 people, or 80% of [Florida Power & Light] accounts in the county, were without power” [15]. According to Maloney, other jurisdictions in Florida, such as Palm Beach and Broward County, also lost power in 68–70% of their accounts due to the hurricane [15]. Figure 1 sketches the yearly total number of outages in the United States and people affected since February 16, 2008 [16, p. 3].

| Year | Total number of outages | People affected |
|---|---|---|
| 2008* | 2,169 | 25.8 million |
| 2009 | 2,840 | 13.5 million |
| 2010 | 3,149 | 17.5 million |
| 2011 | 3,071 | 41.8 million |
| 2012 | 2,808 | 25.0 million |
| 2013 | 3,236 | 14.0 million |
| 2014 | 3,634 | 14.2 million |
| 2015 | 3,571 | 13.2 million |
| 2016 | 3,879 | 17.9 million |
| 2017 | 3,526 | 36.7 million |

Figure 1. Total U.S. Annual Outages and People Affected 2008–2017

In addition, the report offered the pie chart shown in Figure 2 to break down the 2017 reported power-outage incidents by cause [16]. In the annual report, power-outage incidents were grouped into one of eight possible causes. The number next to each pie piece in Figure 2 is the number of outages associated with that cause.

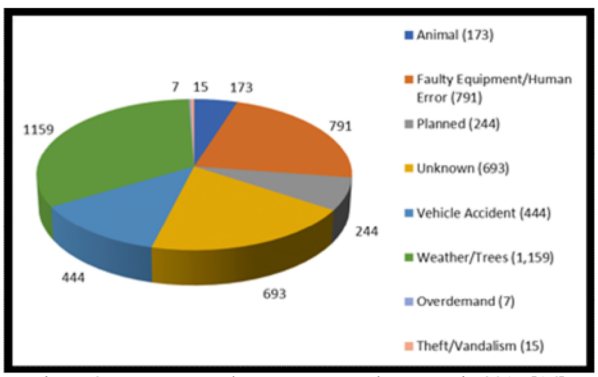


Figure 2. U.S. Reported Power Outages by Cause in 2017 [16]

Based on Eaton’s Blackout Tracker [16] and similar reports that investigate power-outage incidents, key factors behind these outages can be summarized as shown in Figure 3. In our framework (Figure 3), electrical outages have three main causes: (1) hardware and technical failures, (2) environment-related outages, and (3) operation-related failures.

Environment-related incidents comprise the largest portion of power-outage causes. Environment-related incidents can be classified into three distinct categories: weather, wildlife, and trees. In 2017, Wisconsin Public Service delineated the weather-related causes of power outages; a 2005 study by Davies Consulting for the Edison Electric Institute stated that 70% of power outages in the United States are weather related [17][18]. In 2014, Kenward and Raja analyzed power-outage data over a 28-year period; between 2003 and 2012, 80% of all outages were caused by weather [19]. Similarly, in 2012, Campbell highlighted the damage to the electrical grid caused by seasonal storms, rain, and high winds [20].

Severe weather is the leading cause of power outages in the United States: “Between 2003 and 2012, an estimated 679 widespread power outages occurred due to severe weather” [3, p. 3]. Likewise, researchers showed that annual costs changed significantly and were increasingly greater due to major storms such as Hurricane Ike in 2008. “Data from the U.S. Energy Information Administration show that weather-related outages have increased significantly since 1992” [14, p. 7].

In addition to weather, other external forces create power outages. Falling tree branches, for example, are another important cause of power disruption [21]. Animals coming into contact with power lines, such as large birds, are also important culprits in power outages in the United States [16]. Furthermore, human-error incidents cause power outages. Training is essential for technicians and staff to battle outages with proper maintenance procedures [7].

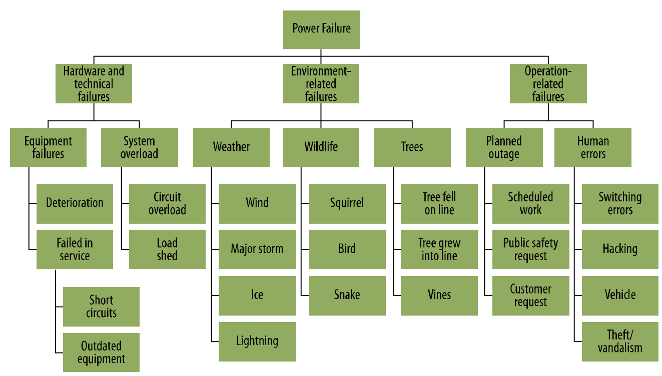


Figure 3. Causes of Power Failure.

