STATISTICAL ANALYSIS OF CRASHES OCCURRING AT INTERSECTIONS IN MALFUNCTION FLASH

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STATISTICAL ANALYSIS OF CRASHES OCCURRING AT INTERSECTIONS IN MALFUNCTION FLASH

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To all my family and friends.

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I would like to thank my entire family for their support which has made this possible.

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SUMMARY

There are many reasons for traffic signals to malfunction such as damage to the controller assembly, conflicting signal indications, or power fluctuations. When the conflict monitor detects a problem the intersection can be put into a flash mode. Flash mode will either show yellow/red or red/red flashing signal indications. A yellow/red flashing mode indicates to drivers approaching the yellow flash to pass through the intersection with caution and for those approaching the red flash to yield. A red/red flashing mode would indicate to all drivers that the intersection should be treated as a four-way stop.

Malfunctions flash events occur randomly and can cause confusion for drivers who do not know how to treat the intersection. Sixty-five malfunction flash crashes were examined out of the reported crashes in Georgia during 2006. In an effort to gain an understanding of the relative behavior of crashes at an intersection in malfunction flash compared to other crashes the 2006 Georgia crash data analyzed using several different categorizations: all crashes, signalized intersection crashes, two-way and four-way stop controlled intersection crashes, and malfunction flash crashes. Out of these groups yellow/red malfunction flash crashes more closely relate to two-way stop sign intersections when comparing characteristics such as manner of collision, severity, and contributing factors. Although malfunction flash mode is an operation of traffic signals it is functionally similar to two-way and four-way stop intersections.

Analysis of collision records from the GDOT accident database occurring under conditions of malfunction flash found that right angle collisions represented a large

majority (73.8%) of these collisions. In the other crash groups reviewed right angle collisions represent a greater portion of fatalities (All Crashes: 55.2%, Signalized Crashes: 87.5%, Two-way and Four-way Stop: 82.8%). An option for reducing the risk of right angle collision is to consistently use only red/red malfunction flash. In previous studies it has been found that red/red flash did not have significantly higher crash rates than normal operation, while yellow/red did have an increase in right angle collisions [10].

CHAPTER 1

INTRODUCTION

The Manual on Uniform Traffic Control Devices (MUTCD) [1] describes that, during normal operation, traffic signals can reduce the occurrences and severity of right angle crashes, allow for more efficient traffic flow, and provide for an orderly movement of traffic. Occasionally there may be disruptions that put drivers into unfamiliar situations, such as a signal under flashing operation. According to surveys discussed by Jenior [2], malfunction flashing operations were a rare occurrence with a median of .05 reported outages per signal per month for traffic control agencies throughout Georgia. It is in these unusual situations that there is a concern for driver expectancy and safety.

There are several different modes of flashing operation that can be used for a signalized intersection. These flashing operation modes include; programmed flash (predetermined time period of flash, most often during low demand periods), technician (manually set from the control cabinet so a technician may perform maintenance), police panel (started by an officer, at the control cabinet, so that they may direct traffic), and malfunction flash (activated when the conflict monitoring unit determines there is an signal error or improper operating voltages) [1, 3].

When one of these situations occur, the signal may display yellow on the main road, red for the minor or it may display a red flash for all directions. The usual design for flashing operation is to have a flashing yellow indication on the major road and a flashing red on the minor road. State regulations may vary slightly, but the Unannotated Georgia Code [4] defines yellow and red flashing signals as the following (40-6-23):

- Flashing Red – "When a red lens is illuminated with rapid intermittent flashes, drivers of vehicles shall stop at a clearly marked stop line… and the right to proceed shall be subject to the rules applicable after making a stop at a stop sign."
- Flashing Yellow – "When a yellow lens is illuminated with rapid intermittent flashes, drivers of vehicles may proceed through the intersection or past such signal only with caution."

Most of these flashing operation modes are planned ahead of time by the local police division, traffic signal maintenance crews, or by traffic engineers. In these cases drivers could expect direction or the flash operation to be resolved fairly quickly. In the cases of malfunction flash the signal may be in flashing operation for about two hours, potentially much longer, after a call is made to the maintenance agency [2]. Also, a malfunction flash event is relatively rare to encounter and can lead to driver expectancy issues as described by Jenior and Bansen [2, 3].

1.1 Study Need

The MUTCD allows for engineers to use their own judgment on whether to use red/red or yellow/red flashing operation according to the guidance in section 4D.11 [1]. To make this decision engineers depend on past research in order to balance safety and traffic performance. There are several previous studies that analyzed traffic during a programmed flash, but there has been little research into malfunction flash. Programmed flash is inherently different from malfunction flash because it is known prior to its activation and its risks can be minimized. A police officer can be stationed at the intersection during the flash operation or repairs can be done during low demand time periods.

Malfunction flashes can occur at any time regardless of the demand on the intersection. Common assumptions of programmed flash operation cannot be applied to malfunction flash operation. Drivers may not obey traffic laws due to their unfamiliarity with flash operation, and without some guidance at the intersection itself may make some unpredictable choices. Driver expectancy, prior experience, roadway conditions, and potential high demands during malfunction flash are all factors that make assumptions of programmed flash operation inappropriate to apply to malfunction flash operation. Jenior found that at several intersections, with yellow/red flashing operation, more than 50% of drivers stopped at the yellow indication [2]. It is in these unpredictable aspects that malfunction flash differs from the other forms of flashing operation. Because of these unique characteristics many of the previous works into flashing operation are not applicable in the case of malfunction flash crashes. There is a need for engineers to analyze actual malfunction flash crashes to be more aware of how to increase safety in the design for malfunction situations.

1.2 Study Objective

The objective of this research is to advance the area of malfunction flash research and to describe what can be expected of malfunction flash crashes. This thesis will focus on malfunction flash crashes in the 2006 Georgia Department of Transportation (GDOT) crash record set. By classifying crashes as under red/red or yellow/red malfunction flash a statistical analysis can be done to determine their characteristics. Through this crash analysis a 'typical' malfunction flash incident can be described and be used as background for future design decisions.

1.3 Study Overview

The focus of this research is on the analysis of the 2006 GDOT crash reports and the GDOT crash database. These records were obtained from GDOT and then processed through several filters. Due to the large volume of data, computer programs were used to find likely malfunction flash crashes and then examined and authenticated by a human analyst. These confirmed crashes were then located in the GDOT crash database and used for much of the analysis in this thesis. All analysis was done after the incidents occurred and were based on information within GDOT records and no personally identifiable information were used in results reported here.

Much of the research focused on reviewing prior literature about flashing operation and crash analysis. The literature sources created a framework for the later analysis of the crash data. After reviewing the literature it was found that there was very little analysis of crash data at intersections during malfunction flash operations. Most research was focused on programmed flash especially during low demand, early morning time periods. The discussion of the literature in Chapter 2 will be focused on crash analysis techniques and the current body of knowledge relating to flash operations.

Chapter 3 describes the process of collecting the crash data and filtering for the malfunction flash crashes. An in-depth discussion is presented on the use of OmniPage 16 Professional ®, the search methods used to locate likely crash reports, and the process to authenticate malfunction flash operations.

Chapter 4 is an analysis of the characteristics of malfunction flash crashes as compared to other groups of crashes. For this thesis crashes for 2006 Georgia crashes were split into four groups; all crashes, signalized intersection crashes, two-way and four-way stop intersections crashes, and malfunction flash crashes.

Each of the crash categories were evaluated and compared based on several areas. The categories for this review were crash severity, manner of collision, and contributing factors. Malfunction flash crashes were examined based on urban and rural locations as well as the type of malfunction flash mode used.

CHAPTER 2

LITERATURE REVIEW

Flashing operation of traffic signals has been used by many jurisdictions during early morning hours to reduce delay and lower electrical costs, or to try to minimize risks from impatient drivers [5-10]. Although the research shows that while there are advantages to using flashing operation, there are also several safety concerns that should be addressed on a case by case basis. Several studies of flash operation since the 1970's have reexamined some of the basic assumptions of its use, such as, drivers always obeying traffic laws, and the extents of the advantages provided by flashing operation [3, 5, 6, 8, 9, 11, 12]. These studies tend to agree that use of flashing operation increases the severity of crashes by an increased risk of right-angle crashes [5, 6, 9, 10, 12]. With mixed advantages, disadvantages, and a lack of specific guidance about flash operation most jurisdictions must make their decisions on the use of flash and the flash model based on previous experience and accident reports.

Most studies, since the 1970's, were focused on programmed flash operation during early morning hours. Although malfunction flash and programmed flash do share similar problems, drivers can face added risk during a malfunction flash [2, 3, 5-10, 12]. Malfunction flash can occur at any time of the day, regardless of the current demand on the intersection. This can present drivers with a difficult situation they would not normally face with other types of flash.

There were few sources of information that directly addressed malfunction flash. While some of the previous work on programmed flash can be used as a basis for research into malfunction flash, much of it cannot be applied. As malfunction flash is a random event it may not fall within the very low volume scenarios typically assumed for programmed flash. Researchers into programmed flash have used several different means in order to reach their conclusions, such as, simulations, accident records, and surveys [2, 3, 5-10, 12-14]. The studies tend to, ultimately agree on certain methods of determining if programmed flash operation is needed and whether yellow/red or red/red flash should be used (volume ratio, accident histories, and sight distance). The literature typically examined intersections with low traffic flows, except for two sources by Oricchio and Kacir respectively [13, 14]. Oricchio examined simulations of a major and minor road intersection of two lanes each with up to 1000 veh per hour. Kacir examined a five by four geometry with up to 900 veh per hour for the major road. No literature was found that examined the crash history of flash operation during high demand periods.

2.1 Summary of Previous Studies of Malfunction Operation

The following section is a summary of the major research sources describing flash operation. Several of these sources are also summarized by Benson, Jenior, and Oricchio [2, 3, 13]. This section will review flash operation studies that focus on crash histories and safety.

2.1.1 Federal Highway Administration (1980)

During the 1970's the FHWA began a major study into the subject of flashing operation. The overall goal of the study was to answer the following questions [10]:

- "Under what circumstances should traffic signals be operated in a flashing mode?"

- “Where flashing operation is used, when should it have a yellow/red pattern and when should it have a red/red pattern?”

To answer these questions the study utilized seven procedures [10]:

- “A literature review of standards and past research studies”
- “A review of applicable state laws”
- “A questionnaire to state and local traffic engineers regarding their practice and personal experiences”
- “A questionnaire to drivers regarding their understanding of flashing operation”
- “Field studies of operations and safety”
- “An analysis of the effects of flashing operation on fuel consumption, vehicle emissions and signal costs”
- “An analysis of analytical models that can be used to predict the effects of flashing and regular signal operation”

The study starts with an extensive literature review that goes back to the first MUTCD printed in 1934. Originally, the MUTCD suggested the use of flashing operation during any two hour time period that drops below the volume warrants. The most recent MUTCD, at the time of the study, recommended that if the volume should drop below 50 percent of the volume warrant for four or more consecutive hours flash could be considered, except for actuated signals. The study shows how the guidance changed over time to become increasingly restrictive in its recommendation of flashing operation. The literature review goes on to describe several studies that investigated flashing operation. In most studies it found that the use of yellow/red flash reduced delay, saved energy, and reduced gasoline use. It also found that there was an increase in accident rates, and in particular right-angle crashes, in several of the studies.

The study also investigated the state of traffic laws regarding flash operation for all fifty states. As of the report, in 1980, the District of Columbia and every state except for Kentucky used a regulation very similar to the following [10]:

> "2. FLASHING YELLOW (Caution Signal). – When a yellow lens is illuminated with rapid intermittent flashes, drivers of vehicles may proceed through the intersection or past such a signal only with caution."

.

There is a similar comparison made to the definition of a flashing red light in that in the District of Columbia and most states have a similar definition [10]:

> "1. FLASHING RED (Stop Signal). – When a red lens is illuminated with rapid intermittent flashes, drivers of vehicles shall stop at a clearly marked stop line…"

Kentucky was the exception to these because it was found to not have defined flashing signals. Massachusetts and Pennsylvania were not listed as having similar flashing red regulation with slightly different wording.

The FHWA sent a survey to find the state-of-the-art in practices of flashing operation. This survey was sent to 360 separate agencies in all 50 states, Puerto Rico, and the District of Columbia [10]. There were 250 responses to the survey which represents 69 percent of the agencies picked for the survey. Of the responses 18 were not used due to being late or incomplete. When the respondents were asked if they use flashing operation during low-volume periods 147 replied that they did and 85 replied they did not. Seventy-nine of the respondents said that they used signal warrants for placing signals into flashing operation. The most common warrant in among the responses was the traffic volume below 50 percent of the signal warrants for a period of 4 hours or more. Of the respondents 147 said they only used yellow/red flash in their districts while 20 said they used red/red flash. Another 37 respondents said they used both flash modes within their districts.

Another survey was also sent to 352 different drivers to analyze their comprehension of traffic control concepts [10]. The drivers were asked if they approached a signal that was flashing yellow, would they stop and yield, or would they slow down and proceed with caution. Ninety percent answered correctly in that they would slow down and proceed with caution. The same drivers were asked what they expected the cross-street traffic to do, at the same signal; about 50 percent of drivers responded correctly.

A detailed analysis of infield data was conducted from data tapes containing San Francisco crash records from January 1, 1974 to April 30, 1977 [10]. The data came from 520 intersections and was split into two time periods, those that occur when flash operation is used and when it is not. Through a comparison of data from both time periods it was found that there was an increase in the crash rates under yellow/red flash mode. This was mainly due to the large increase in right-angle crashes, form .13 to .40 right-angle crashes per year per intersection. Intersections that used red/red flash mode did not experience a significant difference from normal operation.

