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Traffic Congestion Alert System in Work Zone

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Traffic Congestion Alert System in Work Zone

by

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ABSTRACT

Road work zones cause more than ten percent of congestion and are the main reason for non-recurring congestion on freeways. The existing notification system at Iowa work zones was less efficient with handling the fluctuating and short duration messages. In this report, we explain the software developed to send reliable congestion alerts using the real-time traffic data.

The system is implemented to consume the Wavetronix sensor data for every twenty seconds and identifies the traffic congestion state in three predefined formats, such as "Stop traffic ahead, "Slow traffic ahead" and "No congestion." Whenever severe traffic congestion persists more than the threshold time, we immediately notify the district traffic engineers with multimedia text alerts. The text alert content along with the live camera snapshot would help the traffic engineers to analyze the situation and make better and quick responses. In addition to the text alerts, we also provide a data API that gives the real-time work zone bottlenecks. The software was developed to completely platform agnostic and tested and deployed on Microsoft Azure®.

CHAPTER 1. Introduction

1.1 Background

A work zone is defined as a freeway where road construction, maintenance or utility activities happen. Work zones extend from first warning sign to the end of work zone sign and are marked with multiple warning signs, pavement markings, and/or work zone vehicles along the way (2). Since work zone sites introduce narrow passage lanes, closed shoulders or lane shifts, they inherently alter the regular driving conditions and make travellers and construction workers susceptible to accidents. In 2015, it is estimated that 96,626 crashes have occurred in the United States, with an average frequency of one crash for every 5.3 minutes (3). In Iowa, the number of work zone crashes have increased in the last fifteen years. Figure 1.1 displays the work zone crashes trend in Iowa for the last 25 years.

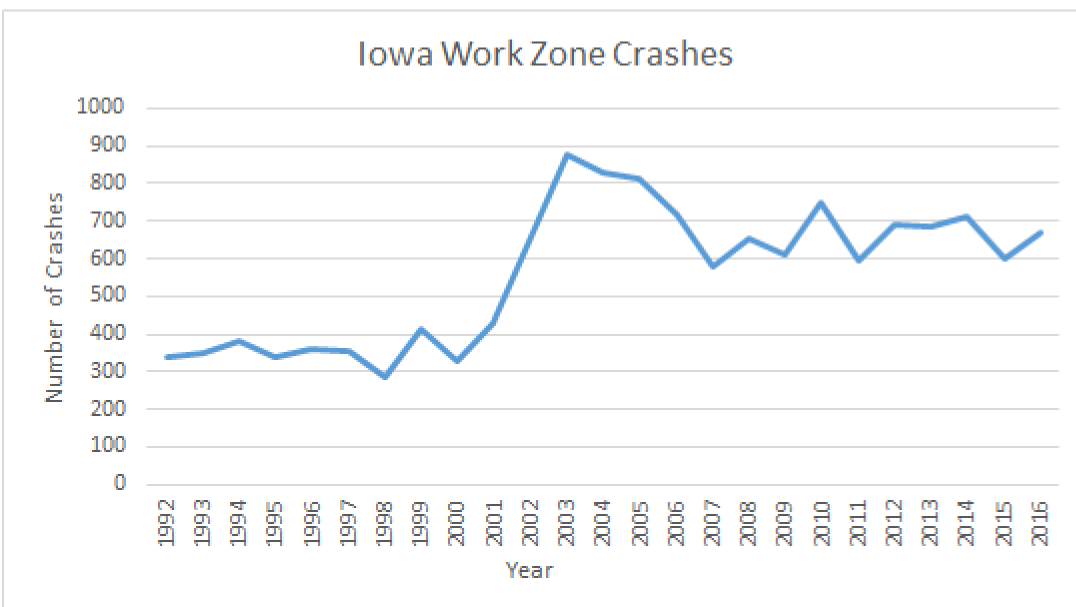


Figure 1.1: Iowa Work Zone Crashes

The major factor for work zone crashes is the speed. In 2014, around 28% of the work zone fatalities caused by the speed. In order to minimize the crash occurrence, it is a common practice to reduce the speed limits on work zones. Because of the reduced speeds, narrow passages, and lane closures, work zones become the point of traffic bottlenecks. In 2014, 10% of overall congestion and 24% of nonrecurring congestion caused by work zones (1).

