Fall 2014

The use of statistics and its analysis in resolving transportation related problems

Venkat Sravan Kothapalli

THE USE OF STATISTICS AND ITS ANALYSIS IN RESOLVING TRANSPORTATION RELATED PROBLEMS

by

VENKAT SRAVAN KOTHAPALLI

A THESIS

Presented to the Faculty of the Graduate School of the

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

2014

Approved by

Suzanna Long, Adviser

Ruwen Qin

Brian Smith

ABSTRACT

Statistical methods are traditionally used to summarize or describe a collection of data. This can be termed as descriptive statistics. This research focuses on application of certain statistical approaches, tools to solve transportation related problems. This research focuses on usage of statistical analysis in determine some of the significant factors and assumptions which should be taken into consideration while developing safety and maintenance related measures by transportation agencies. This research mainly focuses on; testing null hypothesis and frequency analysis. The research therefore is presented in two different case studies: 1) Statistical analysis of the work zone crash historical raw data using bar graphs, histograms to determine the significant contributing factors which might have led to the work zone related crashes. 2) General linear model (univariate) model regression analysis to study the effects of predictor variables factors on the luminous intensity of LED traffic luminaries.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my advisor, Dr. Suzanna Long, for giving me the opportunity to work on LED and related projects. I am grateful to her for the advice and guidance she gave me throughout my Master's program. I also thank Dr. Long for her moral support during my tough times by understanding and encouraging me to focus on my goals. Further, I thank Modot for most of the funding during my Master's program. I would like to thank my committee members Dr. Brian smith and Dr. Ruwen Qin for their suggestions and advice with my research.

I would like to thank my colleagues Sean Schmidt for his technical suggestions. I sincerely appreciate the timely help of Snehal for her support with the data collection activity and Paul Robin for his initial assistance on the work zone project.

A special thanks to all my friends in Rolla for understanding and standing by me during my tough times. Finally, I would like to dedicate this work to my parents (Durga Prasad and Uma) and my sister (Deepthi) for their emotional support and unconditional love and sacrifices.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Page

1. INTRODUCTION

In today's world statistics have become a great tool to analyze and predict the future consequences on the present data by studying the factors in the form of dependent variables which can have significant consequences on the independent variable. Statistical methods and analyses are often used to communicate research findings and to support hypotheses and give credibility to research methodology and conclusions. It is important for researchers and also consumers of research to understand statistics so that they can be informed, evaluate the credibility and usefulness of information, and make appropriate decisions. [1]

Since this study talks about the usefulness of statistics in resolving some of the current problems facing by the transportation agencies, this thesis focuses on two different cases and discuss how statistics, frequency analysis can be used in solving those issues.

Case 1: The purpose of research in field of work zone safety is to reduce the number and severity of crashes .Currently many transportation agencies are studying the statistical significance to determine the most contributing factors towards the work zone related crashes. Even though precautionary measures are taken, they are still fatalities and disabling injuries being recorded near the work zones due to crashes. This has become a challenging study for many agencies to conduct research and analyzes the most leading attributes/factors which are leading to the crashes. This part of thesis focuses on the descriptive statistical analysis of work zone safety-related data in identifying safety improvement strategies and developing work zone crash reduction programs and analysis techniques.

Case 2: Most of the transportation agencies across the country are transitioning in using LED technology rather than incandescent bulbs on many factors such as cost, maintenance, energy cost, safety issues, and life expectancy. This part of thesis would study the statistical significance of the certain predictors on the dependent variable which is “luminous intensity” considered for this study. The data used for this study is the same dataset used to develop a methodology for the replacement schedule of LED indicators using statistics by the research team of Missouri University of Science and Technology. In support to the research a large pool of data has been collected at identified intersections across the state of Missouri and this data supports in statistical analysis, developing a direct relationship on when a LED luminaire needs to be replaced. This study focuses on whether the factors considered have any significance on the degradation of LED luminaire. This case study is mainly to test the null hypothesis and determine whether to reject (or) not reject the assumed hypothesis.

2. CASE I: WORK ZONE DATA

2.1 LITERATURE REVIEW

Many of the local roads, highways and interstates must be maintained and repaired on regular basis to provide quality surfaces for daily purpose commutes. Unfortunately research shows that those who work near those zones have an increased risk of injury and death. On an average 745 fatalities and 40,000 deaths have been recorded across the various work zones in United States. Many Department of Transportation (DOT) offices, Federal Highway Administrations, and American Association of State Highway and Transportation officials are working rigorously to devise work zone safety practices that could reduce the crash numbers in these areas. The major challenges many DOTs face involve identifying factors that could lead to these injuries and fatalities. A number of research studies investigated the unsafe conditions related to work zones [2, 4, 5]. Others analyzed the impact work zone design parameters have on traffic safety and mobility [2, 3, 4, 5, 6, 9]. The National Cooperative Highway Research Program (NCHRP) in their Report 581 developed guidelines for designing construction work zone geometric features which includes horizontal, vertical alignment cross sectional features, and temporary concrete barrier placement [9]. They also recommended guidelines to help transportation agencies both develop and implement plans for night work zones [3].

Temporary traffic control devices are typically used as a safety measure for workers near these work zones. These devices are defined as all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a roadway. The Manual on Uniform Traffic Control Devices (MUTCD) [8] provides guidance on the use and implementation of diverse types of devices. A partial list of these devices includes # temporary control signs,# arrow panels,# channelizing devices ,# temporary raised pavement markers,# high-level working devices,# portable changeable message signs, # temporary traffic barriers, # delineators, # lighting devices, # crash cushions, # vehicle-arresting systems, # rumble strips, and # screens [8].

A number of studies have examined the effects of various highway designs on work zone safety. The high design elements that were analyzed included the following cross section designs, horizontal alignment, vertical alignment, roadside features, and pavement conditions. Previous studies indicated that improvements with in these elements could significantly reduce the amount of crashes in these areas. Many research studies used accident prediction models to quantify the effect of highway design elements on total crash rates for various types of roadways [7]. Statistical models e.g., a generalized linear model and a tree-based regression were such methods used in the accident prediction models.

In 2007, Jonsson studied roadway crashes by modeling different types of crashes and intersections on a rural four lane highway in California. A various models for predicting the number of crashes per crash type were developed using generalized linear modeling and the GENMOD procedure using statistical software, SAS, with the assumption that the number of crashes could have followed a negative binomial distribution. Three different models were developed for each type of crash and intersection: (1) a basic model in which the annual average daily traffic (AADT) was the only single variable considered, (2) a multi -variable model that included all significant variables except the AADT, and (3) a full model that included all variables including the AADT. Jonsson study found that (1) the terrain variable was found to be a good predictor variable for single-vehicle crashes, (2) single-vehicle crashes had a practically linear relationship with the total number of entering vehicles in the intersection, and (3) opposite- and same-direction crashes were primarily related to major traffic flows.[10]

A team of Texas Transportation Institute (TTI) researcher(s) collected data for 15 months in response to 77 fatal work zone crashes in 21 locations of the 25 TxDOT districts in which a total of 88 people lost their lives. The team was in contact with the safety officers who belonged to each of the 25 TxDOT districts. These officers would inform the TTI team of any fatal work zone crash incidents. For data collection a new methodology was developed which relied on site reviews and narrative descriptions of what was observed by the team during the investigation process. The primary goals of each site review and narrative report were to:

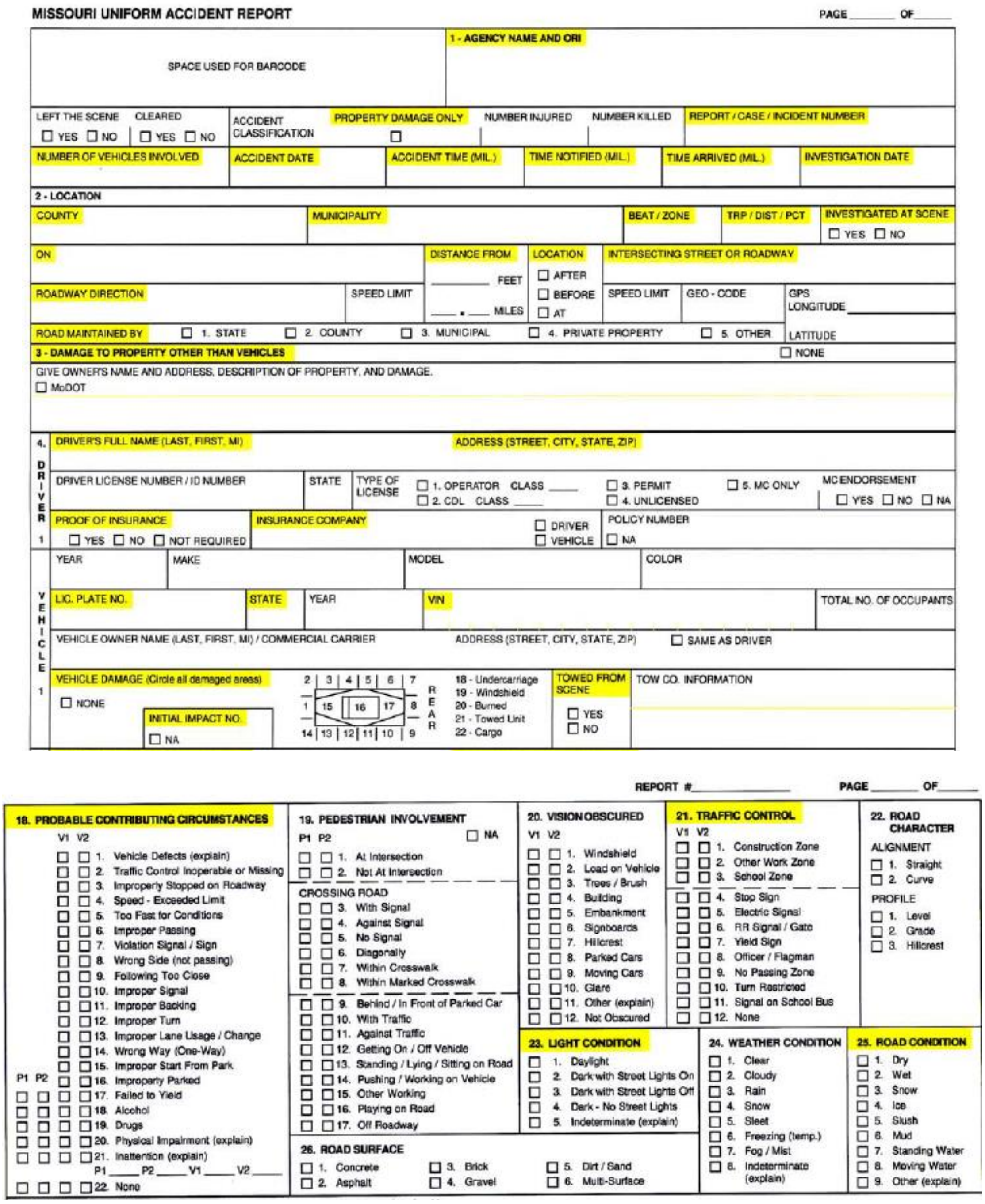
- detailed facts on how, when, and/or why the crash occurred,
- details on the work zones physical presence, condition, traffic control devices, and any other appurtenances,
- details on any deficiencies observed in either the work zone layout or traffic control plan,
- a description of possible countermeasures that could reduce the severity of future crashes. [11]

The 77 fatal crash sites were analyzed for trends based on roadway type, work zone crash location, work zone activity, weather conditions, lighting conditions, alcohol involvement, and large truck involvement. [11] The collected data was then compared to the historical trends extracted from the DPS crash data base on fatal work zones. The TTI researchers concluded that only 8 percent of crashes were directly related to work zone areas, 4 percent involved highway workers, 39 were indirectly related to work zone areas, and 45 percent appeared to be completely unrelated to work zone areas [11]. They recommended that certain work zone counter safety measures be added such as flagger audible warning devices, highly mobile barrier systems for short-term work zone activity areas, and worker-activated panic button warning systems worn by all personnel in the work area.