This study remains one of the most comprehensive investigations into programmed flash. Its approach to analyzing the crash data was used a basis for the research outlined later in this thesis.

2.1.2 Akbar and Layton (1986)

Akbar and Layton published a paper called *Accident Experience of Flashing Traffic Signal Operation in Portland, Oregon* in issue No. 1069 of the Transportation Research Record [5]. The paper summarized statistical analysis of 30 intersections in Portland, Oregon to determine the differences, if any, between flash operation and full-color operation. Signalized intersections were grouped on the following criteria: volume ratios, street classifications, types of approaches, approach speed limits, and parking conditions [5]. The crash data came from computer records from the Portland Bureau of Traffic Engineering. This data was then split into before-and-after groups by when flashing operation was started at several intersections.

The researchers found that most intersections in flashing operation tended to have higher severity accidents than those in full-color operation [5]. In particular it was found that right-angle accidents increased significantly. Researchers suggested that this could be due to that fact that conflicting movements are no longer separated by the signal. It was also suggested that the drivers may have been confused by the situation or had trouble in determining when it would be safe to enter the intersection.

2.1.3 Gaberty II and Barbaresso (1987)

A paper called *A Case Study of the Accident Impacts of Flashing Signal Operations Along Roadways* was published in the Institute of Transportation Engineers Journal (ITE Journal) on July 1987. The study was a validation of a preliminary study by Barbaresso in 1983 titled *Flashing Signal Accident Evaluation*. Data was collected from Traffic Improvement Association of Oakland County (TIA) records for 59 intersections between January 1980 and September 1985. The intersections in the study had previously used flashing operation and were then changed to operate under full-color operation. This would separate the data into 'before' and 'after' sets for comparison.

Gaberty and Barbaresso found that there was a very significant change after the intersections were changed to full-color operation. Between 1980 and 1983 the intersections used flashing operation and recorded 202 right angle crashes [12]. Of those crashes there were 3 fatalities and 124 serious personal injuries. During the period of 1984 to September 1985 the intersections used full-color operation and recorded 8 right angle crashes. Within those 8 crashes were 3 personal injuries and no fatalities.

The researchers concluded that operating in full-color mode significantly decreases right-angle crashes [12]. They also found that rear end crashes were not significantly reduced by the transition to full-color operation. Based on their results the researchers suggest that flash operation should be considered according to signal warrants, but that right-angle crash history should also be taken into account.

2.1.4 Parsonson and Walker (1992)

Parsonson and Walker published a research article called *Issues in Flashing Operation for Malfunction Traffic Signals* in the September 1992 edition of the ITE Journal [8]. The article addresses the question of [8]:

> "If main-street volumes are too heavy for side-street traffic to enter or cross, or if visibility for side-street traffic is poor, how should an intersection be operated when a signal malfunction occurs?"

The article also discussed the current standards and concerns about the use of flash operation. It was stated that in the preceding 20 years signal control equipment had sufficiently improved in quality that fewer malfunction flash incidences should be occuring. However, this reduction in malfunction flash incidences may not be realized due to the conflict monitor's increasing ability to check for several different types of system errors [8]. Another concern that the authors examined was that of sight distance for intersections in malfunction flash. Field observations in the Atlanta area found 10 intersections that would have insufficient sight distance during a yellow/red flash. Speed limits along the major streets, for these intersections, were between 35 and 45 mph [8].

Eight traffic engineering agencies were asked to answers a set of questions during an interview about their policies about malfunction flash [8]. All eight traffic engineers stated they used yellow/red flash while five said they also used red/red flash. Five engineers stated they considered sight distance when deciding whether to use yellow/red or red/red for the flashing mode. These engineers used their experience and judgment to evaluate sight distance.

This article shows how guidelines can differ from region to region on a similar problem. It also goes on to suggest that traffic engineering agencies should evaluate the intersections that use yellow/red flash for proper sight distance. The article offers that one option for these intersections is to request a police office when a malfunction flash is detected. This would minimize risk and allow for better traffic flow until a maintenance team can arrive.

2.1.5 Kacir, Hawkins Jr., Benz, and Obermeyer (1995)

Kacir et. al. published a study titled *Guidelines for the Use of Flashing Operation at Signalized Intersections* in the October 1995 edition of the ITE Journal [7]. The study reviewed the current practice, operation, and crash data in order to answer these two questions [7]:

- "Under what circumstances should signals be placed in flashing operation?

- When flashing operation is used, what color indications should be displayed to the various approaches?”

In the review of the current practice they found a lack of adequate guidelines about the implementation of flashing operations. The method of evaluating the need for flashing operation would depend on the district, and could vary between neighboring districts [7]. The most commonly considered factors are traffic volumes, time of day, accidents, and day of week. The decision between using yellow/red or red/red flash is usually determined after reviewing accident history, consistency with other flashing signals, geometrics, sight distance, and speeds [7].

The authors undertook an operational analysis of flashing operation using the TEXAS and TRAF-NETSIM simulation models [7]. Delay per vehicle was used to determine effectiveness in each model. Pre-timed and actuated signals were tested against signals in yellow/red and red/red flash operation. The study found that, in most cases, yellow/red flash had the lowest delay while red/red flash had the highest delay. Yellow/red flash was found to be most appropriate when the volume ratio (major to minor) was great than 3:1 [7].

The final recommendation from the study was that flash mode should not generally be used at actuated signals since delay is low. Yellow/red flash may be appropriate at pre-timed traffic signals under these conditions; major street two-way volume is less than 500 vph, minor street volume is less than 100 vph, volume ratio is 3:1 or more, and no more than one crash at the intersection in the previous two years [7]. Red/red flash has similar restrictions with the exception of the volume ratio being less than 3:1 and it should be an isolated intersection.

2.1.6 Polanis (2002)

In the April 2002 edition of the ITE Journal Polanis published a study called *Right-Angle Crashes and Late-Night/Early-Morning Flashing Operation: 19 Case Studies* [9]. It is unique among the other studies listed in this literature review in that it has three groups of data; before, after, and a second after. It was found that after the intersections started to use full-color operation there was a decline of 78 percent, in right-angle crashes, at the 19 intersections under study. Six intersections were involved in the second after period. For this after period it was found that the right-angle crash rates were at similar low levels of the first after period.

Polanis goes on to discuss the issue of using flashing operation for minimizing delay. About a third of the 19 intersections covered in this study had volume ratio of 3:1 or more, which is the minimum suggested cutoff for the use of yellow/red flash in other studies [9]. Despite guidelines in other studies suggesting flash operation could be favorable at these intersections Polanis found that this guideline does not guarantee a low likelihood of right-angle crashes. It is suggested that the argument for using flash operation to reduce delay should not be made in general, but used carefully with monitoring.

2.2 Literature Review Summary

Most research about flash operation has focused on when preprogrammed night flash should be used and associated safety concerns. In several studies it was shown that yellow/red flash operation reduced the delay for drivers at night when used in place of normal operation. The same studies also described safety a concern that normal operation at night may cause drivers to ignore the traffic signal resulting in risky situations. When flash operation is used at night, however, there was an increase in crash rates in almost all the reviewed studies, especially right angle crash rates.

Malfunction flash operation represents a very different situation from that examined in the previous studies. Preprogrammed flash operation is designed to occur at low demand time periods while malfunction flash operation can occur at any time. Malfunction flash operation can occur when there is high demand at the intersection and it is unknown whether assumptions of preprogrammed flash are true under those conditions. Further study is needed to examine safety concerns and driver behavior at intersections in malfunction flash.

CHAPTER 3

DATA COLLECTION AND FILTERING

In the literature there is a consensus that during flashing operation right-angle crashes tend to increase, however the literature provides little detail on the crash characteristics, other than they occurred under flash operation [5, 6, 9, 10, 12]. This study will provide further investigation into the characteristics of these crashes using a combination of crash reports and accident databases.

The Georgia Department of Transportation (GDOT) provided electronic versions of crash reports for calendar year 2006 in Adobe Acrobat© (pdf) format. These crash reports were the scanned copies of police reports provided to GDOT that contained the information used to populate the crash databases. The police crash reports contain the drivers' information, car models, observations, and statements of those involved. Unfortunately, there is limited time to collect information and the preprinted forms only request the most commonly needed information. The forms contain a 'Remarks' box that allows the officer to write a description of the crash scene and record testimony of those involved. The remarks box is where an officer would describe important facts that are not covered elsewhere on the form.

GDOT also provided a database that contained information on the crashes, the locations, road geometries, weather, and several other characteristics. This information is taken from police crash reports to create a more detailed document describing the crash. It is from this document that much of the data for this study were taken.

Although the crash reports and crash database contain a great deal of information, there are still some pieces of data that are not listed directly. The provided crash database does not contain an entry to record whether the intersection was operating under malfunction flash. The only method available to determine if the crash occurred under malfunction flash is to read the Remarks box in each individual crash report for comments from the officer.

Reading all of these reports proved impractical, as for 2006 over 340,000 crashes were reported in Georgia. To find the crashes that occurred during malfunction flash an automated search method was required. A simple direct method was not possible as the provided crash reports did not have searchable text. Therefore, the PDF files were converted into a searchable text format using a commercial text recognition program (OmniPage® 16).

With the combination of the Georgia crash database and text files, electronic key word searches were possible. These key words were common descriptors of a malfunction flash event and would be used to create a smaller list of candidate crashes that may involve malfunction flash. These candidate crashes were then reviewed manually to confirm if they were a crash during malfunction flash conditions. After a series of confirmed malfunction flash crashes were identified, additional information could be retrieved from the GDOT crash data and subsequent analyses could be performed.

3.1 Data Preparation

This section describes how the data was filtered and prepared for analysis.

3.1.1 Data Sources

The data was provided by GDOT in two forms; PDF's and a Microsoft Access database. Crash reports were in the PDF format, with summary details provided in the Access database. Crash report files were scanned images of archived microfilm and because of this the PDF files did not have editable text. The Georgia Crash database was provided in Microsoft Access 2003 format. This file served as the source of a majority of the data used in this study.

3.1.2 Filtering Crash Reports

A malfunction flash crash is a rare event among all crashes. With over 340,000 listed crashes for 2006 it would be extremely time intensive to read through each crash report to determine if the crash occurred during malfunction flash. However, by understanding a few characteristics of malfunction flash crashes, the list of potential crash records that require by-hand review to determine if malfunction flash was a factor can be reduced.

3.1.2.1 Database Filtering

As malfunction flash operations only occur at signalized intersections only those crashes that the Georgia Crash database lists as being at a signalized intersection were considered. The number of candidate crashes that occurred at signalized intersection may be further reduced. In the Georgia Crash database signalized intersections are listed as Traffic Control Device (S), Traffic Control with Pedestrian Signalization (P), and Traffic Control Device with Turn Arrow (L) under the LOC_SIGNAL_TYPE variable. For this study only S and L type signalization is included. Also, as this thesis will only examine malfunction flash crashes between drivers crash must have a Total Number of Vehicles (TNV) variable of two or more.

A new query was created in Microsoft Access that would display the accident identifier, total number of vehicles, and the signal type. In the database a new relationship was made between the variables ACC_ID and LOC_ACC_ID. This variable relationship ties together information between the tables in the GDOT accident database. In the criteria box below the LOC_SIGNAL_TYPE a restriction was typed in to only allow signalized intersection crashes to be displayed ("S" or "P" or "L"). For the criteria box of the TNV variable the restriction was to only include crashes with at least 2 vehicles ('>1').

After applying these filters to the Georgia Crash database there is a potential pool of 72,968 crashes.

3.1.2.2 Type-Written Filtering

Even with the reduction of candidate crash records a search of the remaining records to identify malfunction flash incidents requires automation. When reviewing the available collection of PDF crash reports it was discovered that not all crashes were included. Of the 72,968 candidate crashes identified only 68,006 crash reports were available in PDF format. The remaining 68,006 files were a mix of typed-written and hand-written crash records. The program that was used to transfer the files into a searchable format was OmniPage® 16. OmniPage® 16 can reliably translate typed text without previous training, however, the program requires training in order to translate handwriting. As there could be hundreds of different police officers writing the reports it was not possible to train OmniPage® 16 in every case.

Because of the issue of limited time only type written crash reports were used for this analysis. To create a pool of type-written reports involved another filtering procedure was developed. A Microsoft Visual Basic© program was created for a user to quickly identify and record if a file was handwritten or typed. The program created a record for each file and this record was used to sort crash reports as ‘hand-written’ or ‘type-written.’ The user was also given the option to ‘Flag’ a file if they could not determine if the file was typed or had some other issue.

For the Visual Basic program to function the PDF’s that matched the criteria in the database filter were cropped to 1 page and converted to JPEG format using Adobe Professional©. This conversion allowed for simple code to handle recording the results from the user. Cropping the crash reports allowed the program to display just the page with the remarks box, which the user used to determine if the record was type-written or hand-written.

Figure 3.1 displays the interface presented to the user for this stage of filtering. The large space would contain an image of a remarks section of a crash record (an image is not shown to preserve data privacy). The reader would click the appropriate button to indicate if a record was type-written or hand-written. When the reader cannot tell if the crash report is type-written or hand-written from the displayed page they click the button labeled ‘Flag.’ These files would be reexamined to determine in which category they belong.

For this research the crash reports were separated into folders with about 1000 crash reports each. Reducing the number of crash reports being sorted at any one time allowed the code to respond promptly to user commands. In the top left text box the user would indicate the number of the folder being used. When ‘Start’ is pressed the program recognizes the crash reports the user has already marked and starts with the first file that is not marked as true (type written) or false (hand written). The other buttons will now be usable by the reader.