It is necessary for the Traffic Management Center(TMC) to manage the traffic during the construction to minimize the traffic delays and congestion. Dynamic Message Signs(DMS) are used to reduce the traffic delays, prevent the traffic congestion, and reduce the risk of accidents. Dynamic Message Signs posts four different messages, "Traffic Delays Possible," "Slow Traffic Ahead," "Stop Traffic Ahead," and no display. Dynamic Messages can be triggered by the Traffic Operations Center or automatically using the sensors. According to Wang et al. (4), the reliability and the accuracy of the DMS fluctuates with the sensor noise and the existing logic can be improved with the predictive historical analysis.

1.2 Project Objective

This project is developed to:

- Collect real-time traffic data from Wavetronix sensors.
- Utilize the algorithm and code developed by (4) to reduce the sensor noise and analyze the work zone traffic conditions.
- Create and archive the work zone congestion events.
- Send reliable and accurate Multimedia congestion notifications to the traffic engineers to take better and quick decisions on work zone congestion.
- Send notifications to traffic engineers when congestion is cleared.
- Develop data feeds to display real-time bottlenecks.
- Manage the configurations for the Wavetronix sensors and MMS recipients.

1.3 Report Organization

The rest of this report is organized as follows. Chapter 2 gives an overview of the Open Data Service project developed at Institute of Transportation(InTrans) that provides a data ingestion service for the traffic data. Chapter 3 provides the methodologies and software description for the work zone alert module. Chapter 4 shows the results of the work zone events, and text alerts. Chapter 5 explains the impact, future scope, and Chapter 6 provides the conclusion.

CHAPTER 2. OVERVIEW

Work congestion alert project is sub-component of Open Data Service project. In this chapter, we provide a brief overview of Reactor Feeds server software developed for Open Data Services.

2.1 Open Data Services

Open Data Services is maintained by REACTOR lab at Institute of Transportation(InTrans) on behalf of Iowa Department of Transportation (DOT). The Open Data Service is expected to provide a variety of transportation-related data to both internal DOT and external/third party users. A hybrid infrastructure model(Reactor Feeds) of in-house High-Performance Computing(HPC) cluster and the cloud is used to architecture the data ingestion service with data streams, traffic congestion alerts, and data analytic (5). Figure 2.1 shows the high-level architecture of Open Data Services.