Interrupted power supply is no longer a mere inconvenience. As the duration and spatial extent of electricity-system outages increase, costs and inconvenience grow. Critical social services—such as medical care, police and other emergency services, and communications systems—depend on electricity functioning at a minimum. Such failures can bring about catastrophic outcomes; lives can be lost. Grid reliability is an area of research that will help to better explain the causes of outages and aid in prescribing interventions to improve the reliability of the Smart Grid. This report explores Geographic Information Systems (GIS) to correlate population density and power outages in Georgia. This study aims to address whether power outages align with population density.

## III. DATA SELECTION AND ACQUISITION

### *A. Power-Outage Data*

The Electric Power Research Institute (EPRI) data repository includes the primary datasets we used to conduct this analysis [22]. The data sets include data from advanced metering systems, Supervisory Control and Data Acquisition (SCADA) systems, GIS, Outage-Management Systems (OMS), Distribution Management Systems (DMS), asset-management systems, work-management systems, customer-information systems, and intelligent electronic device databases. Access to datasets was provided as part of EPRI's data-mining initiative, an initiative that provides a test bed for data exploration and innovation and seeks to solve major challenges faced by the utility industry [22].

When combined with clever analytic techniques, data provide the potential to transition to a smarter world, where the prevention of power outages may become a true reality, not merely a prediction. The SCADA/OMS/DMS archives at a power utility offer the required data to identify parts of the system that contribute most to overall system downtime. An OMS, for example, provides the data needed to calculate measurements of system reliability. OMS also provides historical data that can be mined to find common causes, failures, and damage. Because OMS has become more integrated with other operational systems such as GIS on the utility side, analysis has become more feasible, allowing researchers to aim to improve grid reliability.

### *B. Population Data*

The U.S. Census Bureau's 2010 Decennial Census data at census-block geography is the population data source. The Research and Analytics Division of the Atlanta Regional Commission using U.S. Census Bureau Topology Integrated Geographic Encoding and Referencing/Line files developed this layer. Polygon features in Census_2010_Blocks_GA are subsets of Census_Blockgroups and Census_Tracts. A link to this data source is available here [23].

## IV. TOOLS AND METHODOLOGY

We used the following tools to analyze and process data and explore trends and patterns.

1. ArcGIS, a scalable and secure software-as-a-service program hosted by the Environmental Systems Research Institute (ESRI), can process data and visualize the results. The ArcGIS Spatial Statistics toolbox provides predesigned statistical tools to analyze spatial distributions and identify patterns, processes, and relationships [24]. Specifically, we used the following tools on the ArcGIS platform.
   - ArcMap ModelBuilder: Provided by ArcGIS to create, edit, and manage models. ModelBuilder (Figure 4) can be viewed as a visual programming language for building workflows that string together sequences of geoprocessing tools [25]. We designed three models with ArcMap ModelBuilder to spatially join the 48 map layers of weather data from GaSDI and the Georgia GIS Clearinghouse website with the outage map layer [26].
   - Optimized Hot Spot Analysis Tool: Provided by ArcGIS, the optimized hotspot analysis tool can be useful to identify statistically significant hot and cold spots of outages using the Getis-Ord Gi* statistic, which returns a *z*-score for each feature in the dataset. For statistically significant positive *z*-scores, a larger *z*-score implies more intense clustering of high values (i.e., a hot spot). For statistically significant negative *z*-scores, a smaller *z*-score implies more intense clustering of low values (i.e., a cold spot). The Hot Spot Analysis tool calculates the Getis-Ord Gi* statistic for each feature in a dataset. The resultant *z*-score tells where features with either high or low values cluster spatially. This tool works by looking at each feature in the context of neighboring features. A feature with a high value is interesting, but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature has a high value and is surrounded by other high-value features. The local sum for a feature and its neighbors is compared proportionally to the sum of all features; when the local sum is much different from the expected local sum, and that difference is too large to be the result of random chance, a statistically significant *z*-score results [27]. Because hot-spot areas are statistically significant, the end visualization is less subjective [27] (Figure 5).