The program also has buttons labeled ‘Next PDF’ and ‘Last PDF.’ This allows the reader to go back and see how they labeled previous crash reports. Two text boxes are located beneath these buttons to display the file location and the ‘true/false’ designation. If the reader has not yet decided if the file is type-written or not the text box will display ‘Undesignated.’

The button labeled ‘Finish’ is used when the reader wants to complete the current session. When clicked the program checks the current folder for a previous set of result and appends the new results into a new text file. The end result of the program is a text file that contains the location of each file and a ‘true/false’ designation. Labeling a file as ‘true’ means the crash report was a type-written document while ‘false’ means the report was hand-written.

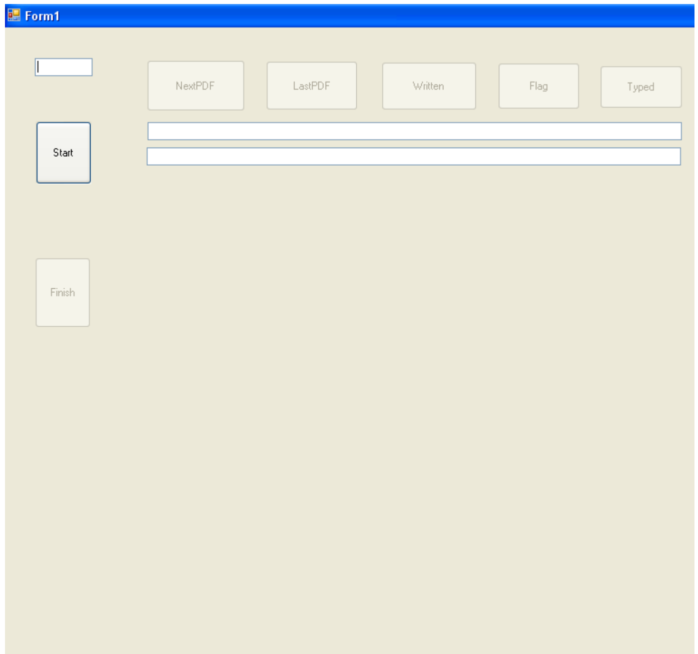

Figure 3.1 User Interface for Type-written Filtering

This additional level of filtering left a potential malfunction flash crash pool of 42,729. A new field was created in the database called ‘Typed’ where a yes was recorded for each crash report that was identified as a type-written document.

3.1.3 Conversion Software

After the crash report files have gone through the previous filters, those files could than be transferred into a searchable format. To translate the files an optical character recognition (OCR) software was required. OCR software is able to take an image of writing and output that text into another format. For example, a JPEG image of a letter is analyzed by the OCR software and a Word document is created as the output. The user now has an editable file that is a close approximation of the original document. The same process is used to take the images of the crash reports and output a text document that can be easily searched through using OmniPage® 16.

OmniPage® 16 is capable of automating this process on large batches of files accurately [15]. The program analyzes the PDF crash reports, recognizes the text, and then outputs the results into the requested format. The entire crash report was converted into a text file. This was done because the remarks section could not be selected for every document. Some crash reports required lengthy descriptions which caused the remarks to continue onto another page. This required that the entire document be converted into a text file so that it could be searched by certain keywords described in the next section.

3.1.4 Malfunction Flash Search

After the entire crash report PDF had been converted into a text file it could now be searched by using keywords. These keywords are common descriptors of malfunction flash events and were used to find the crash reports that most likely occurred under those conditions. The following words were used in the search for malfunction flash events: malfunction, flash, mode, yellow, red, flashing, amber, light, signal, red/red, yellow/red, lightning, ball, and traffic.

By searching for these terms a majority of the malfunction flash crashes can be found quickly without individually reading every report. The search program was set to search through every text file in a targeted folder. To account for small errors such as an officer misspelling a keyword or the OCR program misreading a letter the program performed a wildcard search. One at a time each letter in a keyword would be replaced by a '?.' The use of this character tells the Visual basic program that any character may be in that position. For example if the search string was 'malfunctio?' the program would search for a word that started with 'malfunctio' and ended with any type of character.

This search did result in several false positives being identified. To account for this a result list was created of files for which the program found a matching search string. The reader would then look through the result list to determine which files were actual malfunction flash crashes by reading the crash reports. In most cases, there were far more false positives than malfunction flashes, such as 30 false positive to 1 actual flash event. A new field was then created in the GDOT Accident Database called 'Malfunction' to list each malfunction flash crash.

3.1.5 ArcGIS

ArcGIS© by ESRI is a software package that is used for geographic information systems (GIS). GIS software can present large volumes of data, that are spatially referenced, on interactive maps. This software allows the user to search the data based off many different characteristics such as county names, population densities, roads, zip codes, or distance from another object.

ArcGIS was used to map the locations of accidents within Georgia and to show other characteristics spatially. This was accomplished by creating a connection between the ArcGIS software and the GDOT accident database. Since several tables in the accident database include latitude and longitude data, the crashes could be placed above a map of Georgia.

Population data was taken from the US Census Bureau statistics for 2000 [16]. The population data was uploaded to ArcGIS using the 'Add Data' command and then selecting the census track shapefiles. Population data was connected to the GDOT database by using the 'Join' command. This was done by creating a new table in the GDOT accident database called 'CountyCodes.' This table contained the GDOT codes for every county in Georgia along with the number of type-written reports by county. The GDOT code matches the Federal Information Processing Standard (FIPS) code which can relate entries in both datasets to be displayed in ArcGIS.

3.1.6 SPSS

Statistical analysis in this thesis was performed using SPSS 17©. SPSS can quickly evaluate the large datasets used for this thesis and present the results in forms designed by the user.

For this research the analysis consisted of cross tabulation and frequency comparisons of several groups of crashes. The crash data was split into 4 groups; all crashes, two-way and four-way stop intersection crashes, malfunction flash crashes, and signalized intersection crashes. In this research the characteristics of each group were evaluated on the basis of manner of collision, contributing factors, and crash severity. Malfunction flash crashes were further examined by location and flash mode.

3.1.7 Result Summary

After the filtering process 83 malfunction flash crashes were identified out of the 42,729 crashes that were type-written, occurred at signalized intersections, and involved at least 2 vehicles. In this set of crashes only 65 events were confirmed to have had yellow/red or red/red flash occur before the crash. Fifty-seven of the malfunction flash crashes were yellow/red flash events. Eight crashes were confirmed to be red/red malfunction flash events.

There were several false positives that were removed after the keyword search. Crash reports that contained the keywords were read thoroughly to determine if a malfunction flash occurred before the event and to determine the type of flash (yellow/red or red/red). Six crashes occurred before or directly caused the malfunction flash to occur by damaging signal equipment. Three of the crashes mentioned malfunction flash occurring, but the police officer, witnesses, or one of the drivers stated that flash operation did not occur at the time of the crash.

Nine out of the 83 malfunction flash crashes did occur during a flash event, but could not be identified as yellow/red or red/red. The crash reports for these crashes stated the traffic signal was in malfunction flash without distinguishing the flash mode or only discussed the flashing red approach. When a crash report only discussed a single flashing red approach it cannot be determined if the flash mode was yellow/red or red/red, as both have a flashing red approach.

Only the 65 crashes that were identified as yellow/red or red/red will be included for analysis later in this study. Table 3.1 shows how the original data set was reduced with each step of the filtering process.

Table 3.1 Data Groupings of 2006 GDOT Accident Database[17]

Total Crashes:	342,535
Signalized:	75,115
TNV (2≤X):	280,694
Signalized and TNV (2≤X) Reports:	68,006
Type-written:	42,729
Hand-written:	25,277
Crashes Where a Malfunction Flash Occurred:	83
Confirmed Yellow/Red and Red/Red Flash Events:	65

CHAPTER 4

DATA ANALYSIS

Chapter 4 discusses the crash characteristics from the GDOT accident database and crash reports. As this thesis is focused on crashes that occurred during a malfunction flash event, the data was separated based on a few criteria for comparison purposes. The overall GDOT accident dataset consists of 342,535 reported crashes that occurred in Georgia during 2006 [17]. Through database filtering the list was reduced to 72,968 crashes that occurred at signalized intersection and that involved at least a total number of vehicles (TNV) of at least 2. The added restriction of at least 2 vehicles was used as this research is focused mainly on crashes that occur between vehicles. The files from this group were then separated out based on whether the crash report was type-written or hand-written. Although the database was comprehensive this research did not have a complete set of crash reports. Using the previous criteria there were 68,006 crash report PDF's available to search for malfunction flash crashes. Out of this group it was found that 42,729 crashes had reports that were typed-written. These files were searched and reduced to a group of 65 confirmed malfunction flash crashes.

There are three main crash grouping that will be discussed; all crashes, signalized crashes, and confirmed malfunction flash crashes. These groups will be analyzed and compared to determine their defining characteristics. In addition, national data for 2006 was taken from the National Accident Sampling System (NASS) General Estimates System (GES) and used as a basis for comparison to the findings from 2006 Georgia crashes [18]. GES data is gathered from a nationally representative sampling of 6 million reported crashes each year.

4.1 Data Validation

As discussed in chapter 3 not all of the crash reports could be hand reviewed to find malfunction flash crashes. Without reading each crash report it is difficult to know how many malfunction flash events actually occurred in Georgia in 2006. By using an automated search method, however, a large sample of the events could be found to represent the population.

4.1.1 Search Method Validation

From the 2006 crash reports the search method found 65 yellow/red and red/red malfunction flash crashes out of the 42,729 typed reports that met the criteria. The criteria were that the crash occurred at a signalized intersection and involved at least 2 vehicles. This validation attempts to estimate the percentage of malfunction crash reports in the typed records identified using the OCR text search discussed in Chapter 3.

A the random sample 3000 crash reports were selected from the group of 68,006 available crash reports that occurred at signalized intersections and involved 2 or more vehicles. Each crash report was read thoroughly and a total of 5 confirmed malfunction flash crashes were found in the random selection, which is a rate of .16 percent. This matches well with the expected rate of .15 (65 out of 42,729 reports) from the OCR based search method. This would suggest that a large portion of malfunction flash crashes were found through the automated search.

To determine if the automated search method can find a majority of the malfunction flash events, the results were compared to a Poisson distribution derived from the random sample. Since malfunction flash events are relatively rare events a Poisson distribution may be used to describe their probability mass function [19]. The first series, in Figure 4.1, consists of the typed reports that occurred at signalized intersections and involved at least 2 vehicles. The second series is an estimation of the curve as predicted by the sample over all of the 68,006 available crash reports.

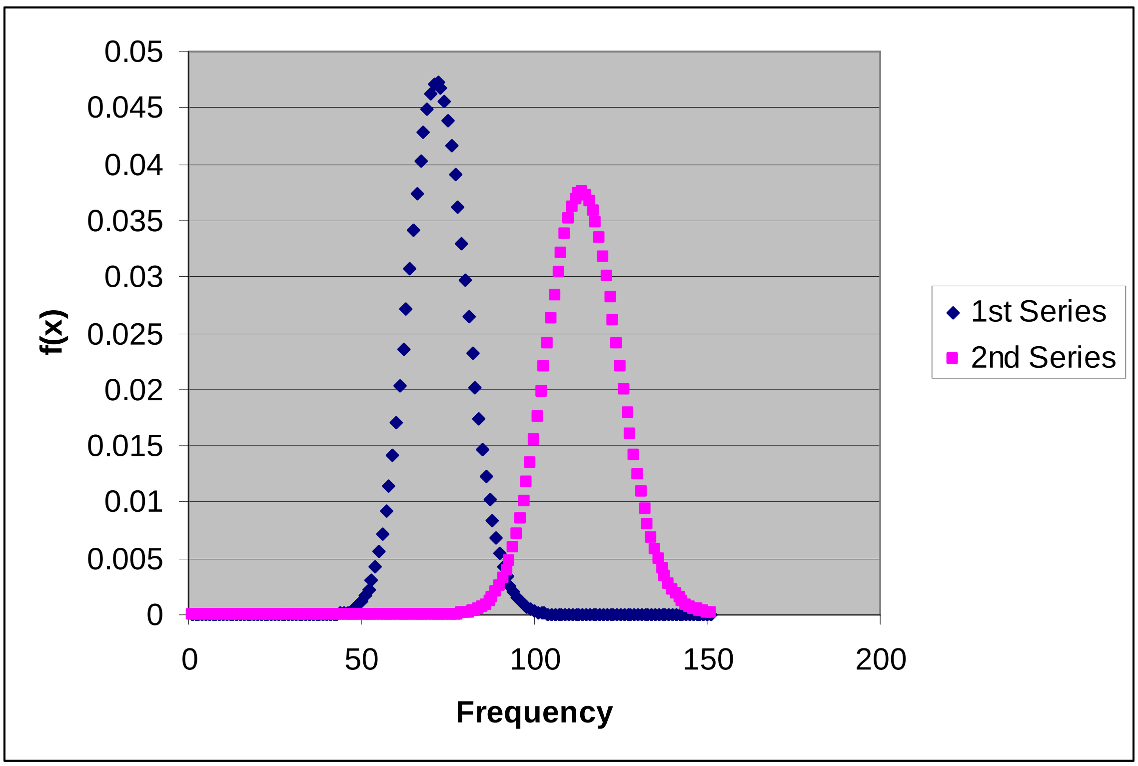

Figure 4.1 Poisson Probability Mass Function of Malfunction Flash Events

Based on the 3000 random sample set the mean of the Poisson distribution would be about 71 malfunction flash crashes among the 42,729 crash reports. This matches well with the search method which found 65 crashes in the same dataset. Taking this further the mean for the available 68,006 crash report set for 2006 would be 113 malfunction flash events. This estimate implies that the automated procedure described above was probably able to identify more than 50 percent of the total 2006 malfunction flash crashes.