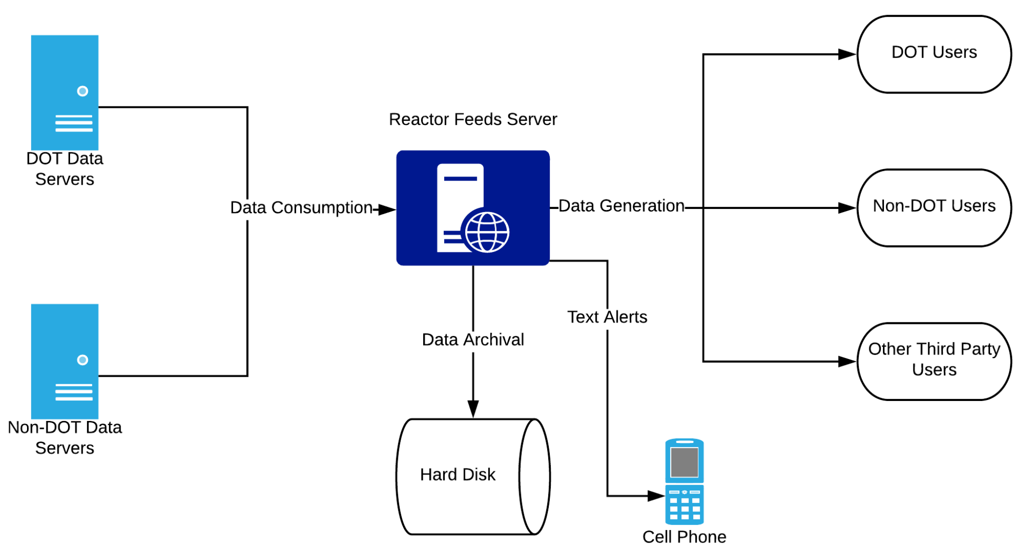


Figure 2.1: High-level architecture of Open Data Services

The Reactor Feeds server from Open Data Services, periodically collects the transportation data from different data providers. The collected data will be processed and transformed into structured formats like CSV, JSON, etc. The transformed data will then be pipelined into the archiving module, where the data will be stored into the hard disk, Hadoop clusters or Databases. The archived data can then be used for future research and applications.The Reactor Feeds server provides performance metrics, and aggregated results of the collected data as data feeds. Table 2.1 shows some data collections and feeds supported by Open Data Services.

Table 2.1: Reactor Feeds Data

Ingested Data	**Data Feed**
Wavetronix Sensor Data	Joint Sensor Feed Data, and Work zone alert data
Inrix Data	Inrix performance metrics
Waze data	Waze incident cluster data
LCPT station data	LCPT monthly performance data

The work zone congestion alerts project uses the Wavetronix data downloaded from the Reactor Feeds and adds text alert extension to the server.

CHAPTER 3. WORK ZONE CONGESTION ALERTS

3.1 Overview

3.1.1 Architecture

Figure 3.1 provides the high-level architecture of the work zone alerts systems. The application consists of the following components.

1. Data Collection: Downloads sensor data periodically.

2. Data Analysis: Data smoothing, sensor noise reduction, and historical data analysis.

3. Configuration Settings: Manages configuration rules and recipient details.

4. Processing: Detects congestion and sends text alerts.

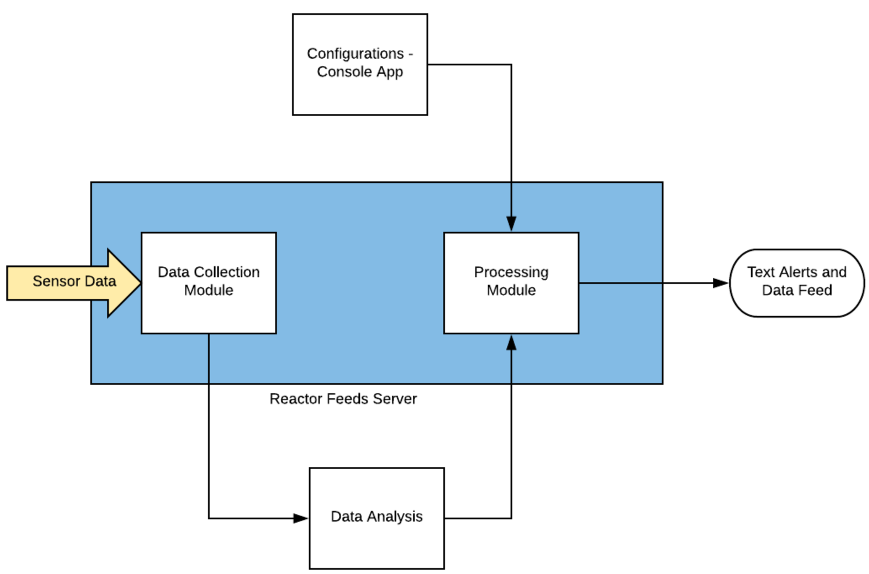


Figure 3.1: High-level architecture of work zone alerts

3.1.2 Software Description

The Reactor Feeds server was developed in Java with Spring Boot framework. We used Spring schedulers to implement the data ingestion service. The data analysis application uses Weka data mining packages for classification, and Jwave for wavelet data smoothing. The Data Analysis module and Reactor Feeds server communicates through Restful services using producer-consumer pattern. The work zone congestion events are stored on MongoDB and managed with Spring Data ORM framework. We developed a web application with Node.js and React.js to manage the configuration settings. Reactor Feeds server interacts with Twilio SMS gateway to distribute the text alerts.