2.2 ANALYSIS OF RAW DATA

A descriptive statistical analysis on historical data was carried out to determine factors most responsible in causing crashes near the work zone areas. This data is represented statistically in a series of bar graphs. The raw data collected consist of significant causes that led to the crashes. Each category has several sub factors depending on the nature of the contributing conditions towards crashes. Using excel functions the graphs were created to determine the significant contributing categories based on the nature of factor leading to the majority of crashes.

The historical data contains all the necessary information in regard to the crashes near the work zone areas. The Statewide Traffic Accident Records System (STARS) is the manual which contains all the information regarding the accidents which have taken place across the state of Missouri. The STARS manual gives guidance and procedures for completing the Missouri Uniform Accident Report (MUAR). The four-page MUAR contains information such as the location of the accident, driver information, vehicle information, collision diagram, road characteristics and even traffic condition. The Missouri State Highway Patrol is responsible agency in providing Statewide Traffic Accident Records System (STARS) training for all police agencies and partners with the Missouri Department of Transportation (MoDOT) to store and archive the information related to crashes. This information is composed of standardized fields and stored in an electronic database; it can be queried using common database language such as ANSI's (American National Standards Institute) SQL (Structured Query Language). (TMS) database. [12]



MISSOURI UNIFORM ACCIDENT REPORT PAGE ____ OF ____

SPACE USED FOR BARCODE

1 - AGENCY NAME AND ORI

LEFT THE SCENE ☐ YES ☐ NO | CLEARED ☐ YES ☐ NO | ACCIDENT CLASSIFICATION | PROPERTY DAMAGE ONLY ☐ | NUMBER INJURED | NUMBER KILLED | REPORT / CASE / INCIDENT NUMBER

NUMBER OF VEHICLES INVOLVED | ACCIDENT DATE | ACCIDENT TIME (MIL.) | TIME NOTIFIED (MIL.) | TIME ARRIVED (MIL.) | INVESTIGATION DATE

2 - LOCATION

COUNTY | MUNICIPALITY | BEAT / ZONE | TRP / DIST / PCT | INVESTIGATED AT SCENE ☐ YES ☐ NO

ON | DISTANCE FROM ____ FEET ____ . ____ MILES | LOCATION ☐ AFTER ☐ BEFORE ☐ AT | INTERSECTING STREET OR ROADWAY

ROADWAY DIRECTION | SPEED LIMIT | SPEED LIMIT | GEO - CODE | GPS LONGITUDE ____

ROAD MAINTAINED BY ☐ 1. STATE ☐ 2. COUNTY ☐ 3. MUNICIPAL ☐ 4. PRIVATE PROPERTY ☐ 5. OTHER | LATITUDE

3 - DAMAGE TO PROPERTY OTHER THAN VEHICLES ☐ NONE

GIVE OWNER'S NAME AND ADDRESS, DESCRIPTION OF PROPERTY, AND DAMAGE.
☐ MoDOT

4. DRIVER 1

DRIVER'S FULL NAME (LAST, FIRST, MI) | ADDRESS (STREET, CITY, STATE, ZIP)

DRIVER LICENSE NUMBER / ID NUMBER | STATE | TYPE OF LICENSE ☐ 1. OPERATOR CLASS ____ ☐ 2. CDL CLASS ____ ☐ 3. PERMIT ☐ 4. UNLICENSED ☐ 5. MC ONLY | MC ENDORSEMENT ☐ YES ☐ NO ☐ NA

PROOF OF INSURANCE ☐ YES ☐ NO ☐ NOT REQUIRED | INSURANCE COMPANY | ☐ DRIVER ☐ VEHICLE ☐ NA | POLICY NUMBER

VEHICLE 1

YEAR | MAKE | MODEL | COLOR

LIC. PLATE NO. | STATE | YEAR | VIN | TOTAL NO. OF OCCUPANTS

VEHICLE OWNER NAME (LAST, FIRST, MI) / COMMERCIAL CARRIER | ADDRESS (STREET, CITY, STATE, ZIP) | ☐ SAME AS DRIVER

VEHICLE DAMAGE (Circle all damaged areas) ☐ NONE | INITIAL IMPACT NO. ☐ NA | 1–17 REAR | 18 - Undercarriage, 19 - Windshield, 20 - Burned, 21 - Towed Unit, 22 - Cargo | TOWED FROM SCENE ☐ YES ☐ NO | TOW CO. INFORMATION

REPORT # ____ PAGE ____ OF ____

18. PROBABLE CONTRIBUTING CIRCUMSTANCES (V1 V2; P1 P2)
1. Vehicle Defects (explain)
2. Traffic Control Inoperable or Missing
3. Improperly Stopped on Roadway
4. Speed - Exceeded Limit
5. Too Fast for Conditions
6. Improper Passing
7. Violation Signal / Sign
8. Wrong Side (not passing)
9. Following Too Close
10. Improper Signal
11. Improper Backing
12. Improper Turn
13. Improper Lane Usage / Change
14. Wrong Way (One-Way)
15. Improper Start From Park
16. Improperly Parked
17. Failed to Yield
18. Alcohol
19. Drugs
20. Physical Impairment (explain)
21. Inattention (explain) P1 ____ P2 ____ V1 ____ V2 ____
22. None

19. PEDESTRIAN INVOLVEMENT ☐ NA (P1 P2)
1. At Intersection
2. Not At Intersection
CROSSING ROAD
3. With Signal
4. Against Signal
5. No Signal
6. Diagonally
7. Within Crosswalk
8. Within Marked Crosswalk
9. Behind / In Front of Parked Car
10. With Traffic
11. Against Traffic
12. Getting On / Off Vehicle
13. Standing / Lying / Sitting on Road
14. Pushing / Working on Vehicle
15. Other Working
16. Playing on Road
17. Off Roadway

20. VISION OBSCURED (V1 V2)
1. Windshield
2. Load on Vehicle
3. Trees / Brush
4. Building
5. Embankment
6. Signboards
7. Hillcrest
8. Parked Cars
9. Moving Cars
10. Glare
11. Other (explain)
12. Not Obscured

21. TRAFFIC CONTROL (V1 V2)
1. Construction Zone
2. Other Work Zone
3. School Zone
4. Stop Sign
5. Electric Signal
6. RR Signal / Gate
7. Yield Sign
8. Officer / Flagman
9. No Passing Zone
10. Turn Restricted
11. Signal on School Bus
12. None

22. ROAD CHARACTER
ALIGNMENT
1. Straight
2. Curve
PROFILE
1. Level
2. Grade
3. Hillcrest

23. LIGHT CONDITION
1. Daylight
2. Dark with Street Lights On
3. Dark with Street Lights Off
4. Dark - No Street Lights
5. Indeterminate (explain)

24. WEATHER CONDITION
1. Clear
2. Cloudy
3. Rain
4. Snow
5. Sleet
6. Freezing (temp.)
7. Fog / Mist
8. Indeterminate (explain)

25. ROAD CONDITION
1. Dry
2. Wet
3. Snow
4. Ice
5. Slush
6. Mud
7. Standing Water
8. Moving Water
9. Other (explain)

26. ROAD SURFACE
1. Concrete
2. Asphalt
3. Brick
4. Gravel
5. Dirt / Sand
6. Multi-Surface

Figure 2.1 Example of the MUAR

The figure 2.1 gives the sample over view of how the report would look like. It could be observed that the various conditions leading to crashes were further divided into several individual factors. The factors considered for the analysis was based on the study carried out in Establish Existing Safety Baseline Based on Historical Data.

Depending upon nature of crash: Run-off-the-road crashes were responsible for approximately 35-36% of all disabling injuries and fatalities. Horizontal curve nature type of crashes contributed to 25% of the fatalities and serious injuries. Intersection type is observed to cause a number of serious injuries rather than fatal crashes. Both tree collisions and head-on type crashes comprised a much smaller of the data 15% fatalities, and approximately 11% were serious injuries (This data is presented in- Figure 2.2)

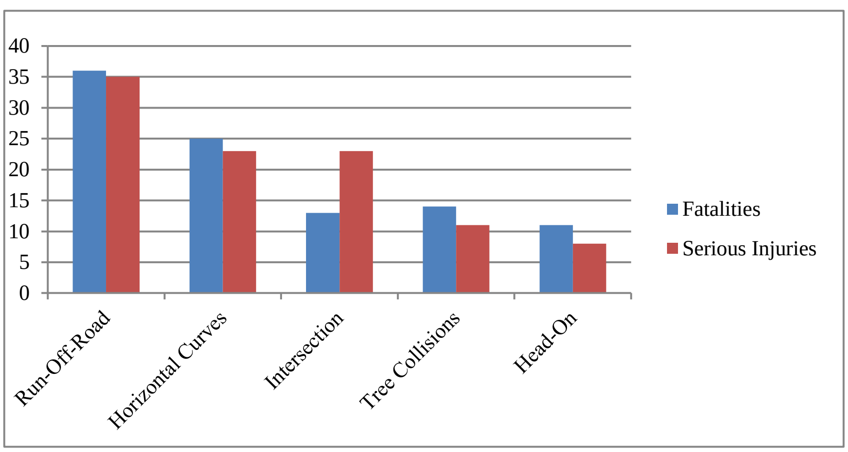


Figure 2.2 Major factors contributing to crashes as categorized by the nature of crash

Depending on driver/passenger characteristics: Based on the numbers the leading characteristics causing fatalities and serious injuries were observed as aggressive drivers and unrestrained occupants. Distracted drivers, young drivers and substance-impaired drivers were also significant and as per the Blueprint for Safer Roadways (a document that outlines strategies to reduce fatal and serious injuries that are often the result of traffic crashes) it was mentioned that approximately 70 percent of fatal crashes that occurred in a Missouri work zone involved a distracted, speeding or substance-impaired driver (Refer - Figure 2.3)

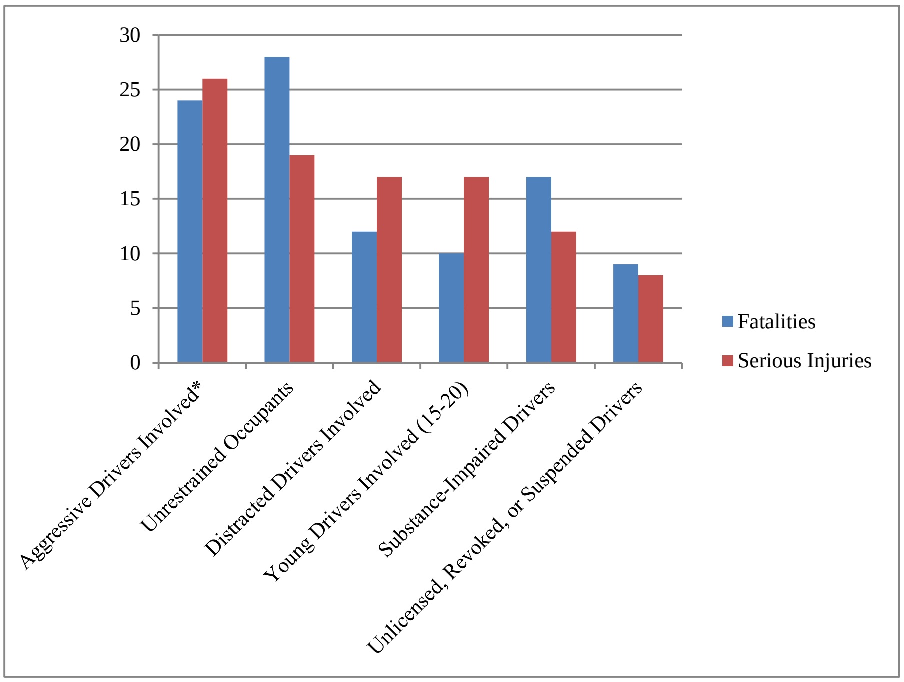


Figure 2.3 Major factors contributing to crashes as categorized by driver/passenger characteristics

*Aggressive drivers includes speeding (over the speed limit), driving too fast for conditions, and following too close categories