4.2 Data Analysis

In this section the characteristics of the malfunction flash crashes can be examined and compared against crashes in general. For this examination four groups will be compared; all crashes, all signalized crashes, two-way and four-way stop intersection crashes, and malfunction flash crashes. The data for this comparison will be taken from the GDOT accident database. This database contains a wide variety of information about the crash itself, the drivers, passengers, location, and other characteristics.

4.2.1 Categories of Malfunction Flash Crashes

There is no field in the GDOT accident database or on the crash report to identify a malfunction flash event, so the only method for identification is to read the 'Remarks' section of crash reports. Crash reports identified as a malfunction flash event were read in detail to determine the circumstances that the crash occurred under.

In most cases, the flash mode (red/red or yellow/red) can be properly identified, but there are cases where such identification is not possible. A traffic signal operating under malfunction flash will either present the driver with a red/red or yellow/red flash. However, some crash reports only describe a red flash in a single direction which means the signal could be flashing red/red or yellow/red on the cross street. In other cases there is a dispute as to the particular flash mode the signal was under at the time of the crash.

During other events the crash itself caused the malfunction flash by damaging signal equipment.

To account for these different situations a new field was created, called 'Malfunction,' in the GDOT accident database that described the malfunction flash event. Crashes that were determined to have occurred during a malfunction flash were recorded under this new field as R/R (red/red flash), Y/R (yellow/red flash), R/X (confirmed malfunction flash, but not known if it was red/red or yellow/red), Unknown (Driver or officer disagreement about condition of flash mode), or 'Flash occurred after the crash.' In total there were 83 crashes that involved a malfunction flash in some manner. Only 65 of these events were identified as yellow/red or red/red. This group of yellow/red and red/red malfunction flashes will be used for analysis later in this thesis. The distribution of these flash categories is presented in Figure 4.2.

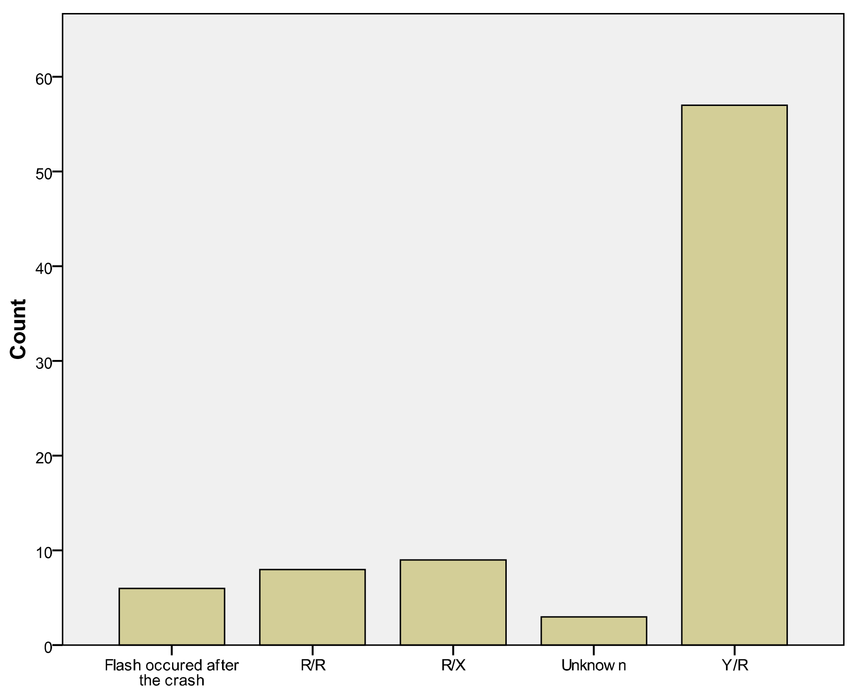

Figure 4.2 Categories of Malfunction Flash Crashes for 2006

Yellow/red flash mode crashes are found in 20 counties in Georgia while red/red flash crashes are reported in 3 counties. However, additional counties could have crashes during malfunction flash as not all instances are included in this analysis, as discussed earlier. For instance, it was noted during the data filtering that several counties have a bias toward hand-written reports and thus crashes from these counties were not included since they could not be converted into a searchable format.

It is clear from the dataset that in most cases a crash at a traffic signal in malfunction flash operation will be a yellow/red flash. Yellow/red flash mode poses a concern as drivers, facing the red flash, may not know if intersecting traffic will stop or continue. In the 1980 study done by FHWA a survey of drivers found that 28 percent believed if they faced a flashing red traffic signal intersecting traffic would stop [10]. Only 33 percent of drivers in the survey correctly stated that they would not be able to know if intersecting traffic would slow or stop. However, it is important to note that it is not possible to discern if yellow/red malfunction crashes are overrepresented relative to red/red malfunction crashes as there is no existing database of malfunction flash type at intersections throughout Georgia. Thus it is not possible to determine the relative exposure of drivers to yellow/red versus red/red flash.

4.2.2 Malfunction Flash Overrepresentation

In previous research by Jenior, survey responses of local agencies reported that signals are normally repaired in less than 2 hours after notification [2]. Assuming that most signals under malfunction flash are repaired within this time period it can be determined if there is an overrepresentation of malfunction flash crashes (yellow/red + red/red) in the dataset.

Table 4.1 Accident Rates as Determined by Ratio of Accidents and Time

Accident Rate Method	Total	Malfunction Flash Event	Ratio
Ratio of Accidents	42,729 Crashes Searched	74 Confirmed Crashes	0.0017
Time out of Year	8,760 Hours Per Year	2 Hours Per Year	0.00023

Based on these assumptions, there is a 7.4:1 ratio between the percentage of crashes that occur during malfunction flash and percentage of time signals are in flash. This indicated that malfunction flash is over represented in the crash database. However, Jenior states that the survey responses were based on the judgment of the responder and not maintenance logs [2]. Due to this possible discrepancy 2 hours may not accurately represent the time an average intersection spends in malfunction flash. He goes on to also state that there may be considerable time before the agency is notified of the malfunctioning signal. Assuming a crash is no more likely during malfunction flash than normal operations it would be expected that the average signal would be in malfunction flash for 14.9 hours per year, based on the 2006 crash data. While the reported 2 hours may be low a 14.9 hour average appears high. Thus, it is likely the conclusion that crashes during malfunction flash are overrepresented, even given errors in the stated assumptions, is correct.

4.2.3 Urban and Rural

When filling out crash reports in Georgia, there is no requirement to fill out the form using computer type characters, only that they should be filled out legibly [20]. Some counties may hand-write the information into the forms while other counties may type most of their crash reports. When this is also combined with certain counties of Georgia being the major population centers, this could lead to an urban bias in the reporting of malfunction flash crashes on type-written forms (the only data considered in this report). Areas that hand-write most reports and have a relatively low population would probably not be well represented in the dataset used for this research. Hand-written reports were not converted to text files so malfunction flash crashes in those reports would not be found by the automated search.

Figure 4.3 shows the population percentages by county in Georgia with an overlay of the yellow/red and red/red crashes. Figure 4.4 shows the percentage each county reported toward the total amount of typed reports.

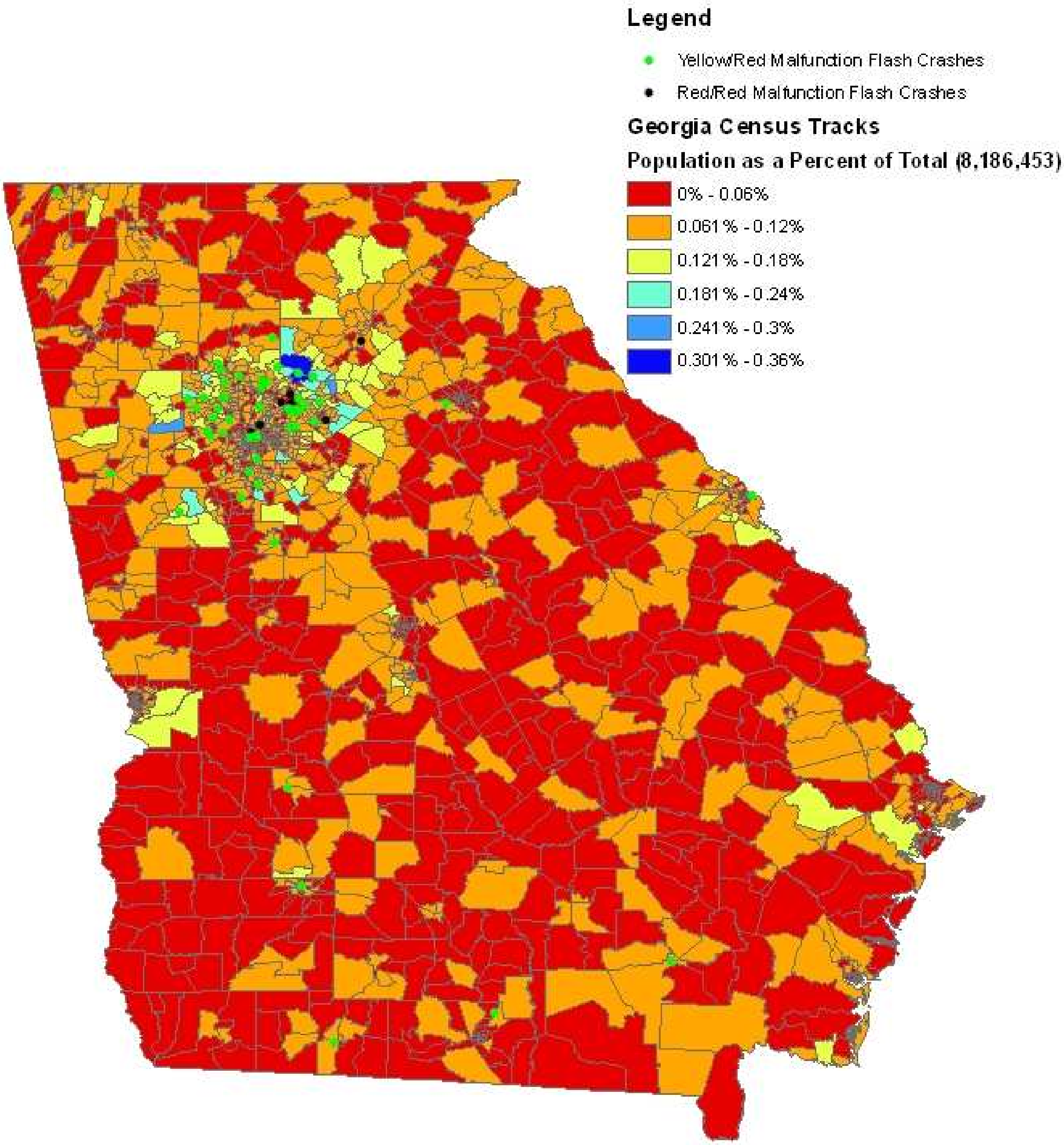

Figure 4.3 Population of Georgia in by Census Tract in 2000 with Yellow/Red and Red/Red Malfunction Flash Overlay [16]

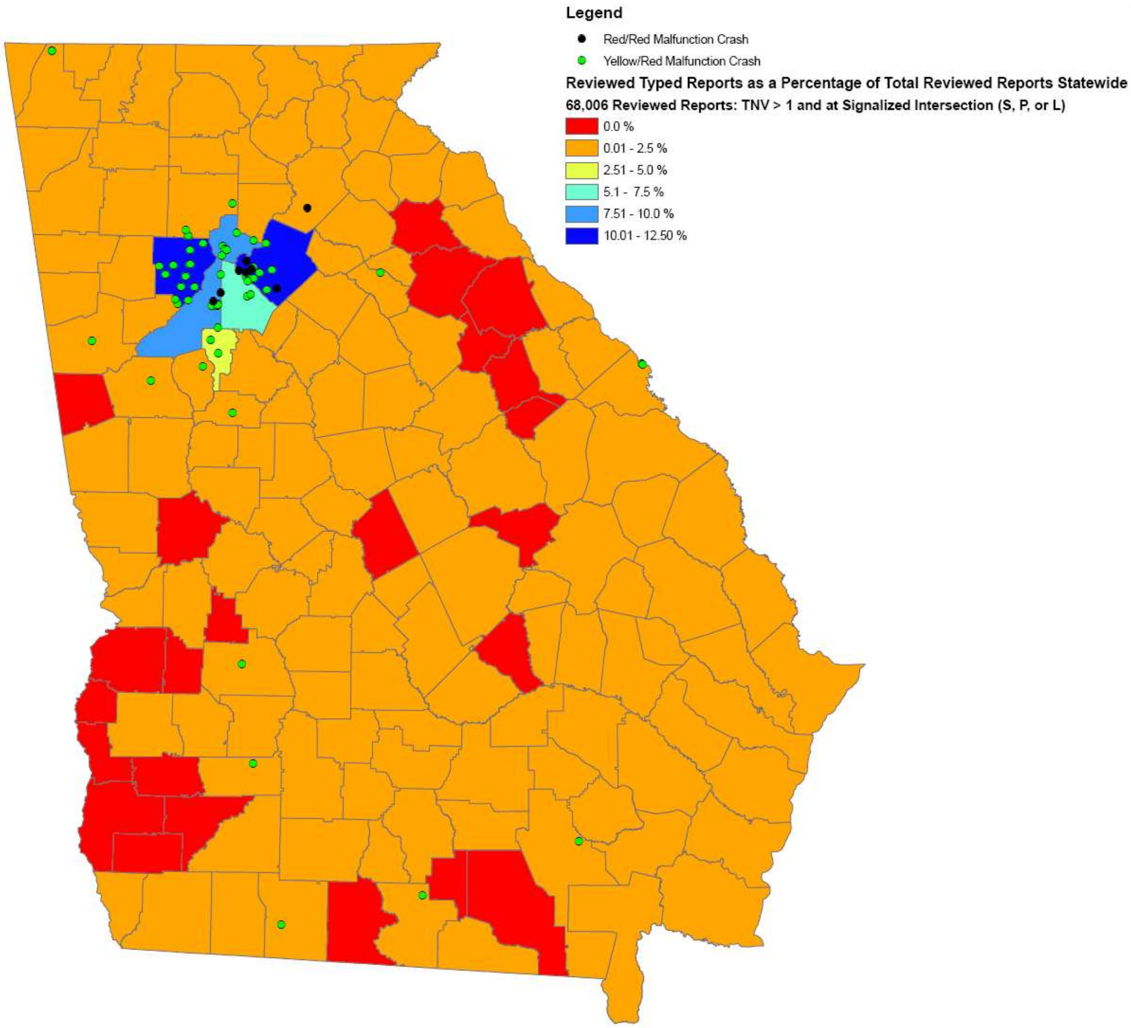

Figure 4.4 Typed Reports Presented by County as a Percentage of the Total Reviewed Reports (TNV > 1 at Signalized Intersections) with Yellow/Red and Red/Red Malfunction Flash Overlay

From Figure 4.3 the major population center in Georgia, for 2000, was the Atlanta metro area while the least dense areas of Georgia were in the southern half of the state. This is similar to Figure 4.4 that shows percentage each county contributed to the reports that were searched. Most of the crash reports that were searched for malfunction flash crashes came from the Atlanta metro area.