3.2 Modules Description

3.2.1 Data Collection

More than 1300 Wavetronix radar sensors are placed on the Iowa road networks. These sensors continuously collect various traffic data like vehicle volume, speeds, and classifications. The Iowa DOT monitors these sensors and provides web services to download the sensor data. The DOT also maintains the Camera inventory metadata. As shown in Figure 3.2, we use schedulers to download the sensor detector data for every 20 seconds, and the sensor inventory and camera inventory data for once in a day.

Data Description

1. Sensor data service gives the vehicle speeds, classifications, and the vehicle volumes on each lane (6).

2. Sensor inventory service provides the metadata about the sensor. It includes the sensor location, operation status, linear-reference, and the detection direction.

3. Camera inventory service provides the information about the camera location, route and the HTTP links to the camera videos and snaps.

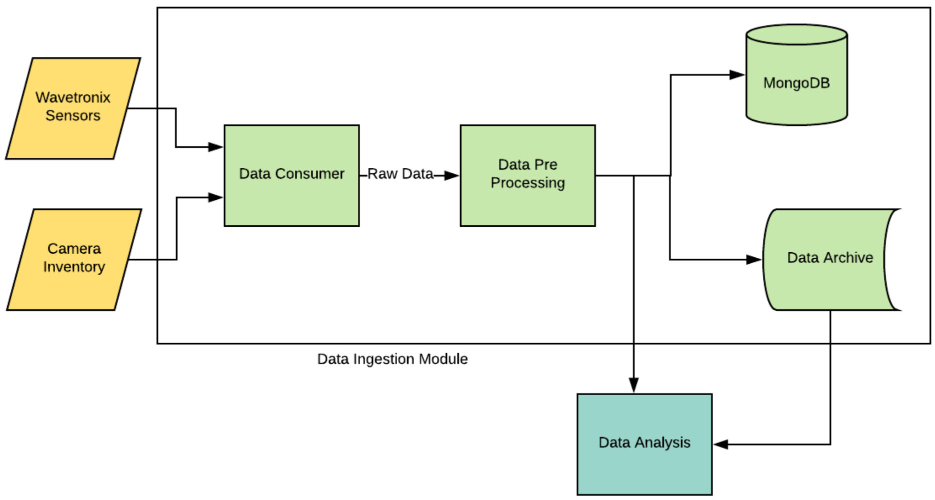


Figure 3.2: Data Collection Architecture

Data Preprocessing

The DOT servers provide the data in raw XML format. As part of data preprocessing pipeline, we convert the XML data into CSV and/or JSON formats using XPath and object mappers. Once the data is transformed, it will be handed over to the data analysis engine to find out the traffic flow status, and the data archive pipeline to store the data into the file system and/or MongoDB.

3.2.2 Data Analysis

The data analysis module applies the fast wavelet transform on the sensor data for smoothing. The application is trained with the historical traffic data and uses decision tree model to classify the average speeds and traffic congestion status. The analysis algorithm and the code are implemented by Wang based on (4).

The algorithm generates one of the following statuses for the work zone, "Stop Traffic Ahead," "Slow Traffic Ahead," or "Normal Traffic." After the classification, the system posts the average speeds and work zone status to the Reactor Feeds server using HTTP POST method.