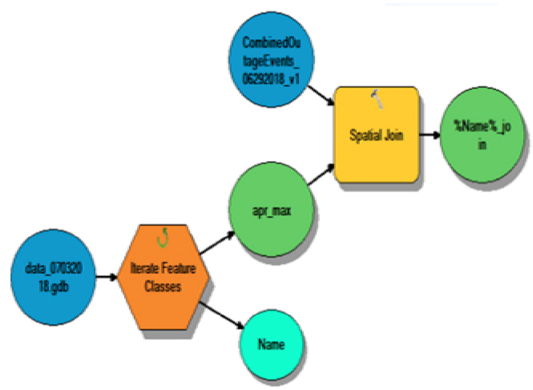


Figure 4. ArcMap ModelBuilder: Spatially Join Outages With Weather

2. GeoDa: a free software package that conducts spatial data analysis, geovisualization, spatial autocorrelation, and spatial modeling. GeoDa has powerful capabilities to perform spatial analysis, multivariate exploratory data analysis, and global and local spatial autocorrelation. It also performs basic linear regression [28].

The project methodology can be divided into seven steps:

1. Load data files from EPRI's Data Repository [22] to ArcGIS.
   - Created a folder (geodata set) and set up local projection to use Georgia's projection system.
   - Imported the data files from EPRI's data repository into the geodata set.
   - Imported basemaps (layers, maps, counties, tracks, roads, etc.) into the geodata set. Sources for Georgia shapefiles follow:
     – Roads shapefile https://catalog.data.gov/dataset/tiger-line-shapefile-2013-state-georgia-primary-and-secondary-roads-state-based-shapefile
     – County shapefile https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2010&layergroup=Counties+%28and+equivalent%29

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- Considering the enormous volume of data, a geodatabase to run more efficiently.

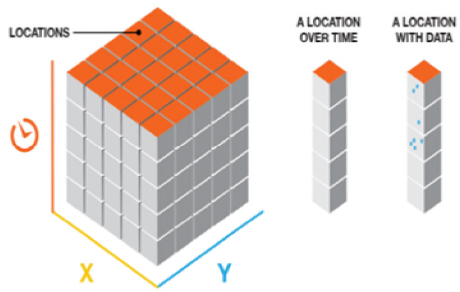


Figure 5. Emerging Hot Spot Analysis Tool [29]

2. Changed the projection of all maps to the World Geodetic System 1984 projection system. This step was necessary to perform calculations using ESRI or Google Earth tools.
   - Used Arc toolbox project (data management tools: Projection & Transformation) to change the projection.
3. Cleaned the outage-events map layer to exclude records that do not have a location (longitude and latitude).
4. Defined and created a study area for the project. Study areas are geographic boundaries to define the extent of analysis. They are typically created when starting a project to ensure the data are confined to a specified area. Only layers in the study area are considered in an analysis, so a study area can enhance processing time. Researchers use two methods or tools to create a smaller subset of data from a larger data set.
   - One way is to select a portion of an existing shape file and create a new layer file from it (or export that to a new shape file) using the ArcGIS select-by-location tool.
   - The other way is to clip an existing shape file using another polygon-shaped file (like using a cookie cutter) to create a new clipped version of the original shape file—ArcGIS Clip (analysis) tool (Figures 6 and 7).

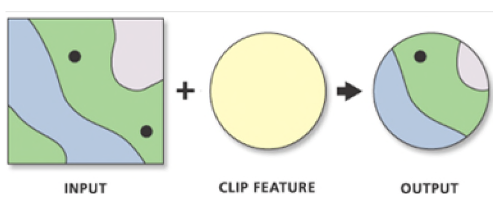


Figure 6. Clip Tool [30]

5. Selected data by block where population and power outage events intersect. This step ensures elimination of the impact of missing data.
6. Ran optimized hot-spot analysis to generate a map (Figure 8) of statistically noteworthy hot and cold spots of population using the Getis-Ord Gi* statistic.