As a consequence of population and percentage of typed reports by county most of the malfunction flash events that were found were within the Atlanta metro area. Because of these issues, even though the majority of malfunction flash crashes found for this study center around Atlanta, this does not imply that signals in this area are more prone to malfunction flash issues than those in rural areas. Although with much of the population centered near Atlanta it would imply that malfunction flash in this area would be exposed to a greater number of drivers than rural areas. The higher population leads to the concentration of malfunction flash crashes to occur in this area with a few recorded incidents across other parts of Georgia.

It could be beneficial to concentrate efforts to minimize incidents of traffic signals falling into malfunction operation in the Atlanta metro area. Minimizing the exposure of malfunction flash to drivers in this area would have the greatest impact in reducing malfunction flash crashes.

4.2.4 Manner of Collision

The manner of collision is a description of how vehicles initially made contact. This category describes crashes as angle, head on, rear end, sideswipe (opposite or same direction), or ‘Not a Collision with a Motor Vehicle.’ For this analysis the category ‘Not a Collision with a Motor Vehicle’ was removed since this term is used for one vehicle accidents [20]. Figures 4.5, 4.6, and 4.7 show the general trends for all crashes, signalized crashes, and malfunction flash crashes respectively for the Georgia 2006 dataset.

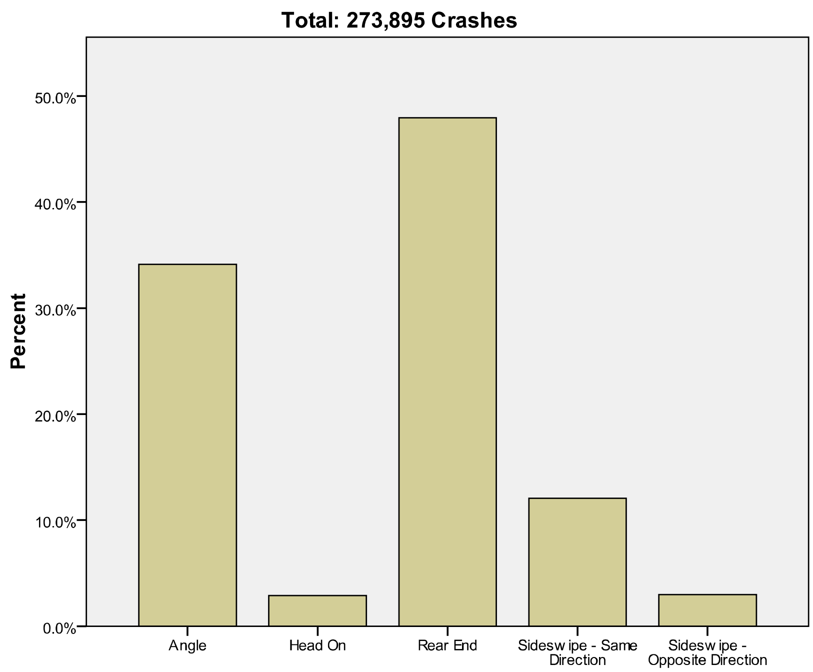

Figure 4.5 Manner of Collision of All 2006 Crashes

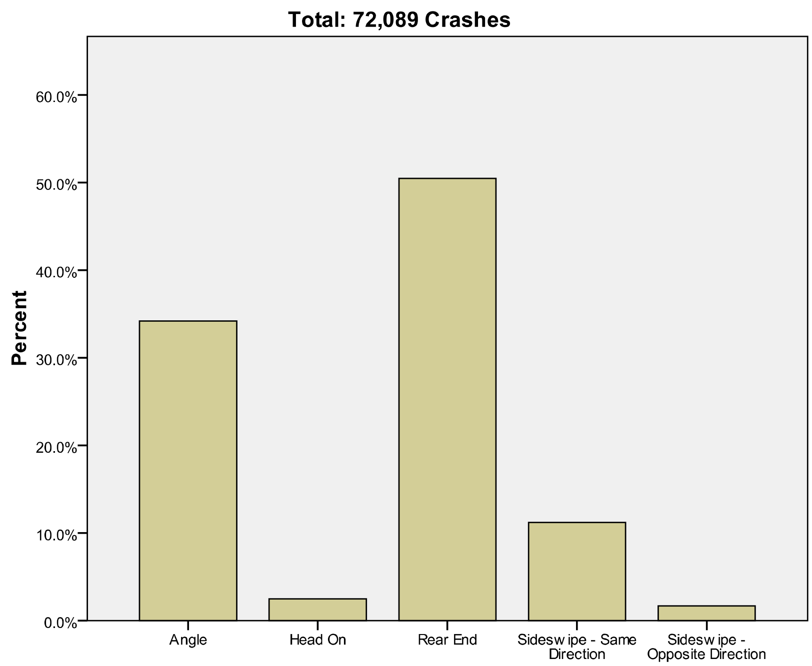

Figure 4.6 Manner of Collision of All 2006 Signal Crashes

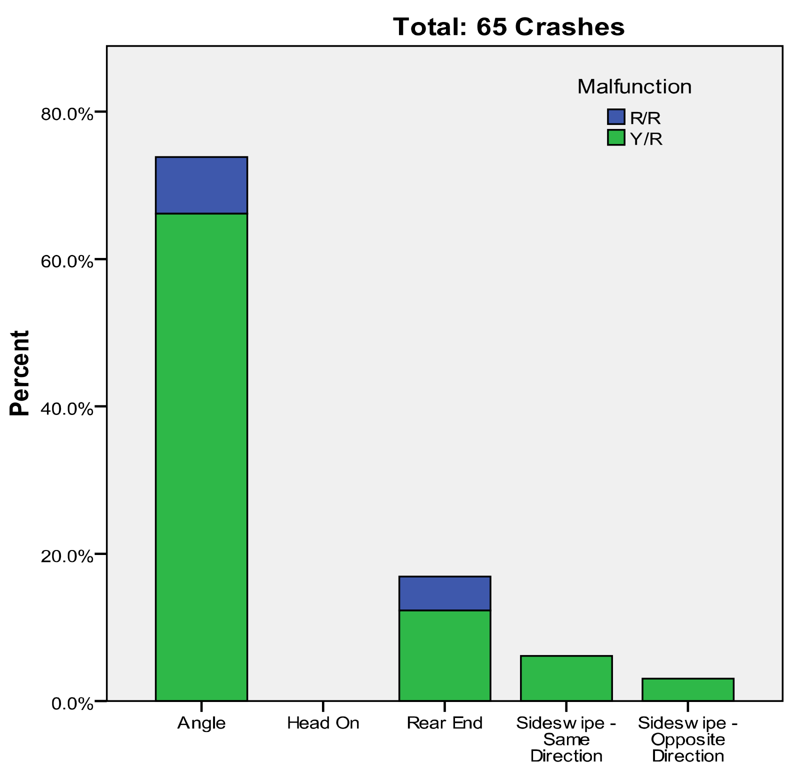

Figure 4.7 Manner of Collision of 2006 Malfunction Flash Crashes

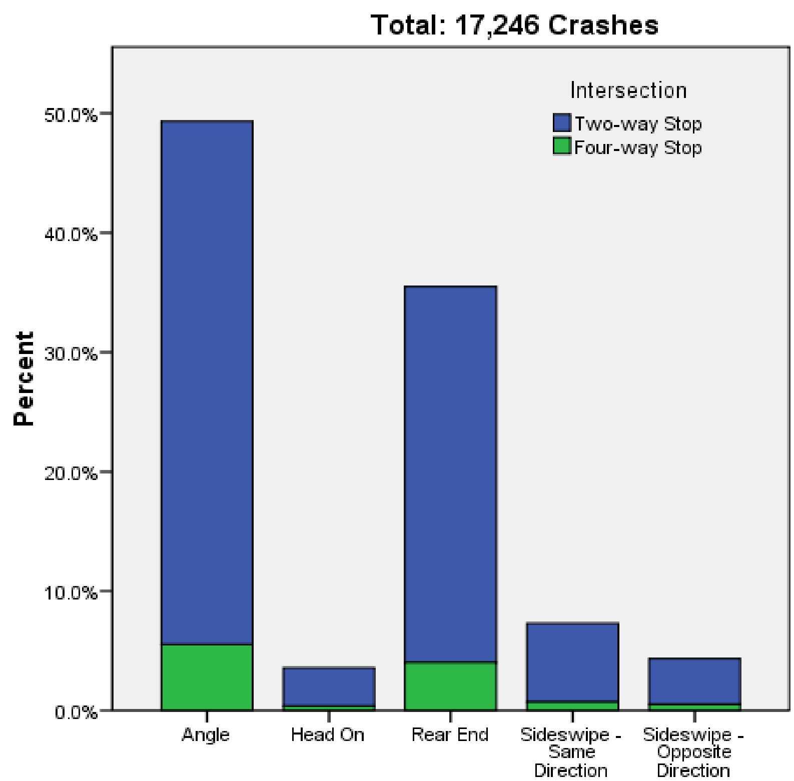

Figure 4.8 Manner of Collision of 2006 Two-way and Four-way Stop Sign Intersection Crashes

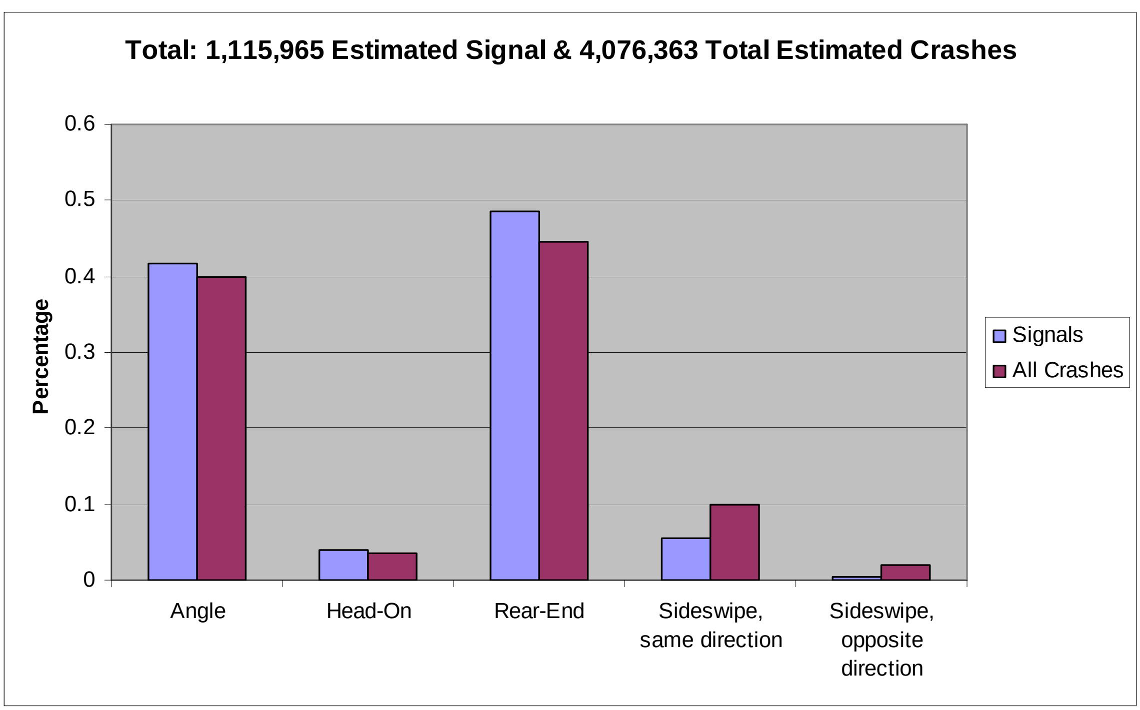

Figure 4.9 Manner of Collision Based on GES 2006 Data for the US

It was found when examining all 2006 Georgia crashes that rear end crashes tend to be the most prevalent followed by right angle crashes. Signalized intersection crashes tend to follow a very similar trend as seen in Figure 4.6 despite representing just 22 percent of the overall crash dataset. In Figure 4.9, the GES data shows comparable characteristics on the national level. Although signalized intersections represent a different set of circumstances than most crashes, the figures show that drivers tend to have collisions in similar ways.