Structure of work zone sensor status posted to the server is:

```
{
    "workzone":"Work zone name",
    "device":"Sensor ID",
    "avgSpeed":"Average speed",
    "alert":"Work zone status identified from the decision tree model"
}
```

3.2.3 Processing Engine

The posted data from data analysis module is used to generate work zone events. A work zone event is, slow or stop status detected by at least one sensor of that work zone. As shown in figure 3.3, work zone events will be created or updated in the database based on the sensors classification report. Schedulers continuously check the database to filter the running work zone events. A congestion text alert will be sent If a work zone is flagged as stopped traffic for at least 5 minutes(configurable). Similarly, a cleared congestion alert will be sent if the traffic goes back to normal for at least 5 minutes.

Algorithms 19, 6, 5 provides the pseudo code for the implementation of work zone event generations, schedulers for congestion and clearance alerts.

Explanation

The algorithm is implemented based on the following assumptions and requirements.

- A work zone can contain multiple sensors.
- A work zone event should be generated if at least one sensor reports SLOW / STOP conditions.
- If all work zone sensors report normal traffic, the currently running event should be ended after a threshold time.
- The status of work zone event should be the worst status detected by all sensors.

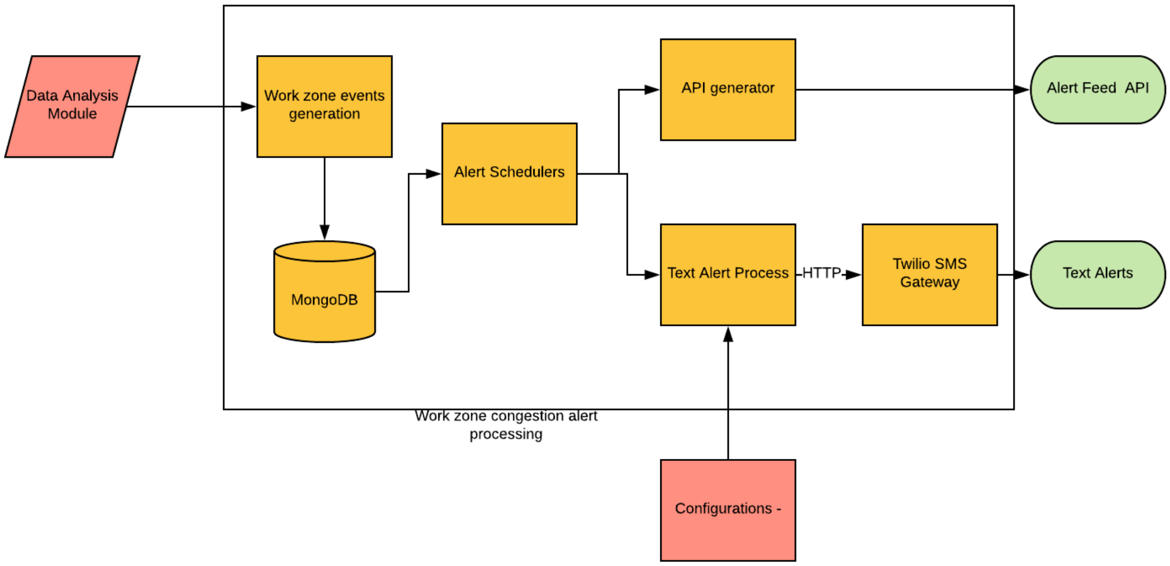


Figure 3.3: Processing Engine Architecture

- Congestion alert should be sent if a work zone event is in STOP condition for more than the threshold time.
- Clearance alert should be sent for all congestion alerts, once the work zone event is ended.

The analysis module sends the sensor reports on work zones. The Algorithm first fetches work zone event that is associated with this sensor. If the sensor reports a congestion then a new work zone event will be created or the existing event will be updated. Similarly, if sensor reports normal condition, then the work zone will be verified to end any running event.