Based on district type: Districts with large metropolitan areas e.g., Kansas City, St. Louis and Springfield seem to be lower in percentage related to severe crashes. The percentage of PDO (property damages only) type crashes are observed to be in majority among all types of the crashes. The severe crashes type have been observed to be higher in percentages in the 1, 2 MoDOT classified districts. The minor type of crashes observed to be even among all the seven MoDOT districts. The fatal crashes observed to higher in the districts 1, 7 .These statistics differ significantly may be because of the characteristics such as length, duration, nighttime, and work intensity among the different districts (Refer- Figure 2.4,where 1 = NE, 2 = NW, 3 = KC (Kansas City), 4 = CD (central), 5 = SL (St. Louis), 6 = SW, 7 = SE)

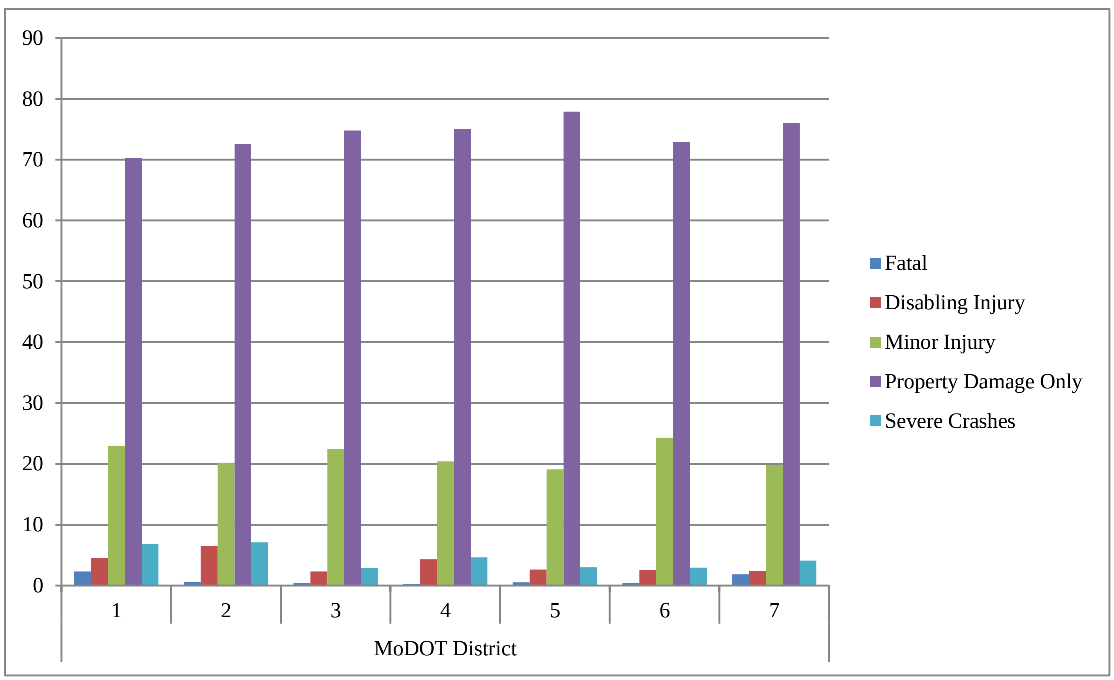


Figure 2.4 Major factors contributing to crashes as categorized by district type

Based on effect of lighting: The majority of severe crashes occurred during day light hours were 48.7% of fatal injuries and 70.7% were severity crashes. Under the fatal crash type daylight and dark with no street lights characteristics have contributed to majority crashes. The roadways with dark and no street lights have observed to contribute 41% of fatal injuries. The dark roadway with street lights turned off is observed to be less contributing factor to all types of crashes. A greater percentage of crashes likely occurred during the day because the volume of the traffic is higher during day time.

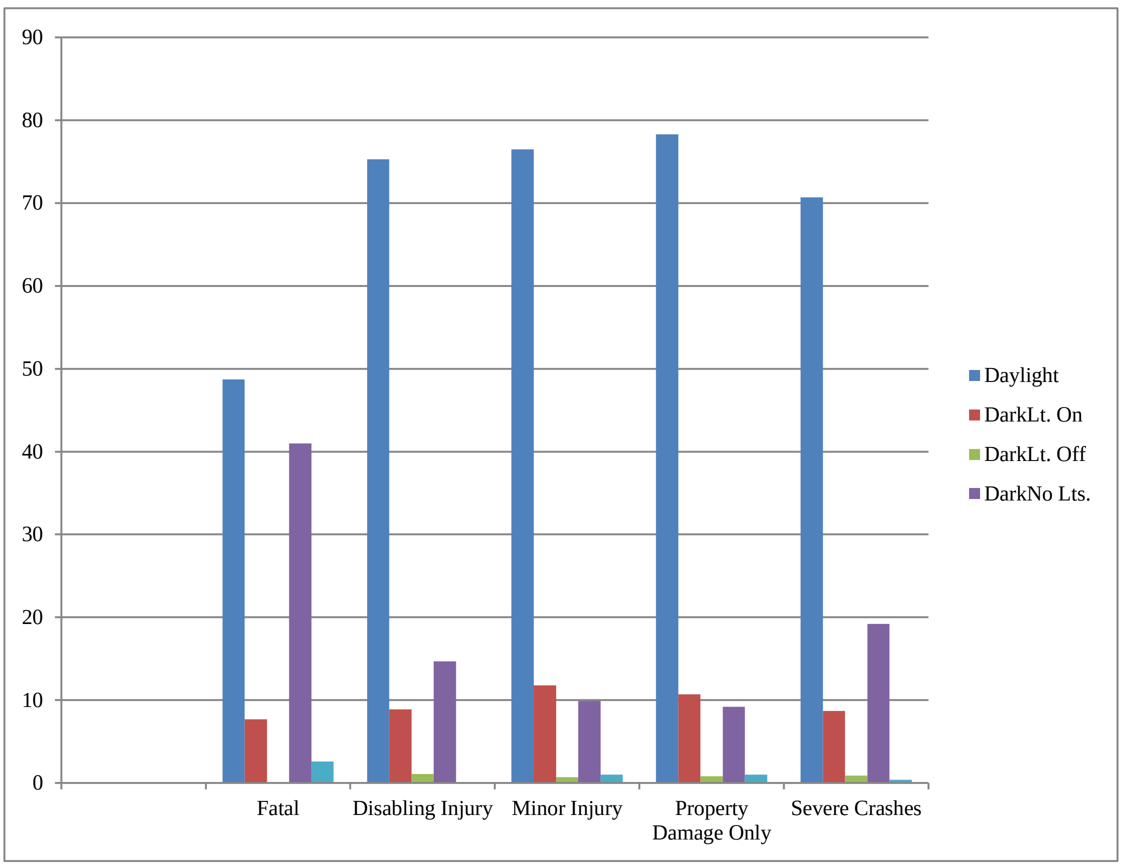


Figure 2.5 Major factors contributing to crashes as categorized by effect of lighting

Based on type of accident: Most of the severe crashes that occurred were the result of the category collision involved motor vehicle in transport. The percentage of fatal crashes is observed to be high among collision involved with fixed object, and collision involved with motor vehicle in transport factors. When compared to the nature of accident and type of collision involved it's observed that 14.3% of fatal injuries occurred due to Collision with fixed object category and 42.9% were Collision with motor vehicle in transport category .(Refer Figure 2.6)

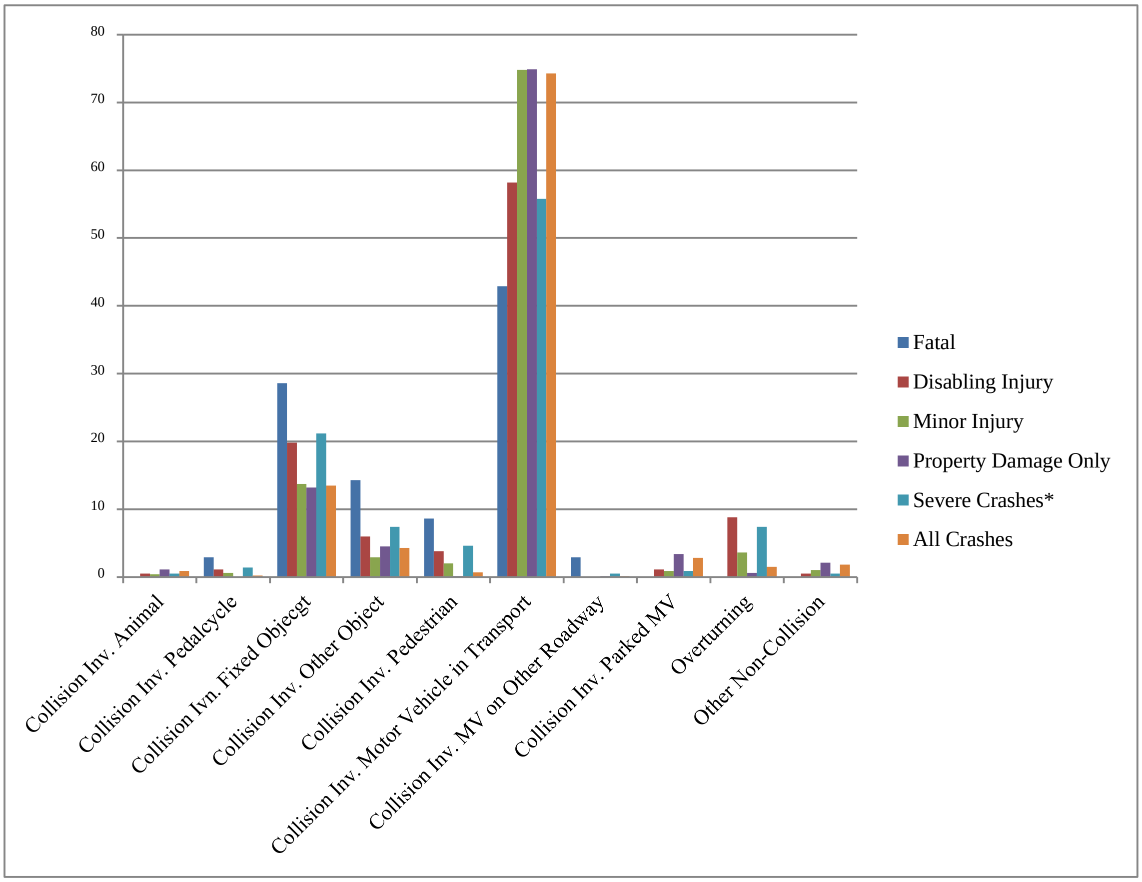


Figure 2.6 Major factors contributing to crashes as categorized by type of accident

*Severe crashes as defined by investigating officials

Based on type of collision: Rear end collisions were most commonly occurring two vehicle collisions recorded. This type of collision could have occurred when the following vehicle was unable to stop before contacting the vehicle. This failure to stop could have been related to a failure to brake in inclement weather. The two vehicle collision data was analyzed to include human factors e.g., inattention, impairment, weather, and congestion. Even though “head on” collision only accounts for 1.2% of all crashes, it disproportionately represents more severe (10.5%) and fatal (31.3%) crashes. (Refer to Figure 2.7)