In the case of malfunction flash crashes, Figure 4.7, 73.8 percent are right angle crashes. Rear end crashes represent a much smaller fraction at only 16.9 percent. This is similar to results in the literature review that found right angle crashes tend to be over represented during yellow/red or red/red operation [5, 9-12].

Comparing two-way and four-way stop intersection crashes, right-angle crashes represent 49.3 percent of those kinds of crashes. Rear-end crashes represented 35.5 percent of all two-way and four-way stop crashes. Although right-angle accidents, at stop sign intersections, do not constitute as high a percentage as in malfunction flash crashes this could be due to drivers' familiarity with stop signs.

When the data is examined by order of driver control (traffic signal, stop sign, malfunction flash) there is an increase in the number of right angle crashes as drivers decide for themselves the right-of-way. At signalized intersections in normal operations, right-of-way is clearly indicted while stops signs allow the driver to make a conscious decision as to whether they have right-of-way. Yellow/red and red/red flash events can present similar situations to two-way or four-way stops respectively, but are less familiar with drivers and contradict driver expectation at that intersection. It is likely that the increased uncertainty in right-of-way at malfunction flash intersections is reflected in the increased likelihood of right angle crashes.

4.2.5 Contributing Factors

After the officer has reviewed the crash, they will indicate what factors contributed to the crash in a field called 'Contributing Factors.' The GDOT accident database lists 28 common contributors to crashes such as weather conditions, distraction, failure to yield, and also an option to list 'No Contributing Factors.' This field can show what action was taken or situation that existed that most likely lead to the crash. The database contains 4 fields to input contributing factors, but this research will focus on the first.

Figures 4.10, 4.11, 4.12, and 4.13 detail what factors were considered the leading contributor to crashes in all 2006 crashes, signal crashes, two-way and four-way stop intersection crashes, and malfunction flash crashes in Georgia. Table 4.2 displays the value codes used in the accident database.

Table 4.2 Contributing Factor Code Values

Contributing Factor Code Values					
1	No Contributing Factors	11	Changed Lanes Improperly	21	Driverless Vehicle
2	D.U.I.	12	Object or Animal	22	Too Fast for Conditions
3	Following too Close	13	Improper Turn	23	Improper Passing of School Bus
4	Failed to Yield	14	Parked Improperly	24	Disregard Police Officer
5	Exceeding Speed Limit	15	Mechanical or Vehicle Failure	25	Distracted
6	Disregard Stop Sign/Signal	16	Surface Defects	26	Other
7	Wrong side of Road	17	Misjudged Clearance	27	Cell Phone
8	Weather Conditions	18	Improper Backing	28	Inattentive
9	Improper Passing	19	No Signal/Improper Signal		
10	Driver Lost Control	20	Driver Condition		

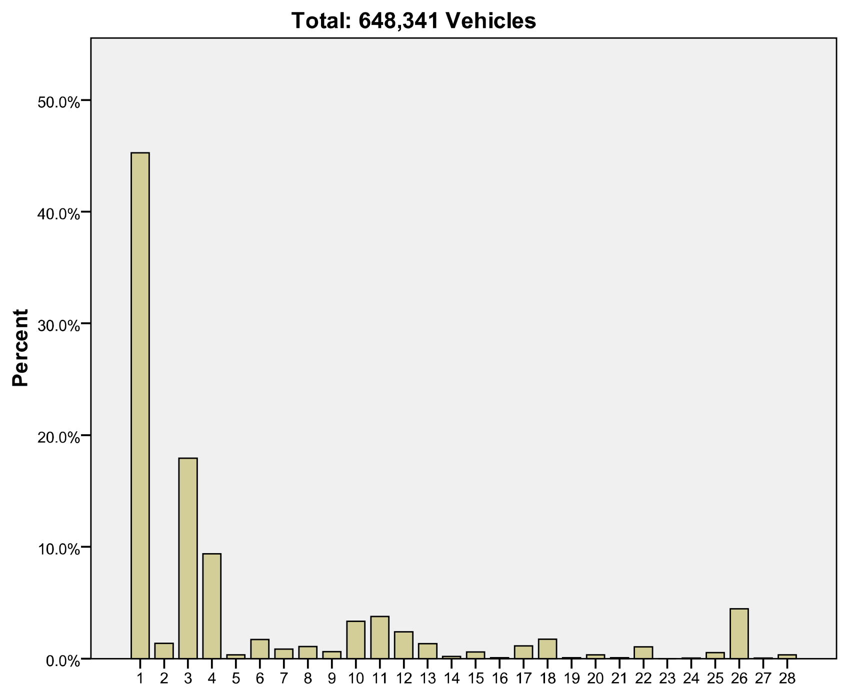

Figure 4.10 Contributing Factors of All Crashes in Georgia in 2006

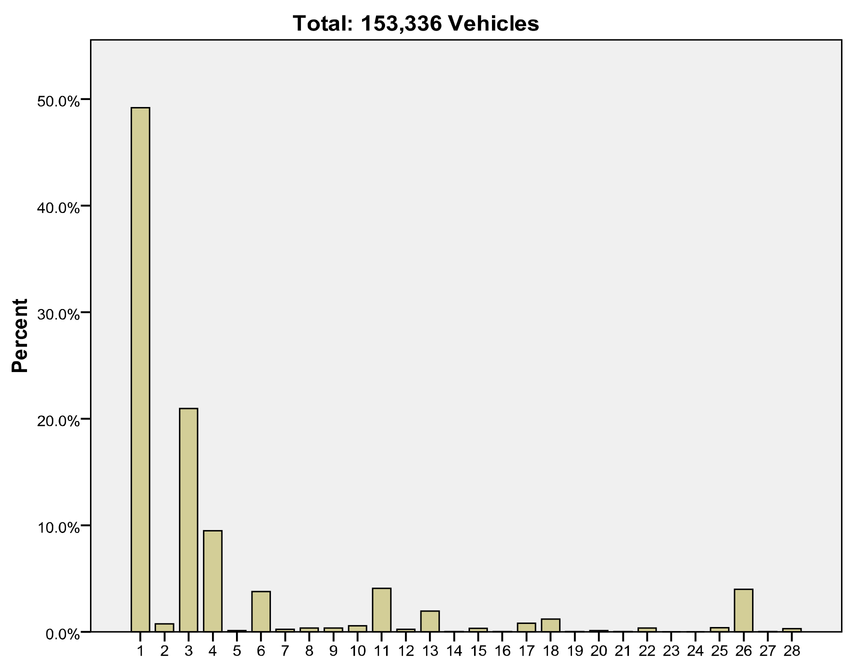

Figure 4.11 Contributing Factors of Signalized Intersection Crashes in Georgia in 2006

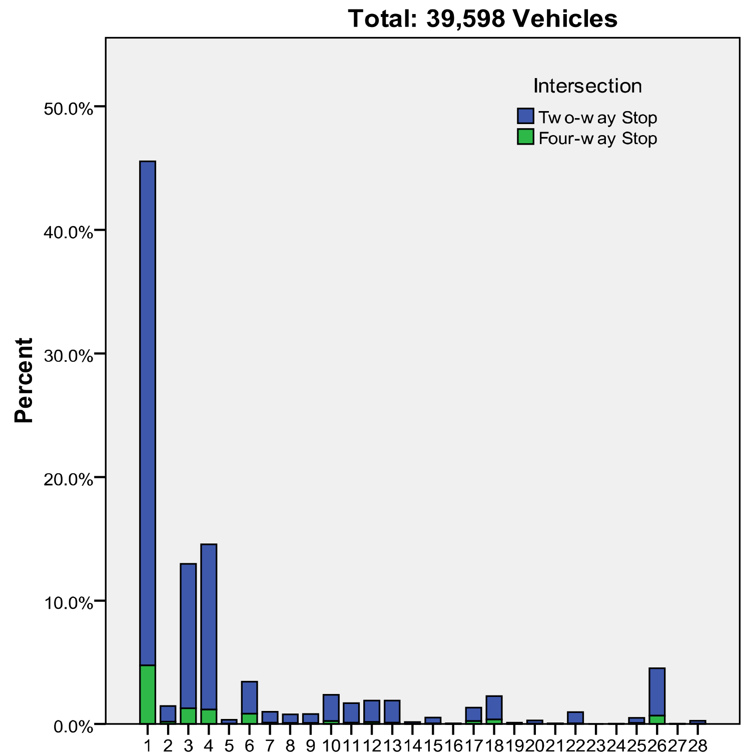

Figure 4.12 Contributing Factors of Two-way and Four-way Stop Intersection Crashes in Georgia in 2006

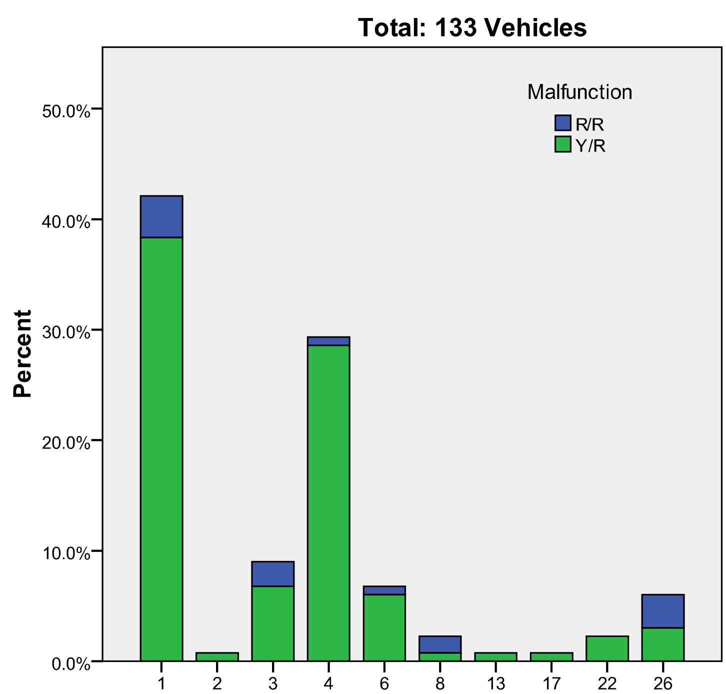

Figure 4.13 Contributing Factors of Malfunction Flash Crashes in Georgia in 2006

A large portion of crashes in general and specifically at signalized intersection do not have an identifiable contributing factor, 45.3 and 49.2 percent respectively in Figure 4.10 and 4.11. ‘Following too Close’ is the second most common category between all crashes and signalized at 17.9 and 21.0 percent, respectively. For all crashes and the signalized crash groups ‘Failed to Yield’ represents 9.4 and 9.5 percent of vehicles involved.

In the cases of stop sign intersections, there is a reduction in crashes that were ‘Following too Close’ to 13.0 percent while ‘Failed to Yield’ increased to represent 14.5 percent relative to all crashes as shown in Figure 4.12.

The complete 2006 crash and signalized crash groups contrast with malfunction flash crashes as ‘Failed to Yield’ is the second most common category at 29.3, displayed in Figure 4.13. Only 9 percent of crashes have a contributing factor of ‘Following too Close.’ From the data, there is a distinct increase in the amount of driver’s failing to yield. This increase may be an underlying factor in the higher percentage of right angle collisions (as seen earlier), possibly leading to a higher likelihood of injuries and fatalities.

There is a similarity in crashes at two-way intersections and yellow/red malfunction flash crashes. Both categories tend to have a higher percentage of ‘Failure to Yield’ over ‘Following too Close.’ The even higher ‘Failure to Yield’ crash rate at yellow/red malfunction flash may be due to mistaken driver expectations. Several crash reports mentioned drivers facing the red flash expected traffic approaching the yellow flash to stop.

Table 4.3 examines the decisions of drivers in crashes at signals in yellow/red flash mode that had 'Failed to Yield' resulting in right angle crashes. In most cases, 73.3 percent, drivers facing the yellow flash did not stop while those facing the red flash did stop. That is, the vehicle facing the flashing red did come to a stop and then pulled out either assuming the cross street vehicle would stop or misjudged the acceptable gap. Cases where either both vehicles stopped or both vehicles continued represent 13.3 percent each. The majority of drivers (86.6%) facing a flashing red and involved in a crash treated the red flash correctly (at least initially) by stopping before entering the intersection. This suggests a significant issue in driver expectation of conflicting traffic behavior.

Table 4.3 Actions Taken by Drivers at Yellow/Red Malfunction Flash Crashes who 'Failed to Yield'

Neither Stopped	Yellow Did Not Stop, Red Stopped	Yellow Stopped, Red Did Not	Both Stopped	Total
4 13.3%	22 73.3%	0 0.0%	4 13.3%	30 100.00%

4.2.6 Crash Severity

Crashes can leave lasting and debilitating issues long after the event occurs. Through proper driver caution and safety planning crash severity can be reduced. For that purpose this section will compare and contrast the qualities of malfunction flash crashes to other 2006 crashes.

In the GDOT accident database there are several categories to describe injuries; Not Injured, Killed, Serious, Visible, and Complaint. A serious injury is defined as any injury that prevents that person from walking, driving, or continuing normal activity as they did prior to the crash [20]. A visible injury is any injury that is apparent to anyone other than the injured person. Complaints are any injury that is claimed by someone in the crash, but are not indicated by any wounds. Table 4.4 outlines the relationship between the manner of collision and severity of driver injuries in crashes at least two vehicles.