Every time, a new work zone event is created, the event will be added to a *alertQueue*. An alert scheduler runs for every one minute and checks the *alertQueue* for persisted stopped events. All such events will be handed over to SMS handlers and will be added to *clearanceQueue*.

A clearance scheduler also runs for every one minute and verifies the events in *clearanceQueue*. If the events in *clearanceQueue* becomes normal, that will be forwarded to the SMS module to trigger clearance alerts.

Algorithm 1: GENERATE WORK ZONE EVENTS(S)

```
Input: S = Sensor Event
function generateWorkzoneEvents(S):
wze ← get current running work zone event
if wze is null then
    if S is either SLOW or STOP then
        Create new work zone event and add this sensor event S
        Add work zone event to alertEventQueue
    end
else
    S′ ← latest sensor event from wze
    if S' is null then
        Add S to wze if S is either SLOW or STOP
    else
        if S is NORMAL then
            End S′ and stop wze if no sensor event running.
        else
            Update S′ with S
        end
    end
end
```

Algorithm 2: CONGESTION ALERT SCHEDULER()

```
function congestionAlertScheduler():
/* Runs every minute */
wze ← Get status of all work zones in alertEventQueue
wzs ← Filter wze with events in stopped state and running for more than threshold time.
trigger congestion alerts on wzs
add wzs to clearanceEventQueue
remove wzs from alertEventQueue
```

Algorithm 3: CLEARANCE ALERT SCHEDULER()

```
function clearanceAlertScheduler():
/* Runs every minute */
wze ← Get status of all work zones in clearanceEventQueue
wzs ← Filter wze with events in normal state for more than threshold time.
trigger clearance alerts on wzs
remove wzs to clearanceEventQueue
```

Text Alert Processing

Once the alerts are triggered by the schedulers, the event information will be handed over to SMS handlers. For congestion alerts, SMS handler prepares the text content by calculating the minimum of all sensor reported average speeds, the range of mile marks where congestion is detected, and the start time of the congestion occurrence. For clearance alerts, it calculates the duration of the congestion. Apart from the text content, it finds the closest camera from the configuration and reads the latest snap from the camera inventory.

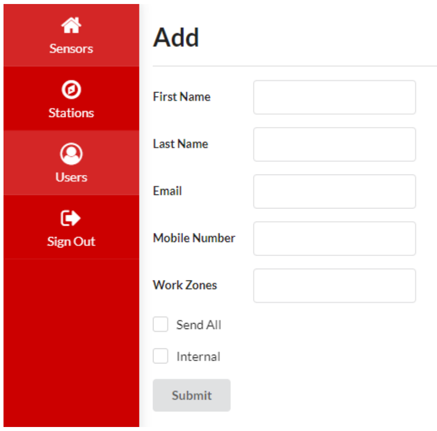
Using the configuration settings, we identify the valid recipients for the particular work zone. We used Twilio SMS gateway service to distribute the MMS to the cell phones. We post recipient numbers, text content, and image to the Twilio HTTP web service, and Twilio sends the MMS to the recipient cell phones.

Alert Feed API

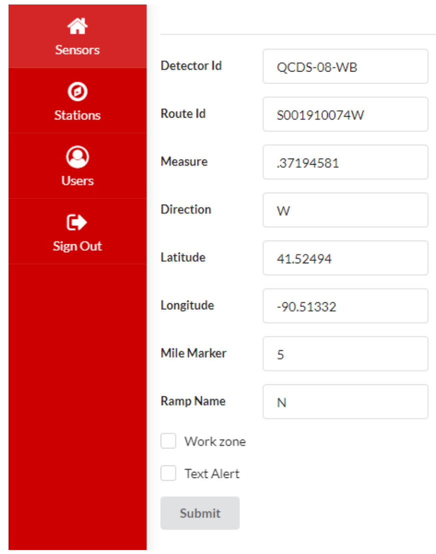
Reactor Feeds server provides a data feed API that gives the real-time work zone congestion (7). The feed gives all SLOW and STOP conditions occurring in the work zones, with average speeds and the mile mark ranges. The data gets updated for every 20 seconds. The Traffic Management Center(TMC) uses this API to display the work zone bottlenecks.