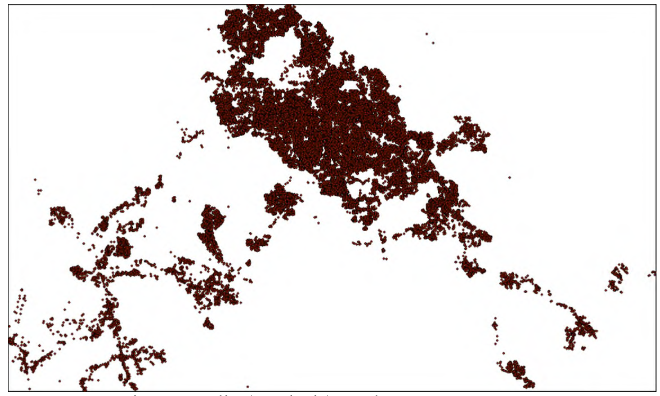

Figure 7. Clip (Analysis) Tool Output Map Layer

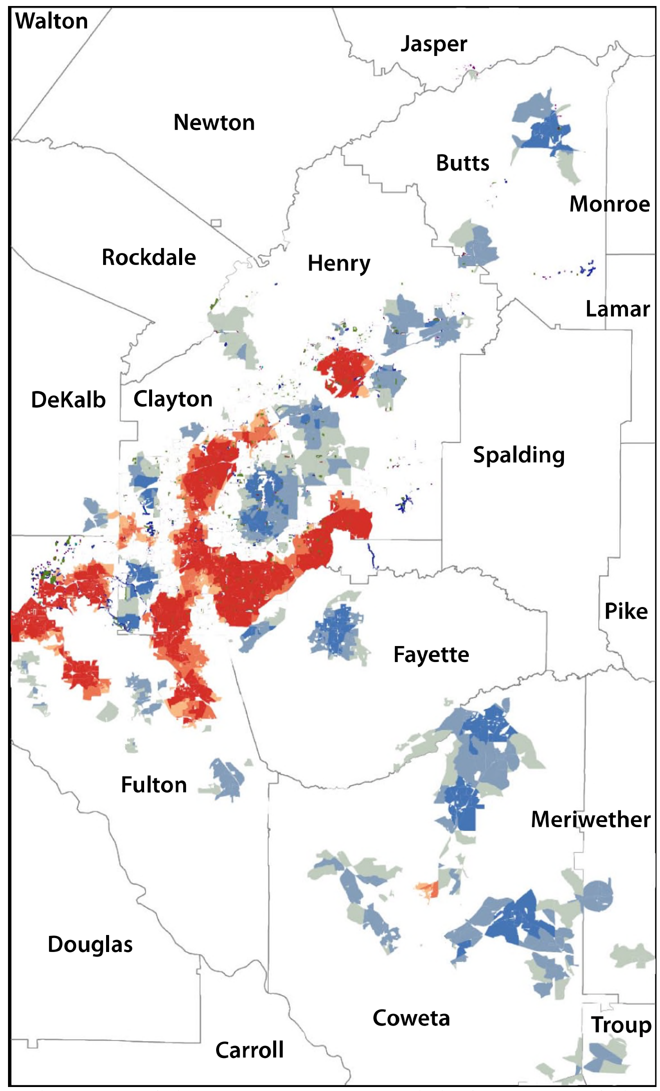


Figure 8. Population 2010 Census Data—Optimized Hot Spot Analysis

7. The final step is to investigate where population hot spots fall compared to the locations of optimized hot spots of power outage (Figure 9) and draw a conclusion.