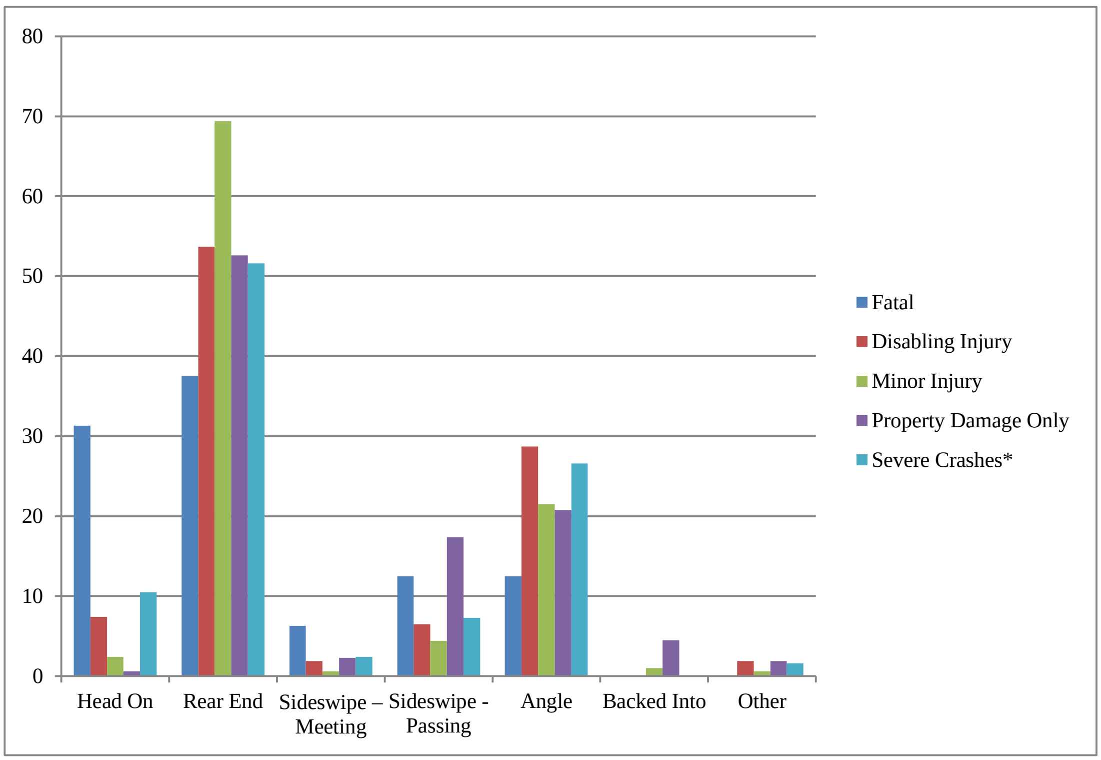


Figure 2.7 Major factors contributing to crashes as categorized by type of collision

*Severe crashes as defined by investigating officials

Based on circumstances leading to crash: Most of the severe crashes occurred were as a result of the factors such Aggressive driver (18.4%), Inattention (17.3%) Improper Lane Usage (7.7%), and Failed to Yield (5.4%) categories. These categories added to 48.8% of total severe crashes. If only fatal crashes type was analyzed then the order of these categories changes to Aggressive drivers (15.1%), Improper Lane Usage (13.8%), Inattention (12.5%), Alcohol (10%) and Failed to Yield (5.8%). (Refer- Figure 2.8)

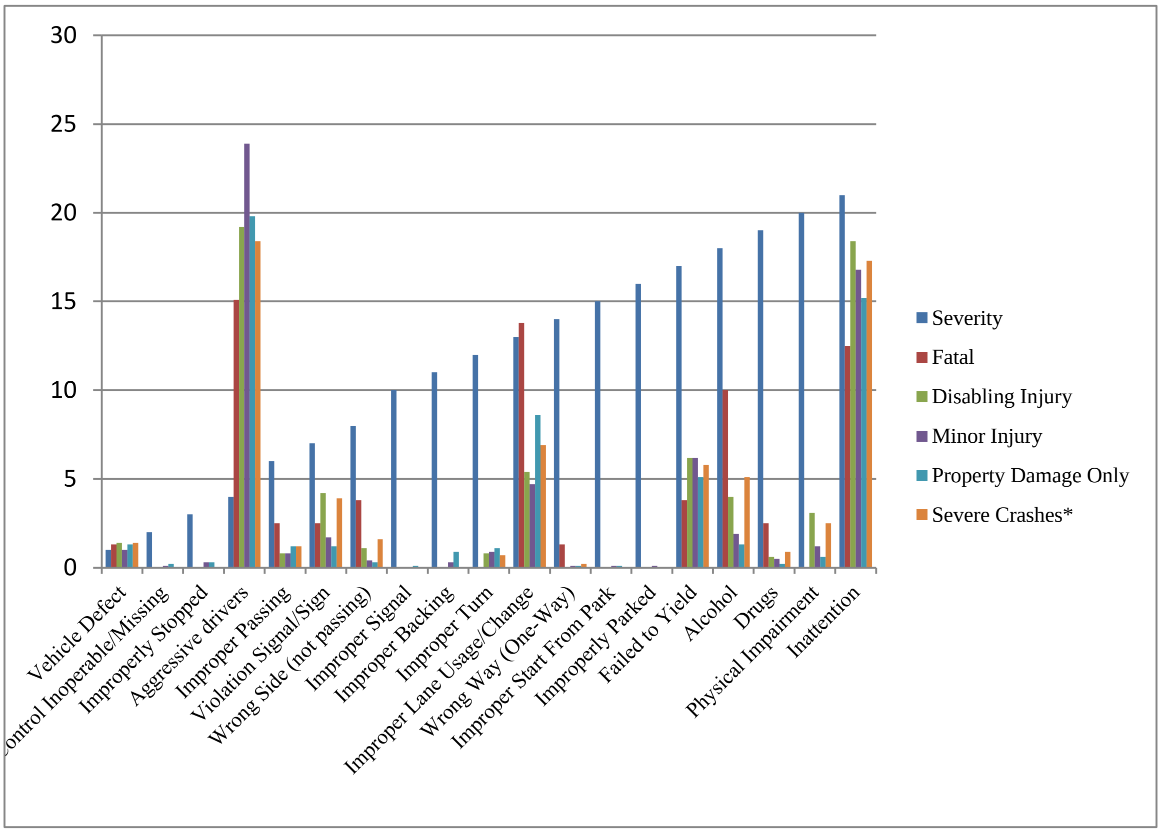


Figure 2.8 Major factors contributing to crashes based on circumstances leading to crash

*Severe crashes as defined by investigating officials

Based on vehicle sequence: Ordered by magnitude, the vehicle sequences with the highest percentages are: going straight (22.9%), collision involving motor vehicle in transport (20.7%), slowing/stopping (11.3%), stopping in traffic (7.8%), skidding/sliding (5.3%), changing lanes (4.7%), collision involving fixed objects (4.7%), avoiding (3.9%), ran off road – right (3.0%) and ran off road – left (2.5%). Most of the high percentage of work zone crashes is related to traffic conditions around the work zone. The vehicle sequence categories of "collision involving motor vehicle in transport", "slowing/stopping" "stopped in traffic", "skidding/sliding" and "avoiding" could all be related to traffic conditions. (Refer- Figures 2.9, 2.10)

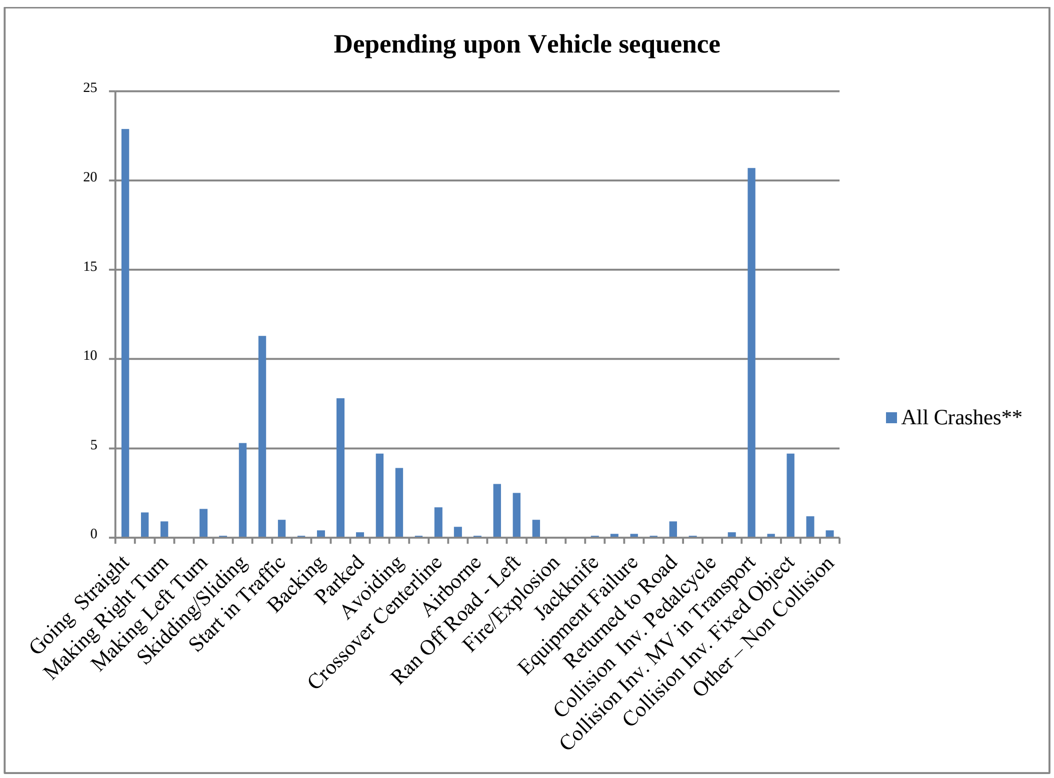


Figure 2.9 Major factors contributing to crashes as categorized by vehicle sequence

** The All Crashes row does not double count severe crashes

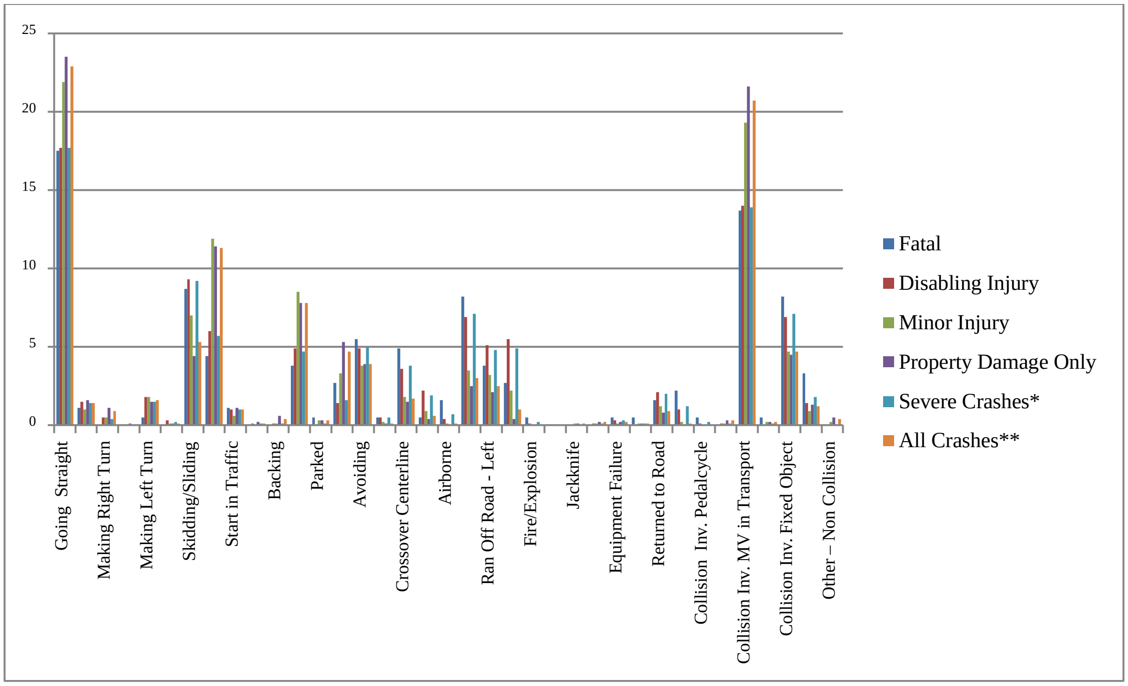


Figure 2.10 Major factors contributing to crashes as categorized by vehicle sequence