Table 4.4 Cross Tabulation of Manner of Collision and Severity of Injury in Crashes of TNV > 1

		Manner of Collision (All Crashes)					Manner of Collision (Signalized Intersections)				
		Angle	Head On	Rear End	Sideswipe -Same Direction	Sideswipe - Opposite Direction	Angle	Head On	Rear End	Sideswipe -Same Direction	Sideswipe - Opposite Direction
		Count	Count	Count	Count	Count	Count	Count	Count	Count	Count
Driver Injury Type	Not Injured	160124	11452	249153	64064	14911	42207	2662	68974	15730	2224
	% of Injury Type	32.0%	2.3%	49.9%	12.8%	3.0%	32.0%	2.0%	52.3%	11.9%	1.7%
	Killed	331	152	72	29	16	35	2	2	1	0
	% of Injury Type	55.2%	25.3%	12.0%	4.8%	2.7%	87.5%	5.0%	5.0%	2.5%	0.0%
	Serious	1269	440	622	186	103	278	57	128	33	9
	% of Injury Type	48.4%	16.8%	23.7%	7.1%	3.9%	55.1%	11.3%	25.4%	6.5%	1.8%
	Visible	7232	1614	3363	662	553	1723	290	470	54	63
	% of Injury Type	53.9%	12.0%	25.1%	4.9%	4.1%	66.3%	11.2%	18.1%	2.1%	2.4%
	Complaint	22413	2700	26868	2479	1163	6368	661	6317	442	214
	% of Injury Type	40.3%	4.9%	48.3%	4.5%	2.1%	45.5%	4.7%	45.1%	3.2%	1.5%
	Collision % of Total	33.5%	2.9%	49.0%	11.8%	2.9%	34.0%	2.5%	51.0%	10.9%	1.7%
		Manner of Collision (Malfunction Flash Crashes)					Manner of Collision (Two and Four Way Stop)				
Driver Injury Type	Not Injured	83	0	18	7	3	14304	928	11447	2430	1379
	% of Injury Type	74.8%	0.0%	16.2%	6.3%	2.7%	46.9%	5.7%	75.0%	63.8%	100.0%
	Killed	0	0	0	0	0	24	0	2	1	2
	% of Injury Type	0.0%	0.0%	0.0%	0.0%	0.0%	82.8%	0.0%	6.9%	3.5%	6.9%
	Serious	0	0	0	0	0	93	17	23	6	7
	% of Injury Type	0.0%	0.0%	0.0%	0.0%	0.0%	63.7%	11.6%	15.8%	4.1%	4.8%
	Visible	5	0	0	0	1	697	101	149	18	39
	% of Injury Type	83.3%	0.0%	0.0%	0.0%	16.7%	69.4%	10.1%	14.8%	1.8%	3.9%
	Complaint	11	0	4	1	0	2188	217	1211	91	91
	% of Injury Type	68.8%	0.0%	25.0%	6.3%	0.0%	57.6%	5.7%	31.9%	2.4%	2.4%
	Collision % of Total	74.4%	0.0%	16.5%	6.0%	3.0%	48.8%	3.6%	36.2%	7.2%	4.3%

After examining the severity of injuries for all crashes in 2006, there is a disproportionate amount of fatalities due to head on crashes. Drivers involved in head on crashes are only 2.9 percent of the dataset, but are 25.3 percent of fatalities. Head on collision deaths represent 8.8 times their proportion of the data. Further, drivers in right angle collisions represent 33.5 percent of all crashes, but are 55.2 percent of the fatalities. Rear end collisions are 49 percent of crashes in general, but are 12 percent of fatalities.

Crashes at signalized intersection tended to be rear end crashes at 51 percent of the dataset however representing only 5 percent of the fatalities. For this group of drivers right angles were the majority of fatalities at 87.5 percent for 2006, but are only 34 percent of signalized crashes. There was a reduction in the number of fatalities relative to all crashes in head on collisions. Head-on collisions are 2.5 percent of signalized intersection crashes and are 5 percent of fatalities in the same group.

In the group of two-way and four-way stop intersections there were no recorded fatalities for head on collisions. Right angle collisions are 82.7 percent of fatalities while only being 48.8 percent of two-way and four-way stop intersection crashes.

For the malfunction flash crashes 16.5 percent of drivers complained or had some kind of injury. In the two and four way stop intersection group 14.0 percent of drivers had complained or had at least a visible injury. The complete 2006 crash group and signalized intersection crash group had 12.6 and 11.5 percent of drivers with complaints of injury, visible injury, serious injury, or fatality.

The two and four way stop and malfunction flash groups share similar qualities. Both groups tend to have a more right angle crashes than crashes in general and at signalized intersections. Drivers involved in malfunction flash crashes were listed as right angle collisions 74.4 percent of the time while two-way and four-way stops tended to be right angle collision in 48.8 percent. While two-way and four-way right angle collisions are not as high a percentage as in malfunction flash crashes, it does represent a significantly larger percentage than crashes in general (33.5) and signalized crashes (34).

Amongst the malfunction flash crashes found in the dataset there were no recorded driver deaths. A review of other years of crash datasets is needed to see the relationship between malfunction flash events and fatalities. However, by examining the rates of complaints of injury, visible injuries, serious injuries, and fatalities in all crash groups inferences can be made about malfunction flash. In each group right angle collisions represented a significantly greater portion of fatalities than the percentage of drivers involved in that category. From this it can be inferred that malfunction flash crashes represent a riskier situation with their high rate of right angle collisions (74.44 percent).

Although the data is not sufficient to distinguish characteristics of red/red flash versus yellow/red flash it is likely that red/red flash is the preferable mode of flashing operation. It is likely that when all drivers face a flashing red signal higher speed right angle crashes would be exchanged for rear end and low speed right angle crashes.

CHAPTER 5

CONCLUSIONS

Malfunction flash is a necessary, but undesirable mode of signal operation. Using malfunction flash operation means that in some way the traffic signal failed. By understanding the characteristics of crashes at malfunctioning signals, risks can be minimized for drivers. Up to this point most research into malfunction flash has focused on preprogrammed night use. Preprogrammed night flash can present drivers with a very different situation than malfunction flash during high demand periods. The conclusions reached by this thesis are presented in the following section.

5.1 Data Analysis

For 2006 there were 342,535 total reported crashes in Georgia. Of these crashes this thesis examined signalized intersection (72,968), two and four-way stop intersection (39,598), and malfunction flash crashes (65) from the GDOT accident database.

Malfunction flash crashes were found by a filtering process and automated word search. The first filter limited the search to signalized intersections crashes. The second filter further reduced the search to type-written reports. This restriction was made due to study time limits and certain restrictions on the OCR software. Typed crash reports were processed by the OCR software and text files were created from the original file. This conversion from PDF to text format was done because the PDF crash reports did not allow editable search. With the text files an automated keyword search was done to find likely malfunction flash crash reports. The remarks section of crash reports were then read thoroughly to determine if they were malfunction flash crashes. Positive results of this search were recorded and updated in the GDOT accident database.

Most malfunction flash crashes, found in this thesis, occurred within the Atlanta metro region. This was most likely due to the much higher population density relative to other parts of Georgia. The high population density means more drivers could be exposed to a malfunction than in any other area of Georgia. Focusing resources on minimizing malfunction flash operation in this area would have the most significant impact on lowering the rate of malfunction flash crashes.

The majority, 73.8 percent, of malfunction flash crashes result in right angle collisions while crashes in general and those at signalized intersections are most often rear end crashes (51 percent). Two-way and four-way stops act similarly to malfunction flash crashes in that the most common manner of collision were right angles, at 49.3 percent. However, this difference is not as pronounced as malfunction flash crashes since rear ends crashes represent 35.5 percent of two-way and four-way crashes compared to only 16.9 percent under malfunction flash. Since two-way and four-way stop intersections are comparable to how yellow/red and red/red flashing signals should operate the differences are most likely due to driver expectations and lack of driver understanding of the flashing traffic control under higher volume conditions. Drivers may not know whether the intersecting traffic will continue through or stop, creating a risky situation.

The most common contributing factor category for crash type was 'No Contributing Factor.' In crash groups of all crashes and signalized intersection crashes 'Following too Close' was the second most common at 17.9 and 21.0 percent, respectively. This was then followed by 'Failed to Yield' category by 9.4 and 9.5 percent for all crashes and signalized intersection crash groups. Two-way and four-way stop displayed significantly different behavior with 13 percent belonging to 'Following too Close' and 14.5 percent being 'Failed to Yield.' Malfunction flash crashes showed an even greater shift toward 'Failed to Yield' at 29.3 percent and 'Following too Close' at 9.0 percent.

From analysis of crash data severity there are two categories of crashes that are overrepresented in fatalities; head on and right angles. In all crashes head on collisions involve only 2.9 percent of drivers, but are 25.3 percent of fatalities. Right angle crashes are 33.5 percent of total drivers and represent 55.2 percent of fatalities. Signalized intersection and stop sign intersections show a sharp decrease in the representation of fatalities due to head on collisions. Two-way and four-way stop intersection did not have any reported fatalities for head on collisions, however, right angle collisions were 82.8 percent of fatalities while only 48.8 percent of drivers were involved in that type of crash. In each group right angle crashes represented a higher percentage of fatalities than its percentage of drivers. In malfunction flash crashes right angle collisions involve 74.4 percent of drivers. The overrepresentation of fatalities for right angle collisions in the general dataset suggests a very unsafe situation for drivers during this flash mode.

5.2 Recommendations

Although malfunction flash mode may operate in a similar fashion to stop sign intersections the data suggests that drivers tend have a higher likelihood of involvement in more hazardous right angle crashes. There are several different approaches that can be taken to try to minimize the risk of drivers to malfunction flash mode.

- Traffic signals should use only red/red flash for malfunction flash mode. This promotes more drivers to come to a complete stop before entering the intersection. Yellow/red flash should not be used at all in this case as driver expectation may become to expect all intersecting traffic to stop leading to more right angle crashes.
- Traffic signal monitoring should be improved through automatic notification or increased public awareness of contact information. Quicker response times would limit the exposure to drivers and reduce accidents of this type.
- The focus should be on reducing malfunction flashing the Atlanta metro area. A signal operating in malfunction flash mode would expose more drivers in Atlanta than most other areas of Georgia.

5.3 Limitations and Recommendations for Future Study

Road safety encompasses a wide variety of situations that determine a driver's overall safety. By understanding the characteristics that lead to malfunction flash crashes a more comprehensive approach can be taken to reduce risks to drivers. There are still many paths of inquiry for future research into malfunction flash. A few areas to expand upon in future studies could be:

- Examine all type-written and hand-written reports for malfunction flash crashes.
- Increase the size of dataset to include multiple years of crash data.
- Analyze if there is a correlation between crash severity, manner of collision, red/red flash, and yellow/red flash.

- Examine differences between yellow/red and red/red malfunction flash events with a larger dataset