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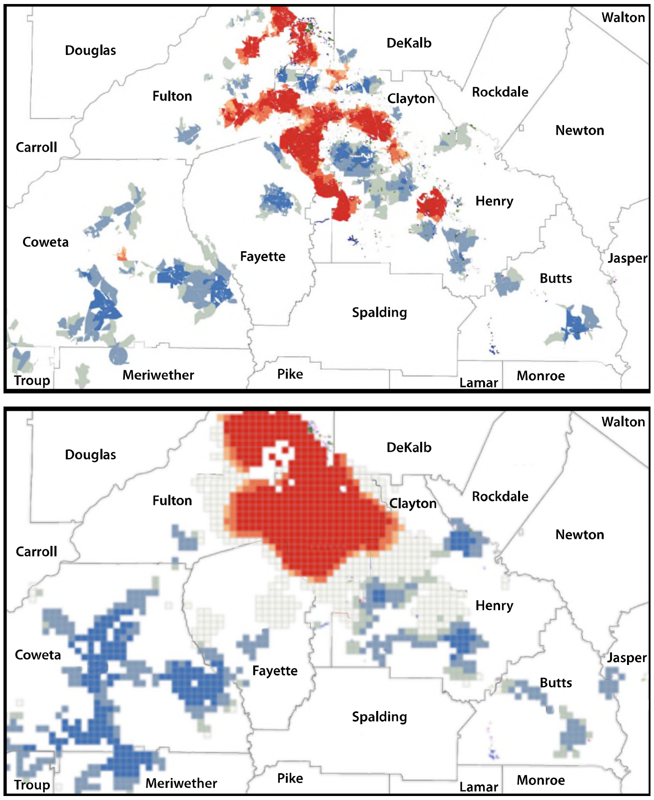


Figure 9. Population Hot Spots Compared to the Power Outage Hot Spots

## V. RESULTS & DISCUSSION

From a visual comparison of the two maps, the majority of population hot spots fall in one big area of hot spots in Clayton and Fulton Counties where power outages are statistically significant. The only exception is the population hot spot in Henry County and south Clayton County where no statistically significant outages occurred (Figure 10).

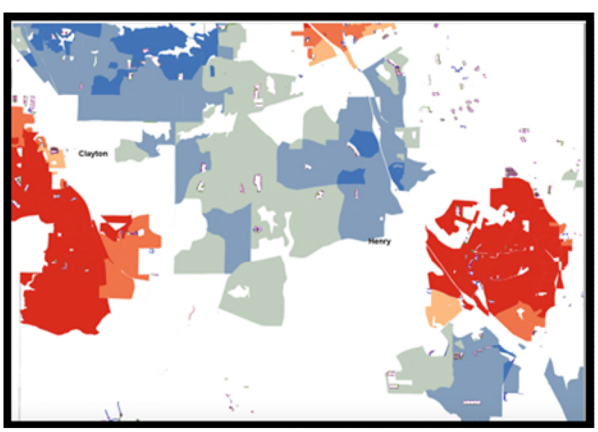

Figure 10. Population Hot Spots Outside Statistically Significant Outage Areas

It appears that, due to the Underground (UG) structures used there, these population hot spots do not show statistically significant outages. UGs contributed to lessening the number of power-outage events so this high-population area is not an outage hot spot (Figure 11).

Figure 11. Underground Structures in Henry and South Clayton Counties

The GIS data has a field (CONSTRUCTION_TYPE) that helps identify UG versus Overhead (OH) assets in the DMI data. Also, the OMS of work-management data contains a field (srv loc) that specifies if the location is OH or UG.

## VI. CONCLUSION

This study aimed to address how location analytics enhance understanding of power outages. To answer the research question, we explored GIS and aimed to identify a correlation between population density and power outages in Georgia. Initial investigation, using ArcMap software as a visualization tool, revealed areas where an association emerged between power-outage events and population density.

The GIS model presented in this study can help advance smart-grid reliability by, for example, revealing a root cause of power failure, defining a solution for a blackout through data, or implementing a solution with continuous monitoring and management. In this study, we show the novel use of location analytics to enhance power-outage understanding.

Future research should include analysis in ArcGIS Pro, which is ESRI's next-generation desktop GIS product that provides professional 2D and 3D mapping and added tools to advanced visualization, analytics, and imaging.

From this research, we conclude that GIS offers a solution to analyze the electric-grid distribution system. Our model provides evidence that GIS can perform the analysis to investigate power-failure events and their causes. If additional funds and data become available, researchers can expand on this analysis, build on ArcMap source code, and create a custom solution for the utility industry to control and forecast power outages. GIS can be a main resource to assist electronic inspection systems, to lower the duration of customer outages, to improve crew-response time, and to reduce labor and overtime costs.

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