* Severe crashes as defined by investigating officials

** The All Crashes row does not double count severe crashes

Based on population of area: It can see that that a majority of the crashes for each severity occur in urbanized areas. 73.7% of minor injury crashes have been observed in urbanized areas, and 72.5 % contributed to PDO type crashes. Since the urbanized areas seem to be more populated could be a contributing factor to various types of crashes in urbanized areas. But there is a negligible difference in the percentages among the urbanized and rural areas on the fatal type severity crashes. The urban areas seem to less in numbers contributing to severity of crashes when compared to other two areas based on the population categories. (Refer - Figure 2.11)

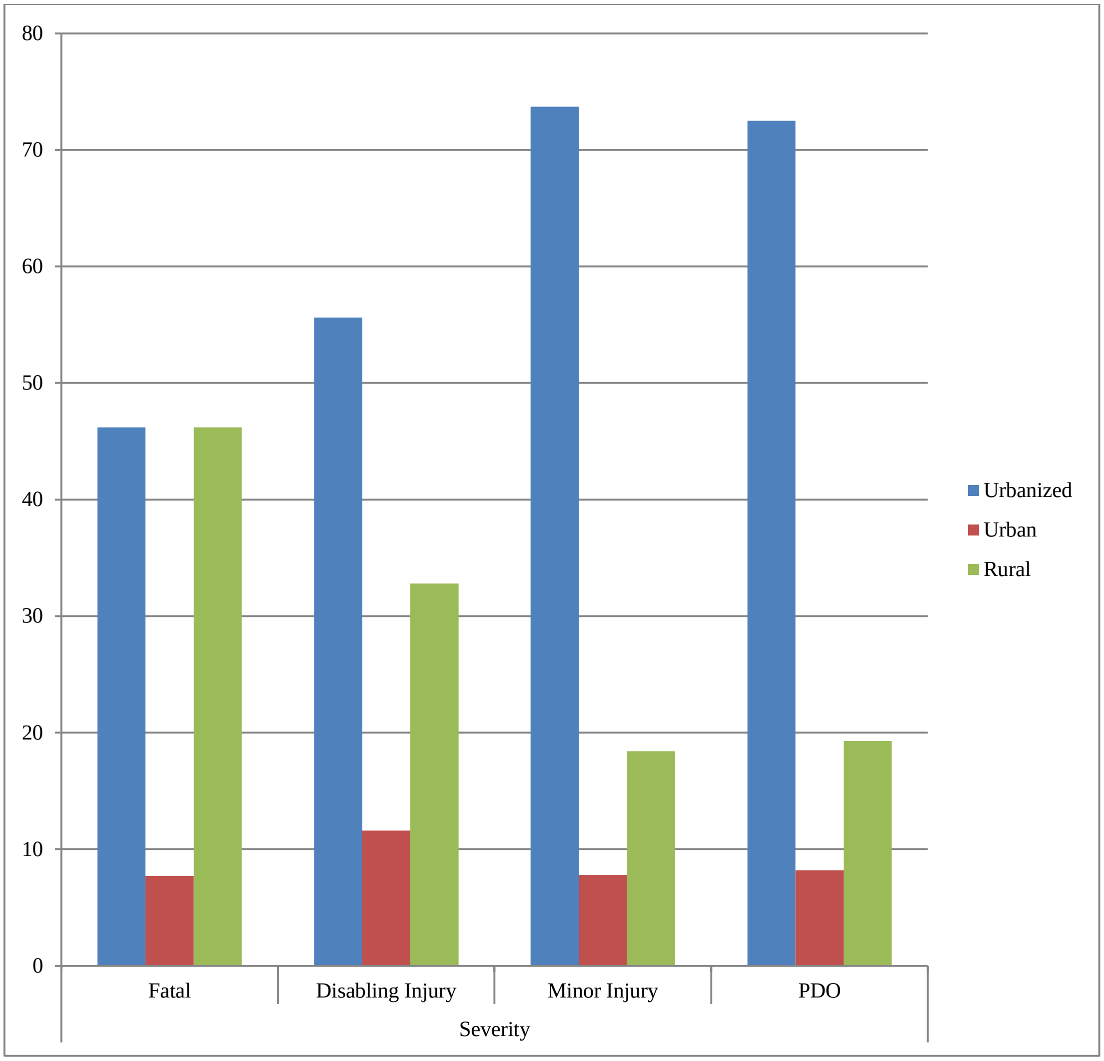


Figure 2.11 Major factors contributing to crashes as categorized by population of area

Based on speed limit: It can be observed that most of the accidents approximately 20% have occurred between speed limit of 55 mph to 60 mph. This could be because on the expressways and interstates at speed limit of 55 mph to 60 mph most people commute through them. Disabling injuries was observed to be the highest among the other crashes (injuries) at speed of 60mph (Refer- Figure 2.12)

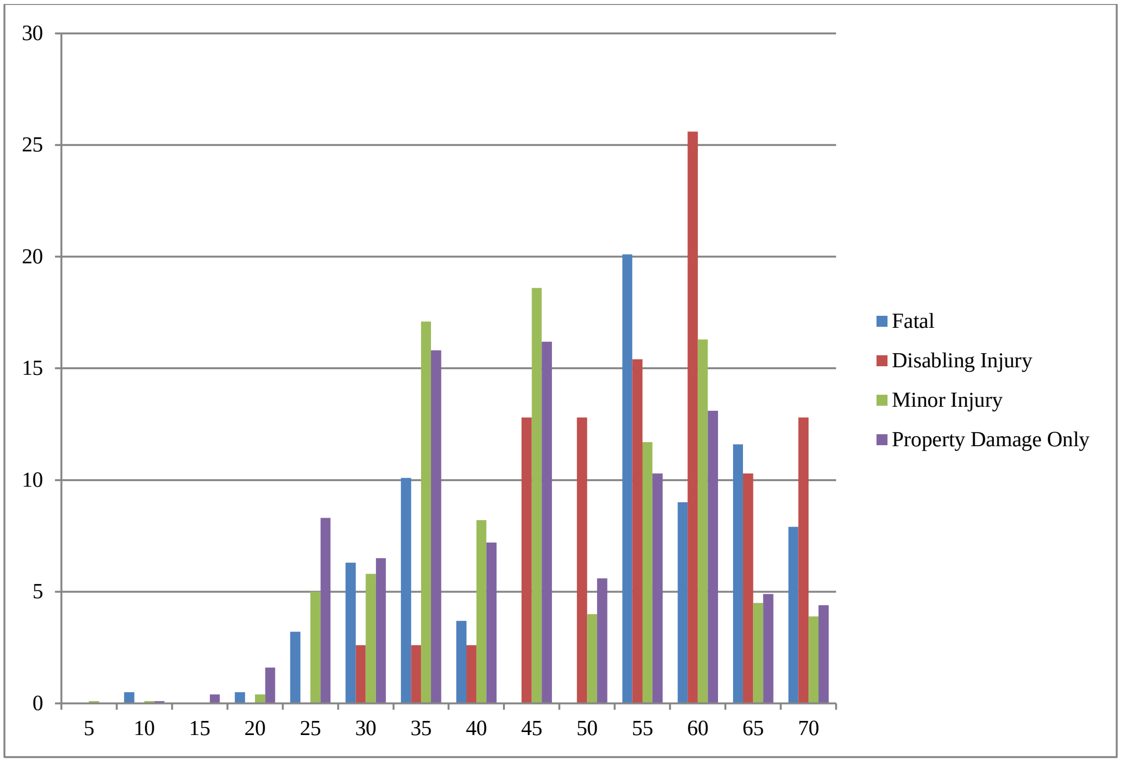


Figure 2.12 Demonstration major factors contributing to crashes based on speed limit

Based on functional classification: Interstates account for 48.6% of the total work zone crashes and 47.2% of the serious crashes (see figure 12). These percentages are directly related to the high traffic volume on these roadways. The percentage of severe crashes is large on expressways as well at 4.5%. Combing the speed limit together with the functional classification reveals several patterns. The highest speed facilities e.g., interstates do not contribute much of fatal crashes, but do contribute severe crashes which could be because of higher volume of traffic on interstates. Lower speed facilities e.g., minor collectors and local roads do not experience severe crashes. (Refer- Figure 2.13, where IS-interstate, Fwy- freeway, Expr-expressway, Pr.Art-arterial, Col-collector, Maj-major, Min-minor)

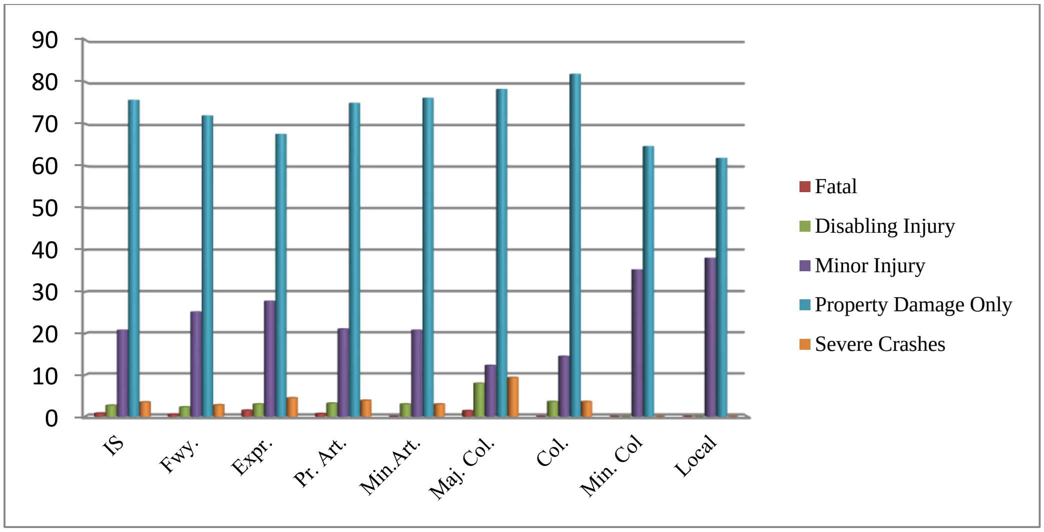


Figure 2.13 Major factors contributing to crashes as categorized by functional classification

Based on traffic condition: The traffic condition for each crash is divided into three categories. One is normal, two is accident ahead and three is congestion ahead. It can be observed that 35.7% of all work zone crashes are not under normal traffic conditions. (Refer- Figure 2.14, Traffic Condition 1- normal, Traffic Condition 2- accident ahead, Traffic Condition 3- congestion ahead, and Traffic Condition U- under normal)

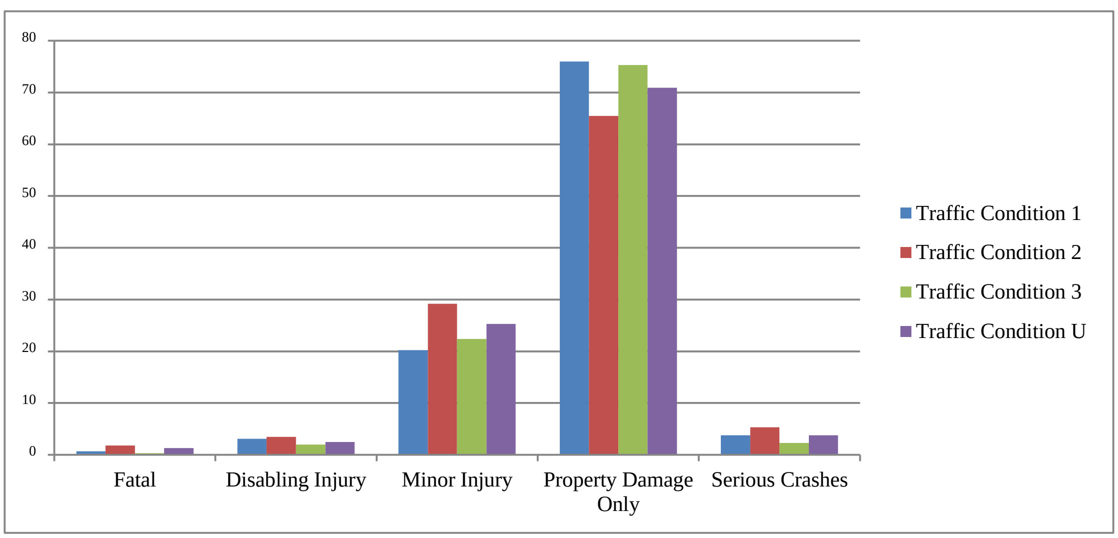


Figure 2.14 Major factors contributing to crashes as categorized by traffic condition

2.3 CONCLUSION

Certain factors within MoDOT raw crash data which could have led to higher incidence of accidents near work zone have been identified. Inattentive driving, failing to maintain an appropriate distance between two moving vehicles and changing of lanes suddenly are leading in percentages causing crashes near work zones. Most crashes seem to have occurred in either urbanized and rural zones because drivers seemed to be unaware of the driving conditions near construction or work zone areas .Following road signs correctly, complying with the driving rules within a restricted zones and so forth could prevent such crashes. Interstate, expressways and major collector roads are the routes in which the percentages of work zone related crashes were recorded more. This increase may be related to the high amount of traffic access on these routes.