3.2.4 Console Application

It is an important use case to send work zone alerts to only the people who are monitoring or maintaining that work zone. The application should also work without a restart on dynamic changes with the recipient details, like adding/modifying the recipient details. The console application solves these problems. In the console application, an administrator can log on to the system and modify the recipient details. The application also enables the admin to flag the sensors as part of work zones. Figure 3.4a, and 3.4b displays the console app user interface components.



(a) Adding an user



(b) Modifying sensor details

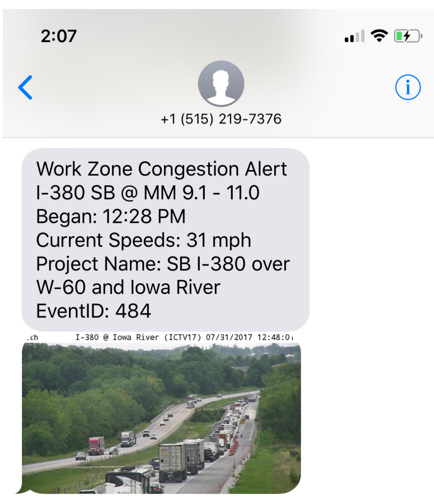
Figure 3.5: Console App

3.2.5 Sensor Quality Assurance

It is critical for the application to send reliable and accurate congestion data to the users. As part of testing, it is identified that some sensors stop working before DOT identifies them as inoperable sensors. In order to reduce the false positive rates, the system sends internal text alerts to notify whenever a work zone event runs for more than two hours.

CHAPTER 4. Results

The software was launched in early June 2017 to monitor 70 Wavetronix sensors in 26 work zone sites throughout Iowa. From then, the application has been sending text alert message to the DOT traffic engineers to keep them updated with the work zone congestion. Figures 4.1a, 4.1b shows the congestion and clearance alerts distributed to cell phones for I-380 work zone project on July 31, 2017.



(a) Congestion Alert

(b) Clearance Alert

Figure 4.2: Text Alerts

The software has generated 906 work zone events and sent 60 sever congestion alerts to the traffic engineers in 2017. The work zone event statistics can be seen in Table 4.1.

Figures 4.3, and 4.4 displays the distribution of work zone events over time and work zones.

Table 4.1: Work zone events statistics

Total Events	906
Stop Events	99
Slow Events	897
Congestion Duration	264 hrs
No. of Text alerts sent	60
Longest Event Duration	115 mins