APPENDIX A

MALFUNCTION FLASH EVENT SORTER CODE

```
Option Compare Text
Imports System.IO


Public Class Form1
    Dim Pictures() As String  'Records the name of the file.
    Dim PicType() As Double 'Boolean

'Records if the file is typed(-1, true) or written(0,false). If the file has not been looked at
then the default is 0.

    Dim Names As String
    Dim Position As Double = 0
    Dim i As Double = 0
    Dim NoRepeatLists As Double = 0   ' Prevents user from accidently hitting start twice.
    Protected FullPath As String
    Private MyImage As Bitmap
    Dim FolderOfPictures As String = "************************”
    Dim Results As String  'This is where results file will be printed. .
    Dim Test As String 'This is used as a test to see if a file has already been evaluated.



    Private Sub Start_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Start.Click

'Start Button Code

        If NoRepeatLists < 1 Then

            Dim TexttoInt As Double
            If IsNumeric(FolderNumber.Text) Then
                TexttoInt = CInt(FolderNumber.Text)
            End If

Dim FILE_NAME As String = FolderOfPictures + FolderNumber.Text + "\Results.txt"

            If File.Exists(FILE_NAME) Then
                Dim objReader2 As New System.IO.StreamReader(FILE_NAME)
                Test = objReader2.ReadToEnd
                objReader2.Close()
            End If


            If IsNumeric(FolderNumber.Text) And TexttoInt > 0 And TexttoInt < 69 Then
                Dim di As New DirectoryInfo(FolderOfPictures + FolderNumber.Text + "\")
```

```
        'Create an array representing the files in the current directory.

        Dim fi As FileInfo() = di.GetFiles()

        Dim fiTemp As FileInfo

        For Each fiTemp In fi
            Names = fiTemp.Name
            Position = InStr(Names, "Page_1_")

'This value is used to record the position of the file name in the results file.
            Dim Position2 As Double = 0

'If the Results file exists, perform a check to determine if the current filename has already
been evaluated.
            If File.Exists(FILE_NAME) Then
                Position2 = InStr(Test, Names)
            End If

'This line is used as a check to ignore files that did not get properly deleted. Some PDF
files were long and resulted in multiple pages being converted into JPEG format. File
names with “Page_1_” indicates the files with the remarks box.
            If Position > 0 And Position2 = 0 Then
                ReDim Preserve Pictures(i)
                ReDim Preserve PicType(i)
                Pictures(i) = fiTemp.FullName
                PicType(i) = 2
                Position = 0
                i += 1
            End If

        Next fiTemp
        If Not i = 0 Then
            i = 0
            Dim PicPath As String = Pictures(i)
            MyImage = New Bitmap(PicPath)
            FileName.Text = Pictures(i)
            Designation.Text = "Undesignated" 'CStr(PicType(i))
            PictureBox1.Image = CType(MyImage, Image)
            MessageBox.Show("File list loaded. Ready to start displaying images.")
            Written.Enabled = True
            Flag.Enabled = True
            LastPDF.Enabled = True
            NextPDF.Enabled = True
            Typed.Enabled = True
            Finish.Enabled = True
```

```
                NoRepeatLists = 1
                FolderNumber.Enabled = False
            Else


'This set of code removes information from the screen and greys out the buttons so the
user doesn't create an error. If the picture list is empty and then last, next, written, or
typed buttons are used the program will throw an error.
                FileName.Text = Nothing
                Designation.Text = Nothing
                PictureBox1.Image = Nothing
                Written.Enabled = False
                Flag.Enabled = False
                LastPDF.Enabled = False
                NextPDF.Enabled = False
                Typed.Enabled = False
                Finish.Enabled = False

                FolderNumber.Enabled = True
                NoRepeatLists = 0
                MessageBox.Show("This picture folder has already been completed. Please
move on to next folder.")
            End If
            i = 0
            fi = Nothing  'Clears out the file list.
        Else
            MessageBox.Show("Please put in a valid number into box. Such as 1, 2, 3, ...,
68 for the group of pictures you are going through. Value must be a number and be
within 1-68.")
        End If
    Else
        MessageBox.Show("File list has already been created. Program is ready to start.")
    End If
End Sub

Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load

'This codes greys out several buttons when the program loads. The buttons will be usable
after the user inputs the folder number.
    FileName.Text = Nothing
    Designation.Text = Nothing
    PictureBox1.Image = Nothing
    Finish.Enabled = False
    LastPDF.Enabled = False
    NextPDF.Enabled = False
```

```
        Written.Enabled = False
        Typed.Enabled = False
        Flag.Enabled = False

    End Sub

Private Sub Finish_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Finish.Click

'Finish Button Code

        Dim j As Double
        Dim List As String = ""
        Dim Bool As String = ""
        Dim FILE_NAME As String = FolderOfPictures + FolderNumber.Text +
"\Results.txt"

        If File.Exists(FILE_NAME) Then
            Dim objReader As New System.IO.StreamReader(FILE_NAME)
            List = objReader.ReadToEnd
            objReader.Close()
        End If

' This loop creates the results string that will be written to the text file as the final output
of this program. Each line consists of 'file name True/False/Flagged'
        For j = LBound(Pictures) To UBound(Pictures)
            If PicType(j) = -1 Then
                Bool = "True"
                List = List + vbNewLine + Pictures(j) + " " + Bool
            ElseIf PicType(j) = 0 Then
                Bool = "False"
                List = List + vbNewLine + Pictures(j) + " " + Bool
            ElseIf PicType(j) = 1 Then
                Bool = "Flagged"
                List = List + vbNewLine + Pictures(j) + " " + Bool
            Else
                Bool = "Undesignated"
            End If
        Next

        Dim objWriter As New System.IO.StreamWriter(FILE_NAME)
        objWriter.Write(List)
        'objWriter.Write(CStr(i))
        objWriter.Close()

        MsgBox("Text written to file:" + FILE_NAME)
```

```
        Erase Pictures, PicType
        NoRepeatLists = 0
        i = 0
        FolderNumber.Enabled = True

'This set of code removes information from the screen and greys out the buttons so the
user doesn't cause errors in the program.
        FileName.Text = Nothing
        Designation.Text = Nothing
        PictureBox1.Image = Nothing
        Flag.Enabled = False
        Written.Enabled = False
        LastPDF.Enabled = False
        NextPDF.Enabled = False
        Typed.Enabled = False
        Start.Enabled = True
    End Sub

Private Sub NextPDF_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles NextPDF.Click

'Next PDF button

        If i < Pictures.Length - 1 Then
            i += 1

            MyImage = New Bitmap(Pictures(i))
            FileName.Text = Pictures(i)
            If PicType(i) = -1 Then
                Designation.Text = True
            ElseIf PicType(i) = 0 Then
                Designation.Text = False
            ElseIf PicType(i) = 1 Then
                Designation.Text = "Flagged"
            Else
                Designation.Text = "Undesignated"
            End If
            'Designation.Text = CStr(PicType(i))
            PictureBox1.Image = CType(MyImage, Image)
        Else
            MessageBox.Show("This is the last PDF.")
        End If
    End Sub

Private Sub LastPDF_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles LastPDF.Click
```

```
'Last PDF Button Code

        If i > 0 Then
            i -= 1
            MyImage = New Bitmap(Pictures(i))
            FileName.Text = Pictures(i)
            If PicType(i) = -1 Then
                Designation.Text = True
            ElseIf PicType(i) = 0 Then
                Designation.Text = False
            ElseIf PicType(i) = 1 Then
                Designation.Text = "Flagged"
            Else
                Designation.Text = "Undesignated"
            End If
            'Designation.Text = CStr(PicType(i))
            PictureBox1.Image = CType(MyImage, Image)
        Else
            MessageBox.Show("This is the first PDF.")
        End If
    End Sub

Private Sub Written_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Written.Click

'Hand-written Button Code

        Results = Results + vbNewLine + Pictures(i) + " = Written"
        i += 1

        If i < Pictures.Length Then
            MyImage = New Bitmap(Pictures(i))
            PicType(i - 1) = 0
            FileName.Text = Pictures(i)
            If PicType(i) = -1 Then
                Designation.Text = True
            ElseIf PicType(i) = 0 Then
                Designation.Text = False
            ElseIf PicType(i) = 1 Then
                Designation.Text = "Flagged"
            Else
                Designation.Text = "Undesignated"
            End If
            'Designation.Text = CStr(PicType(i))
            PictureBox1.Image = CType(MyImage, Image)
```

```
      Else
         PicType(i - 1) = 0
         MessageBox.Show("This is the last PDF.")
         i -= 1
         FileName.Text = Pictures(i)
         If PicType(i) = -1 Then
            Designation.Text = True
         ElseIf PicType(i) = 0 Then
            Designation.Text = False
         ElseIf PicType(i) = 1 Then
            Designation.Text = "Flagged"
         Else
            Designation.Text = "Undesignated"
         End If
      End If
   End Sub

   Private Sub Flag_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Flag.Click
'Flag file button

      Results = Results + vbNewLine + Pictures(i) + " = Flagged"
      i += 1
      If i < Pictures.Length Then
         PicType(i - 1) = 1
         MyImage = New Bitmap(Pictures(i))
         FileName.Text = Pictures(i)
         If PicType(i) = -1 Then
            Designation.Text = True
         ElseIf PicType(i) = 0 Then
            Designation.Text = False
         ElseIf PicType(i) = 1 Then
            Designation.Text = "Flagged"
         Else
            Designation.Text = "Undesignated"
         End If
         PictureBox1.Image = CType(MyImage, Image)
      Else
         PicType(i - 1) = 1
         MessageBox.Show("This is the last PDF.")
         i -= 1
         FileName.Text = Pictures(i)
         If PicType(i) = -1 Then
            Designation.Text = True
         ElseIf PicType(i) = 0 Then
            Designation.Text = False
```

```
        ElseIf PicType(i) = 1 Then
            Designation.Text = "Flagged"
        Else
            Designation.Text = "Undesignated"
        End If
    End If
 End Sub

Private Sub Typed_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Typed.Click

' Type Button Code

    Results = Results + vbNewLine + Pictures(i) + " = Typed"
    i += 1
    If i < Pictures.Length Then
        PicType(i - 1) = -1
        MyImage = New Bitmap(Pictures(i))
        FileName.Text = Pictures(i)
        If PicType(i) = -1 Then
            Designation.Text = True
        ElseIf PicType(i) = 0 Then
            Designation.Text = False
        ElseIf PicType(i) = 1 Then
            Designation.Text = "Flagged"
        Else
            Designation.Text = "Undesignated"
        End If
        ' Designation.Text = CStr(PicType(i))
        PictureBox1.Image = CType(MyImage, Image)
    Else
        PicType(i - 1) = -1
        MessageBox.Show("This is the last PDF.")
        i -= 1
        FileName.Text = Pictures(i)
        If PicType(i) = -1 Then
            Designation.Text = True
        ElseIf PicType(i) = 0 Then
            Designation.Text = False
        ElseIf PicType(i) = 1 Then
            Designation.Text = "Flagged"
        Else
            Designation.Text = "Undesignated"
        End If
        'Designation.Text = CStr(PicType(i))
    End If
```

```
    End Sub
End Class
```

APPENDIX B

KEYWORD SEARCH CODE

```
Option Compare Text
Imports System.IO


Public Class Form1

Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
    Dim WA(13) As String
    WA(0) = "malfunction"
    WA(1) = "flash"
    WA(2) = "mode"
    WA(3) = "yellow"
    WA(4) = "red"
    WA(5) = "flashing"
    WA(6) = "amber"
    WA(7) = "light"
    WA(8) = "signal"
    WA(9) = "red/red"
    WA(10) = "yellow/red"
    WA(11) = "lightning"
    WA(12) = "ball"
    WA(13) = "traffic"

    Dim WC(13) As Double
    WC(0) = 0
    WC(1) = 0
    WC(2) = 0
    WC(3) = 0
    WC(4) = 0
    WC(5) = 0
    WC(6) = 0
    WC(7) = 0
    WC(8) = 0
    WC(9) = 0
    WC(10) = 0
    WC(11) = 0
    WC(12) = 0
    WC(13) = 0
    Dim TC(13) As Double
    TC(0) = 0
    TC(1) = 0
    TC(2) = 0
    TC(3) = 0
    TC(4) = 0
    TC(5) = 0
```

```
        TC(6) = 0
        TC(7) = 0
        TC(8) = 0
        TC(9) = 0
        TC(10) = 0
        TC(11) = 0
        TC(12) = 0
        TC(13) = 0
        Dim Names As String

        Dim F As Double = 0 'String length value
        Dim J As Double = 0  'Represents keyword in search loop
        Dim i As Double = 0  'Represents position in keyword replaced with '?'

        Dim TestCheck As Boolean

        Dim Sub1 As String = ""
        Dim Sub2 As String = ""
        Dim SW As String = ""
        Dim Result As String = ""
        Dim Result2 As String = ""
        Dim Check As Boolean = False
        Dim Record As String = ""


        Dim FolderOfText As String = "***********************************"

'This command creates an array filled with files in the target directory.
        Dim di As New DirectoryInfo(FolderOfText)
        Dim fi As FileInfo() = di.GetFiles()
        Dim fiTemp As FileInfo

'Loop to go through each file in the target directory.
        For Each fiTemp In fi
            Names = fiTemp.Name
            Dim FILE_NAME As String = fiTemp.FullName
            Dim objReader As New System.IO.StreamReader(FILE_NAME)
            Dim Text As String = objReader.ReadToEnd
            objReader.Close()

' Loop to go through each keyword in the list
            For J = LBound(WA) To UBound(WA)
                F = WA(J).Length

'This loop replaces each letter with ? so that searches can pick up small spelling errors.
                For i = 0 To F - 1
```

```
            Sub1 = WA(J).Substring(i, 1)
            Sub2 = WA(J)
            SW = "*" + Replace(Sub2, Sub1, "?") + "*"
            TestCheck = Text Like SW

            If TestCheck Then
                WC(J) = 1
                i = F
                Check = True
                TC(J) += 1
            End If
            TestCheck = False

        Next

        Sub1 = ""
        Sub2 = ""
        SW = ""

    Next
```

‘The following two if statements record the files that fit their respective criteria. The if statements should be changed depending on what criteria are being searched for.

```
    If (WC(1) = 1 And WC(13) = 1 And WC(7) = 1) Then
        Result = fiTemp.Name + vbNewLine + Result
    End If

    If (WC(1) = 1 And WC(13) = 1 And WC(8) = 1) Then
        Result2 = fiTemp.Name + vbNewLine + Result2
    End If
```

‘The Record variable was used to record, for every file, if any of the keyword strings were found.

```
    Record = fiTemp.Name + " " + CStr(WC(0)) + CStr(WC(1)) + CStr(WC(2)) +
CStr(WC(3)) + CStr(WC(4)) + CStr(WC(5)) + CStr(WC(6)) + CStr(WC(7)) +
CStr(WC(8)) + CStr(WC(9)) + CStr(WC(10)) + CStr(WC(11)) + CStr(WC(12)) +
CStr(WC(13)) + vbNewLine + Record


    WC(0) = 0
    WC(1) = 0
    WC(2) = 0
    WC(3) = 0
    WC(4) = 0
    WC(5) = 0
    WC(6) = 0
```

```
            WC(7) = 0
            WC(8) = 0
            WC(9) = 0
            WC(10) = 0
            WC(11) = 0
            WC(12) = 0
            WC(13) = 0
            F = 0
        Next fiTemp


        Dim objWriter As New StreamWriter(FolderOfText +
"Results\WildcardSearch\Results5a7a13.txt")
        objWriter.Write(Result)
        objWriter.Close()

        Dim objWriter2 As New StreamWriter(FolderOfText +
"Results\WildcardSearch\Results5a8a13.txt")
        objWriter2.Write(Result2)
        objWriter2.Close()

        Dim objWriter1 As New StreamWriter(FolderOfText +
"Results\WildcardSearch\Record.txt")
        objWriter1.Write(Record)
        objWriter1.Close()

        MessageBox.Show(CStr(TC(0)) + vbNewLine + CStr(TC(1)) + vbNewLine +
CStr(TC(2)) + vbNewLine + CStr(TC(3)) + vbNewLine + CStr(TC(4)) + vbNewLine +
CStr(TC(5)) + vbNewLine + CStr(TC(6)) + vbNewLine + CStr(TC(7)) + vbNewLine +
CStr(TC(8)) + vbNewLine + CStr(TC(9)) + vbNewLine + CStr(TC(10)) + vbNewLine +
CStr(TC(11)) + vbNewLine + CStr(TC(12)) + vbNewLine + CStr(TC(13)))

    End Sub
End Class
```

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