It is surprising that most of the work zone related crashes have taken place in a broad day light that too in a very not obscured vision conditions, this might be because of the drivers who are involved in these crashes would have been inattentive and rash .Since the traffic commuting is more in the daylight the occurrence of accidents near the work zones seem logical.

Based on the historical data some other parameters have been analyzed which led to several crashes near work zone areas. The below Table 2.1 gives a summary of all the parameters and their factors based on several categories leading to crashes.

Table 2.1 Analysis of parameters leading to Majority of crashes in work zone areas

Field Description	Highest contributing Factors (%) among the list of field description items.
MODOT_District_No	St Louis (SL) 39.7% and Kansas City (KC) 32.48%
Accident Type	MV in Transport 91.7%
Type of collision	Rear End 64.2%
Road Alignment	Straight 88.7%
Road Profile	Level 61.37 %
Light _Condition	Day Light 81.79%
Weather_ Condition	Clear 72.67%
Road Conditions	Dry 88.68%
Road Surface	Asphalt 67.5%
Urban-Rural-Class	Urbanized 71.19%,and rural 15.91%
Traffic Conditions	Congestion ahead 35.7% (of total crashes)
Vision Obscured	Not obscured 93.12%
Characteristics of Driver	Aggressive drivers and unrestrained occupants 70%
Nature of Crash	Run off the roads (36%), following too close (13.8%), and improper lane changing (7.7%)

Table 2.1 Analysis of parameters leading to Majority of crashes in work zone areas "(cont.)"

Circumstances leading to crash	Inattention (15.6%), following too close (13.8%), and improper lane changing (7.7%)
Functional Parameter	Interstates and expressways to 48.6%
Speed limit	Approximately 20% have between a speed limit of 55 mph and 60 mph (typical speeds on expressways and interstates)
Vehicle Sequence	Going straight (22.9%) and colliding with a motor vehicle in transport (20.7%)

Most crashes took place near the metropolitan areas. Motor vehicles involved in transport were more responsible for crashes than any other type of accidents. Rear end collisions (64.2%) were related to the severity of the crash. Straight roads with a leveled contributed most to severe crashes near work zone areas. Day light 81.79% and clear weather 72.67% were most contributing factors based on lightning, weather conditions where most of crashes have taken place. As a precautionary measure the speed limits restriction near the work zone areas were always imposed, but instead of restricted limits 20% of the crashes have been recorded between speed limit of 55mph and 60 mph on expressways and interstates. Both Interstates and highways under a functional parameter contributed to 48.6 % of crashes. It is observed that 35.7% of crashes have been recorded in a congested traffic conditions. Based on the driver characteristics aggressive drivers and unrestrained occupants have led to 70% of the crashes. A dry road condition on an Asphalt road surface have led to 88.68% (dry), 67.5 %(asphalt) of the crashes respectively.

Further in research a complex models such as multi linear, logistic models can be applied to run the regression analysis of the raw data using statistical software's to identify the key dependent variables which might are directly affecting our variable of interest i.e. severity of the crashes near the work zone areas. Future research "can" or "include" the process of identifying the key variables and then encoding the various independent variables into a binary format thus creating a modified data set. Then regression models like multiple linear regressions can be ran on the this binary encoded raw data for more accurate predictions.

3. CASE II: LED TRAFFIC LUMINARIES

3.1 LITERATURE REVIEW

LED technology recently replaced the incandescent lamps in traffic signal systems. This technology has a larger product lifetimes and smaller energy consumption than the incandescent lamps. These LEDs were first introduced in early 1960s. Initially only the red color LED’s had a higher performance and a greater light output. Various companies like Hewlett-Packard, Cree, Siemens, Toshiba, and Nichia conducted a significant amount of research to improve the efficiency of green, yellow, and blue. IBM computers were the first to use LEDs. These LEDs which replaced the tungsten bulbs that controlled punch card readers. The application of LEDs has grown significantly over the years. A significant research is being conducted to introduce LEDs into smart contact lens where these LED’s can be of a value edition to that lens.

Before transitioning from incandescent lamps to LED technology National Cooperative Highway Research Program (NCHRP) Project 5 was initiated to do research on the feasibility and implementation of LED technology into traffic signals. The purpose of the research was to show that the LED traffic signals met the applicable standards for color and intensity without adversely affecting the safety and operation of the roadways. In fact, the economic benefit urged many DOT agencies to introduce LED technology into traffic signaling systems. After introducing this technology, public agencies had to come up with the ways to predict the replacement schedules of the LEDs. The standards used in replacement of conventional incandescent bulbs differ for the LEDs and therefore the engineers working for the DOTs had to come up with sustainable replacement strategies. [13]

The use of LEDs has a number of inherent drawbacks. For example they degrade over time rather than failing catastrophically. Degradation in traffic signals without proper regular maintenance and inspections may pose a serious threat to traffic. The LED degradation usually occurs because of the abrasion of UV stabilized polycarbonate. This polycarbonate basically protects the LEDs from harmful sun rays etc. The typical specification of this polycarbonate is about 60 months of exposure in a south facing Arizona Desert installation without appreciable degradation. [14]

In 1998 the Institute of Transportation Engineers (ITE) released a purchase LED specification Vehicle Traffic Signal Head part 2 (VTSCH part 2) to meet the needs of public agencies in expanding the use of LEDs in traffic signaling system. In 2005, ITE replaced the VTSCH part 2 with VTSCH –LED as a performance specification. This VTSCH-LED became a standard for public agencies and this document stated all requirements as a minimum performance specification or alternative requirements based on an engineering study. [17, 18] These standards were written after carefully considering all the unique properties of LEDs and incorporated testing and performance requirements to ensure the overall safe performance of the products. The National Cooperative Highway Research Program (NCHRP) funded the Lighting Research Center (at Rensselaer Polytechnic Institute) to recommend a certain replacement strategies for the LED traffic signals. LRC recommended that for a 10-year operating life LED signal light, a replacement period of 8 years minimizes overall replacement costs (Thus 12% of traffic signals could be replaced each year) and for 7 year operating life, a replacement period of 6 years minimizes overall replacement costs (17% of traffic signal lights could be replaced every year) [20].

From the cost perspective, NCHRP in their research recommended that by replacing the installed older LED's through a proper replacement schedule with the newer ones would have advantages like less power consumption, reduction in CO_2 emissions, better signal visibility, better signal uniformity, and reduction in emergency light outcalls for older LEDs failing. [14] Based on the work documented by Behura (2007) and Urbanik (2008) many of the transportation agencies have been replacing the LED traffic lights based on the spot visual inspection and changing them immediately if failed in the visual inspection. [15,19] For example, the Municipality of Dunwood, a town in Georgia, have come up with their own methodology of replacing the LED's for every four years based on their LED Traffic signals policy.

In 2006 a survey was conducted on the public agencies and LED manufactures by ITE. [20] The survey summarized that the usage of LED modules in traffic is predominant, most public agencies do not have any replacement program and the LED's are generally replaced after complaints from the commuters, most agencies use 5 year warranty , but they tend to replace no longer than the six year cycle . The survey also ascertained that most agencies do not have adequate funding for monitoring the replacement program for LED modules. In 2011 Sammat Engineering Services, LLC carried out a research on the Evaluation of life expectancy and development of the replacement schedule of LED's for traffic signals in the District of Columbia sponsored by DDOT, Washington D.C. Initially Sammat engineering collected data of LED traffic signal lights from 30 intersections as identified by the DDOT (District Department of Transportation). A device (Spectra III LED Degradation tester) was used to measure the intensity of LED signal lights. Their research based on the analysis of the data and on the degradation rates compounded for each LED traffic signal indicator concluded recommended an average replacement period of 7 to 9 years. [21]

In 2010 a similar study was carried out on the evaluation of useful lifetime and replacement schedule for LED traffic signals using statistical methodology and field study. The research was initiated and carried out by the research team at Missouri University of Science and Technology, with the funding from Missouri Department of Transportation. The study was done by collecting data across various intersections in Missouri, and that data was further studied through statistical methodology. The major advancement of this study was the use field instrument in collecting the data, which was developed in the laboratories of Missouri University of Science and Technology. This instrument was valuable in collecting two important metrics: light luminance and the distance from the traffic indicator to point of measurement. [22] A comprehensive statistical analysis was performed on the collected field data to indicate whether the light readings had been affected by "LED type", "manufacturer", and "age". However, this study was limited only to short data collection time frame and recommended an opportunity to expand the magnitude of study in terms of number of traffic lights considered and the length of period of time. In 2014 in continuation to 2010 study, the research team at Missouri University of Science and Technology used a comprehensive statistical model by including lateral and longitudinal regression analysis to estimate and predict the replacement schedule of LED traffic luminaries based on the age groups and manufacturer type. This study concluded successfully in predicting the replacement schedules as follows: DIAL Green Arrow 14.1719 years, DIAL Circular Red 17.6077 years, DIAL Yellow Arrow 12.7728 years, GE Circular Green 6.6339 years, GE Green Arrow 9.7866, GE Yellow Arrow7.4503 years, GE Circular Yellow 2.6718 years, and LTEK Circular Yellow 5.0582 years. [23]

3.2 GENERAL LINEAR MODEL UNIVARIATE ANALYSIS

The GLM (general linear model) Univariate procedure provides both regression analysis and analysis of variance for one dependent variable by one or more factors and/or variables. These factor variables divide the population into groups. The General Linear Model procedure can be used test the null hypothesis and to determine the effects of other variables on the means of various groupings of a single dependent variable. Interactions between factors as well as the effects of individual factors can also be analyzed. In addition, the effects of covariates and covariate interactions with factors can be included. For regression analysis, the independent (predictor) variables are specified as covariates.

This study has been carried out to study the effects of factors such as color, manufacturer type, season, and age of a particular LED luminaire on the intensities of the LED traffic signals. The luminous intensity has been considered as the dependent variable.

In any experimental design, the independent variable is the variable that is manipulated by the experimenter to determine its relationship to an observed phenomenon (dependent variable). Thus the independent variable is considered the "cause," while the dependent variable is considered the "effect".

The factorial analysis of variance (ANOVA) is an inferential statistical test that can be used to determine whether or not each of several independent variables affects the dependent variable (the main effect). It also helps in revealing whether or not the main effects are independent of one another (For example, it helps in determining whether or not two or more independent variables interact with each other.

3.3 ERROR CHART

Before running an ANOVA it is necessary to test sub-groups e.g., FYA (flashing yellow arrow),G (green),GA (green arrow),R (red), RA (red arrow),Y (yellow) ,YA (yellow arrow) part of the independent categorical variable "color". Using error charts it can be examined to observe whether the subgroups within the categorical variables are showing any statistical significance on the dependent variable "intensity". Likewise it can be tested for other categorical variables

The vertical lines in below Fig.3.1 define the lower and upper confidence intervals. The circles (in the middle) define the means of different color lights. An overlapping of the means (Standard Error bars) among the group indicates a statistical significance of lights FYA, GA, RA, and YA on the 95% confidence interval of intensity with no difference in their means exist. The standard error (SE) bars of lights G and R overlap over each indicating a statistical significance on intensity.