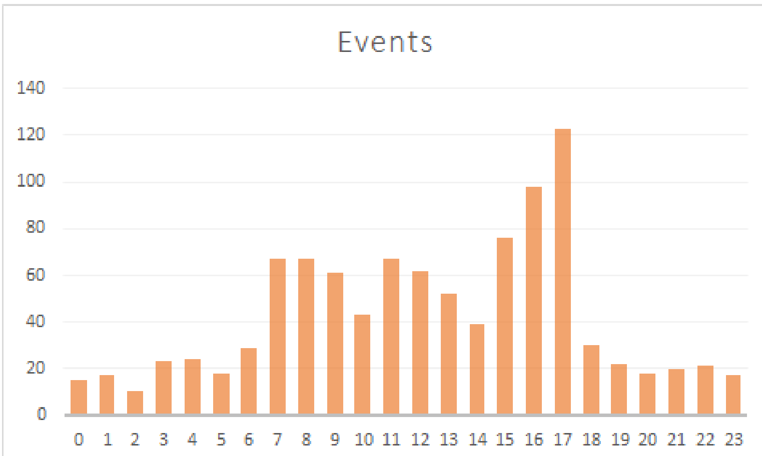


Figure 4.3: Congestion distribution over time

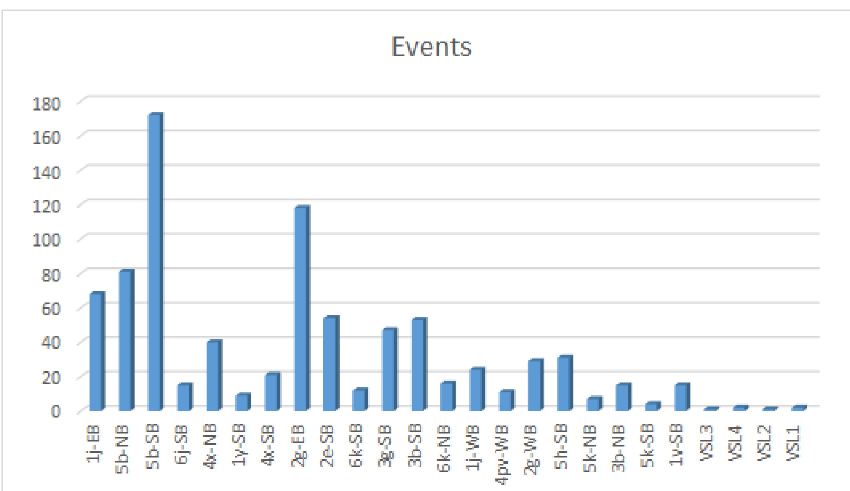


Figure 4.4: Congestion distribution over work zone projects

CHAPTER 5. Impact and Future Scope

Multiple research questions can be pursued after introducing this system. A survey can be conducted to identify the field engineers opinion on text alerts. Several new research questions can be studied using the work zone events, like a study on congestion frequencies and the work zone locations. Future work zone management can be planned efficiently using different work zone event parameters.

The application can be further improved by introducing new data feeds into the system. For example, a combination of INRIX, and Waze data provides great insights into the existing sensor data. Adding a live video analysis can improve the reliability of the system. The system can also be extended to monitor the complete Iowa road network.

CHAPTER 6. Conclusion

The work zone constructions are required to improve the aging infrastructure and to build new routes. Work zone activities happen often on already congested roads and lead more congestion. The Traffic Management Center(TMC) manages the work zones to reduce the congestion and harmonizes the traffic flow. It is important to keep the traffic engineers abreast of congestion statuses on work zones.

In this work, we have developed a software to immediately notify the engineers on severe traffic congestion. The inclusion of the camera images, average speeds, and the queue lengths carries better understanding of the situation and help the engineers to take quick decisions. We developed data feed APIs to provide real-time work zone bottlenecks thorough out Iowa. The use of work zone events can further lead to new research topics on work zone manangement and planning.

REFERENCES

[1] *FHWA work zone mobility facts* https://ops.fhwa.dot.gov/wz/resources/facts_stats/mobility.htm

[2] J. Dan Turner (1999) https://www.fhwa.dot.gov/publications/publicroads/99mayjun/workzone.cfm

[3] *FHWA work zone safety statistics* https://ops.fhwa.dot.gov/wz/resources/facts_stats/safety.htm

[4] Shefang Wang, Anuj Sharma, Skylar Knickerbocker(2018) Analyzing and Improving the Performance of Dynamic Message Sign Reporting Work ZoneRelated Congestion *Transportation Research Record: Journal of the Transportation Research Board* https://doi.org/10.3141/2617-09

[5] Vamsi Krishna J, Skylar Knickerbocker(2018) *Open Data Service User Manual* https://iastate.app.box.com/s/wmsik1f0ygg3hn6a8xw5txe61vxdjuqt

[6] *Sensor Feed Documentation* http://reactorfeeds.org/docs/feeds/sensorfeed

[7] *Work zone congestion bottleneck feed* http://reactorfeeds.org/feeds/alertfeed