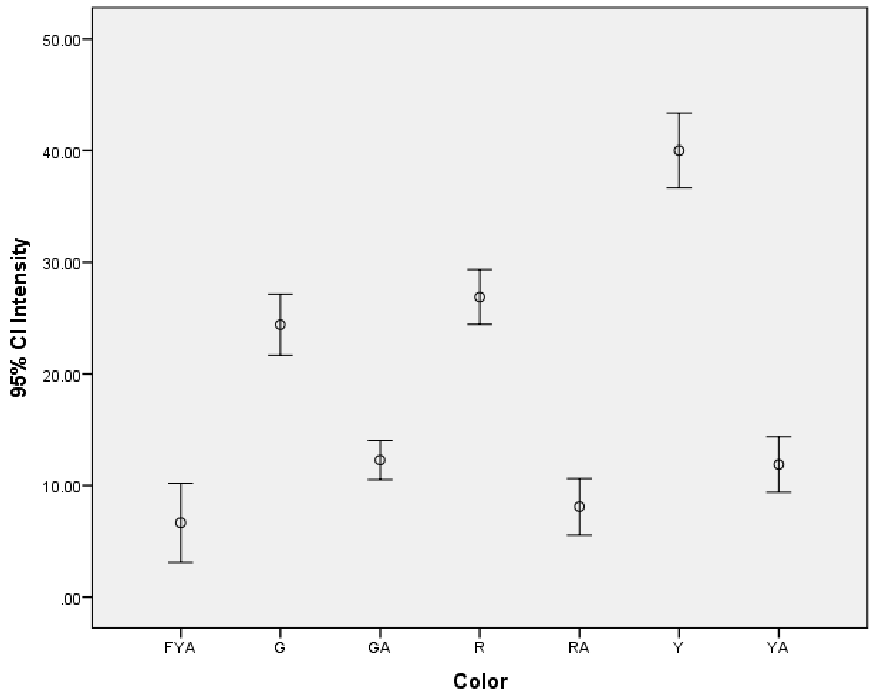


Figure 3.1 Error Chart (Color)

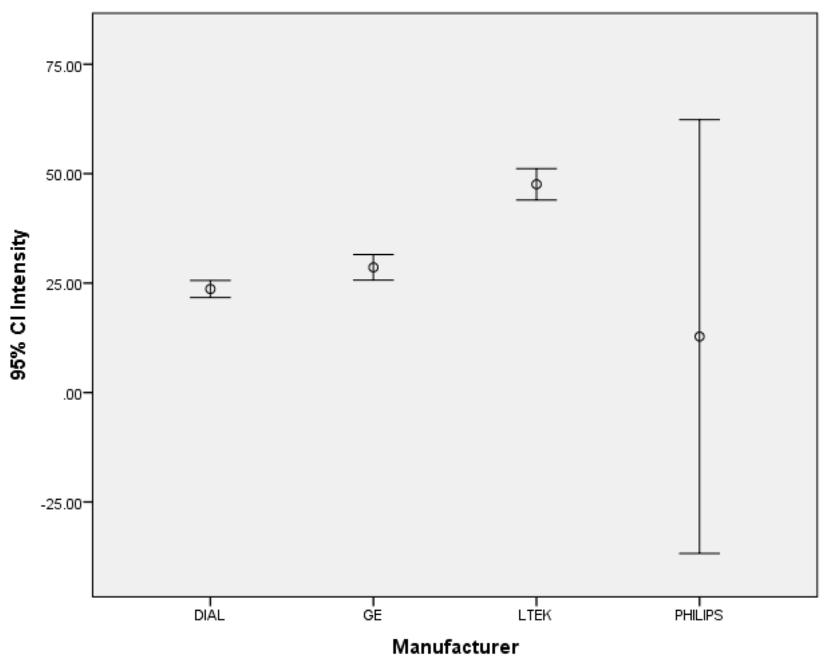


Figure 3.2 Error chart (Manufacturer)

If SE bar in Fig.3.2 of PHILIPS is compared to the other three remaining manufacturer (DIAL, GE, and LTEK) SE bars then an overlapping is observed indicating no difference in their means on the 95% confidence interval of intensity. The SE bar of LTEK is compared then it is seen that it overlaps only with PHILIPS, but no overlapping on DIAL, GE SE bars. This means there is a difference in means of LTEK when compared to DIAL and GE. The SE bars of DIAL, GE only overlap among each other indicating a differences in their means on the 95% C.I of intensity.

3.4 NORMALITY TEST

A normality test was conducted on the dependent variable "intensity" to determine whether or not the data is normally distributed. A normality test was done by plotting the data using frequency distribution (histograms), normal Q-Q (quantile-quantile) plots. As an assumption to any parametric statistical analysis (like regression analysis) it is considered that the dependent variable data is normally distributed. A normality test is a confirmation to such assumption. The data was not normally distributed when the dependent variable was initially tested for normality. Thus, using SPSS software the intensity data was converted into a normally distributed data.

Table 3.1 Descriptive statistics (Normality test)

			Statistic	Std. Error
Intensity	Mean		.2182	.00386
	95% Confidence Interval for Mean	Lower Bound	.2106	
		Upper Bound	.2258	
	5% Trimmed Mean		.2181	
	Median		.2185	
	Variance		.007	
	Std. Deviation		.08152	
	Minimum		.00	
	Maximum		.41	
	Range		.41	
	Interquartile Range		.13	
	Skewness		.055	.116
	Kurtosis		-.636	.231

The skewness in table 3.1, is in the positive side with a standard deviation of .081 .The tables also gives values of the several other parameters such as median, max, min values, range of the data. The positive skewness indicates that the data distribution is positively skewed.

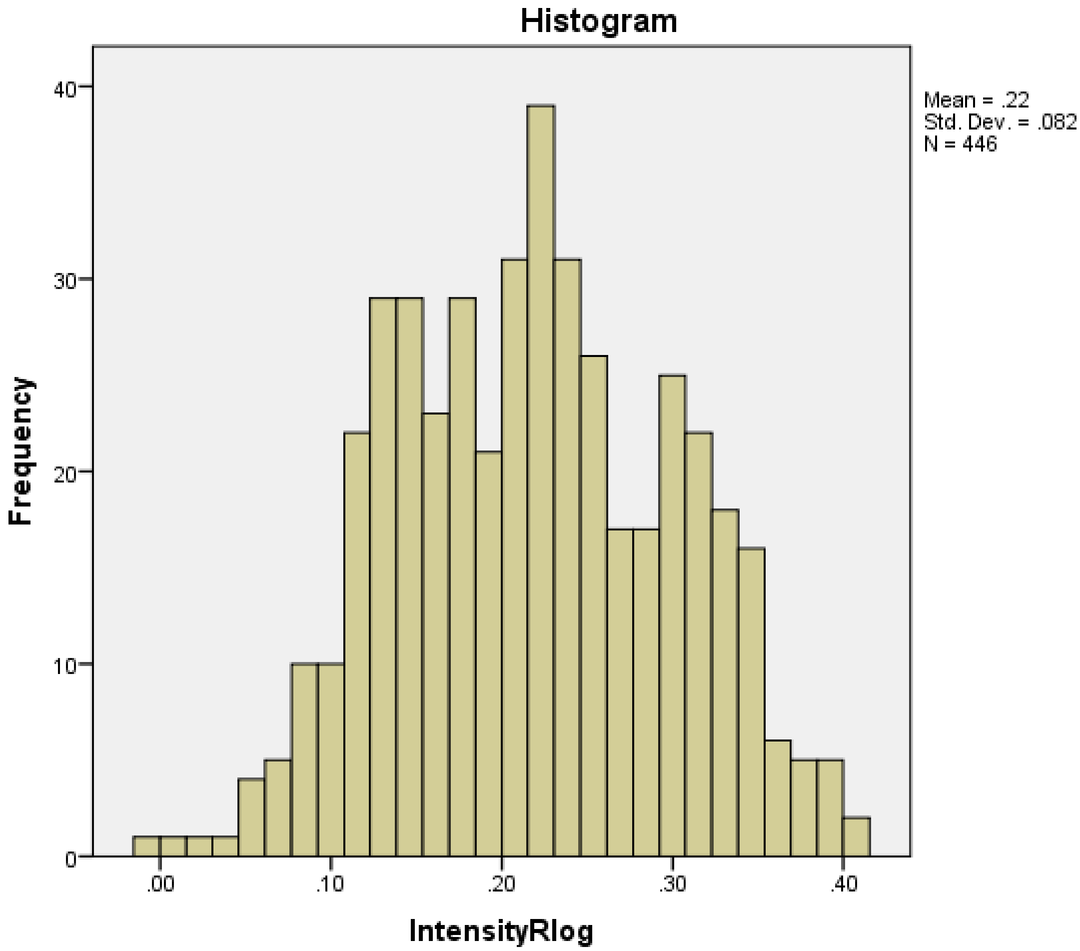


Figure 3.3 Histogram

The dependent variable data in Fig.3.3 shows a normally distributed spread data with a bell shaped curve. In this frequency distribution plots the observed values are plotted against their frequency, which provide us both a visual judgment about whether the distribution is bell shaped and insights about gaps in the data and outliers outlying values. A common pattern is the bell–shaped curve known as the “normal distribution.” In a normal distribution, points are as likely to occur on one side of the average as on the other.

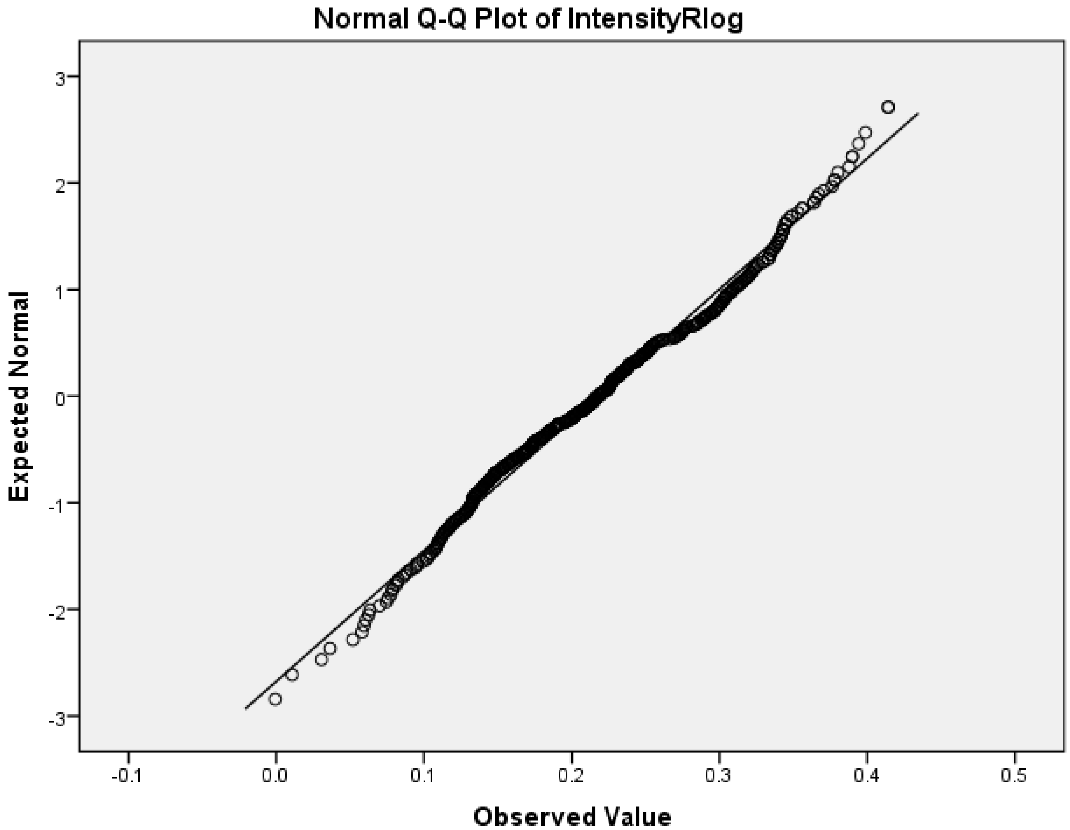


Figure 3.4 Normal Q-Q plot

A normal Q-Q Plot can be used to determine the normality graphically. If the data is considered as normally distributed, then the data points will be close to the diagonal line. If the data points stray from the line in an obvious non-linear fashion, the data are not normally distributed. From the above figure of normal Q-Q plot, we can assume that the data is normally distributed. It is one of the graphical methods to determine whether the data follows normal distribution. Therefore, in this case we can assume that the dependent variable “intensity” data is normally distributed.

3.5 LEVENE'S TEST FOR EQUALITY OF VARIANCES

The Levene's test is based on the following equation:

Design = Intercept + Age + Manufacturer + Season + Color + Manufacturer * Season + Manufacturer * Color + Season * Color + Manufacturer * Season * Color

Table 3.2 Levene's test for equality of variances parameters

Dependent Variable Intensity

F	df1	df2	Sig.
5.292	26	421	.000

The Levene's Test of Equality of Error Variances tests one of the assumptions of ANOVA, namely, that the variances of each condition are approximately equal or not. Equal variances across samples are known as the homogeneity of variances. Certain statistical tests (e.g., analysis of variance) assume that variances are equal across groups or samples. The Levene's test can be used to verify that assumption. Levene's test works by testing the null hypothesis that the group's variances are the same. The output probability is the probability that at least one of the samples in the test has a significantly different variance. If this variance is greater than a selected percentage (typically 5%) then parametric tests cannot be applied usefully. SPSS easily provides the Levene's test statistic for parametric tests that need it.

In general, ‘α’ value is considered to be 0.05. If the p value is lesser than or equal to α level for the test, then the H_0 (null hypothesis) is rejected and it is concluded that difference exists between the variances. The value of sig in Table 3.2 (which is $p < 0.005$) indicates that the variances across the independent variables are not equal and therefore, the null hypothesis is rejected.

A general linear model univariate analysis can be modeled to validate Levene’s test of equality conclusion whether to reject or not reject the hypothesis. SPSS software was used to analyze the data for general linear univariate analysis. The main purpose for this GLM is to study the effect of independent factors on the dependent variable; here the dependent variable is the intensity of light. The independent variables are combination of both categorical and continuous (covariate) variables. These variables must be defined before the GLM analysis can be run. The factors (e.g., color, manufacturer type, and season) are considered to be the categorical variables. Dummy tables for the categorical variables have to be created for the analysis and the SPSS software will do this by default.

3.6 ANOVA (GENERAL LINEAR MODEL)

The ANOVA was initially conducted only on the data that contained summer, and winter data sets. Therefore, only the data belonging to summer and winter was used. Only two sub-groups exist in the “Season” predictor variable used in the study. The SPSS was used to conduct generalized univariate analysis. It was modeled as:

$$\text{Intensity}= b_0+b_1A_i+b_2B_i+b_3C_i+b_4D_i+b_5BC_i+b_6CD_i+b_7BD_i+b_8BCD_i+\varepsilon_i$$

Where b_0 represents the intercept, A_i represents the predictor variable factor "age," Bi represents the "season," C_i represents the "color," and D_i represents factor "manufacturer." Interactions BC_i, BD_i, CD_i, and BCD_i represent the combined effects of the predictor variables. The output from two-way ANOVA, is shown in the Table 3.3

Table 3.3 ANOVA

Tests of Between-Subjects Effects Dependent Variable, Intensity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	68167.734[a]	27	2524.731	15.126	.000
Intercept	23150.023	1	23150.023	138.695	.000
Age	2545.562	1	2545.562	15.251	.000
Season	9.571	1	9.571	.057	.811
Color	36230.874	6	6038.479	36.177	.000
Manufacturer	1417.047	3	472.349	2.830	.038
Season * Color	2003.913	6	333.986	2.001	.064
Season * Manufacturer	82.324	2	41.162	.247	.782
Color * Manufacturer	7550.323	5	1510.065	9.047	.000
(Season * Color *Manufacturer)	1048.268	3	349.423	2.093	.100
Error	70103.306	420	166.913		
Total	462398.826	448			
Corrected Total	138271.041	447			

a. R Squared = 0.493 (Adjusted R Squared =0 .460)

The ANOVA gives the values of various parameters. The P value tests the null hypothesis where the data from all groups are drawn from populations with identical means.

If the value of P is large, then the means are not necessarily different. If the overall P value is small, then any observed differences are likely due to random sampling. The idea that all populations have identical means can be rejected. This does not mean that every mean differs from every other mean. It only means that at least one differs from the rest. The fraction of the overall variance (R^2 sometimes referred to as η2 or eta squared) of all of the data, pooling all of the groups is attributable to differences among the group means. This fraction compares the variability among group means with the variability within the groups. A large value means that a large fraction of the variation is related to the treatments that define the groups. The R^2 value is calculated from the ANOVA table, it equals the between group sum-of-squares divided by the total sum-of-squares. This value is a descriptive statistic that quantifies the strength of the relationship between group membership and the variable you measured. [24]

The above output in rows "Age group," "Color," "Season," "Manufacturer," "Season*Manufacturer," "Color*Manufacturer," "Season*Color," and "Season*Color*Manufacturer" indicate whether or not the independent variables (the "Color", "Age group," "Manufacturer," "Season") and their interactions have a statistically significant effect on the dependent variable ("intensity"). The predictor variable "season" (with a p value of 0.811) shows strong evidence that this variable do not have any significant impact on the intensity dependent variable. The interactions "Season*Color" and "Season*Manufacturer" have F (6,420) =2.001, and F (2,420) =.247 values with high p values of 0.064 ($p>0.05$) and 0.782 ($p>0.05$) respectively. Therefore, no statistical significant difference exists in the means of intensity. The independent variables (age group, color, and manufacturer) have a statistical significance on the dependent variable with lesser p values. The "season" has a smaller statistical significance. Its interactions with other factors such as "color", "manufacturer" also indicates very small statistical significance.

Thus ANOVA was run again and the "season" predictor variable was excluded .The output is given in Table 3.4.

Table 3.4 ANOVA (excluding "season" variable)
Tests of Between-Subjects Effects Dependent Variable, Intensity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.506[a]	14	.108	31.946	.000
Intercept	4.102	1	4.102	1218.330	.000
Age Group	.040	1	.040	11.832	.001
Color	1.048	6	.175	51.883	.000
Manufacturer	.016	2	.008	2.372	.094
Color *Manufacturer	.219	5	.044	12.979	.000
Error	1.451	431	.003		
Total	24.186	446			
Corrected Total	2.957	445			

a. R Squared = 0.509 (Adjusted R Squared = 0.493)

After excluding the predictor variable "season" from the further analysis a better R square is observed which means better correlation among the considered predictor variables to the dependent variable. The predictor variables in the ANOVA (e.g., "age group," "color;" and "manufacturer") had p values close to and less than 0.05 are showing statistical significance on the "intensity". Although the factor "manufacturer" was less significant alone its interaction with the "color" impacted the dependent variable.

Additional data (i.e., the fall dataset) was analyzed to determine whether or not it would alter the earlier assumptions. The predictor variable “season” was included into the univariate analysis with three subgroups: winter, summer, and fall. A generalized univariate analysis, (ANOVA) was then used to understand this data which included the season predictor variable.

Table 3.5 ANOVA (including fall data set)

	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	88.635[a]	41	2.162	51.945	.000
Intercept	134.032	1	134.032	3220.529	.000
Age group	.130	1	.130	3.115	.078
Color	30.915	6	5.153	123.806	.000
Season	.731	2	.365	8.779	.000
Manufacturer	1.335	3	.445	10.690	.000
Color * Season	3.320	12	.277	6.648	.000

Table 3.5 ANOVA (including fall data set) ("cont.")

Color * Manufacturer	5.510	5	1.102	26.478	.000
Season * Manufacturer	.637	5	.127	3.061	.009
Color * Season * Manufacturer	.810	7	.116	2.782	.007
Error	62.677	1506	.042		
Total	2950.746	1548			
Corrected Total	151.312	1547			

a. R Squared = 0.586 (Adjusted R Squared = 0.575)

The data in Table 3.5 indicates that when data was added (e.g., fall dataset) R square value improved. The "season" predictor variable was significantly statistically important to dependent variable "Intensity." An R square value of 0.586 indicates a strong correlation between the considered predictor variables ("age group," "season," "manufacturer," and "color type") and the luminous intensities. The p value 0.078 from the predictor variable "age group" was slightly higher than 0.05. Interactions among the predictor's variables had a strong statistical correlation on the dependent variable when the fall data set was included.

3.7 CONCLUSION

Initially without the inclusion of fall dataset into the analysis, it was observed that predictor variables such as “age group,” “manufacturer,” and “color” types have shown a significant statistical importance on the considered dependent variable (“intensity”).

When the same dataset was analyzed, but with the by inclusion fall data it was observed that the predictor variables “age group,” “manufacturer,” “season,” and “color” were showing a strong statistical significance on the luminous intensity. Also with the inclusion of fall data showed higher R square value which means there could be a stronger correlation between the independent and considered dependent variable.

The study of the statistical significance of the predictor variables (e.g., “age group,” “manufacturer,” “season,” and “color”) on the luminous intensities of traffic signals can be a useful assumption to future studies that investigate why luminous intensity in LED traffic indicators degrade. Recently these factors were used to determine the estimated life expectancy of a LED traffic signal light (based on manufacturer and age groups). [22]

Four different manufacturers “GE”, “LTEK”, “DIAL”, and “PHILIPS” were examined under the “manufacturer” variable. This variable was found to have a significant impact on a traffic signals luminous intensity. Thus LED traffic luminaries manufactured by different manufacturer’s exhibit different degradations in the luminous intensity .Sample data was studied on both “DIAL” and “GE” manufactures where the traffic lights belonged to 6 year age group. This sample analysis showed that each of these manufacturers' lights had impacted the luminous intensities of traffic signal lights.

Since different age groups are showing the impact on the intensities of LED, the age group (the date of installation to present day) can be considered as an important factor in further studies of studying the degradation of luminous intensity of LED traffic luminaries. Color was another predictor variable which was showing a strong statistical significance on the intensities of the traffic light. With the inclusion fall sub group into the "season" predictor variable; the R square value increased by showing a good indication correlation between the independent and dependent variables. With the inclusion of the fall data it was observed that all the considered predictor variables ("age group", season, color, and manufacturer type) were showing a strong significance on the intensity of LED traffic lights.

This study and the accompanying results can be a considered a useful null hypothesis testing in studying the effects of color, manufacturer, season, and age group categories on LED luminary intensities .These effects were the significant predictor variables that were used to estimate replacement schedules of traffic lights. Therefore based on the above results we reject the null hypothesis and determine that the predictor variables such as color, season, age group, and manufacturer were showing a statistical significance on the luminous intensities of LED traffic luminaries. Therefore the objective of this thesis was concluded by rejecting the null hypothesis testing.

4 SUMMARY AND RECOMMENDATIONS

From the analysis of both the cases (work zone and LED traffic luminaire) as detailed in previous sections a useful and significant recommendations can be made which could be helpful for the transportation agencies like MoDOT. These recommendations could be helpful in focusing on road safety near work zone areas and the further study the important factors (predictor variables) consider on the degradation of luminous intensities of LED traffic luminaries.

From the case I, through the descriptive statistical analysis of historical raw data it could be determined that by focusing and improving certain areas could reduce considerable amount of crashes near work zones. The factors like inattentive driving and restrained occupants had led to several crashes .By educating drivers, commuters and possibly bringing laws to restrict usage of phones while driving can reduce down the crashes related inattentive driving to a certain extent. It was also observed that most crashes had happened in an urbanized areas, this could be due to larger populations living in those areas. Interstates and highways under functional classification category were also observed to contribute several crashes. This could be due to commuters driving at higher speeds, or, exceeding posted speed limits. Therefore, through precautionary measures like imposing lower speed limits, setting up warning signs, and cautioning drivers in advance of any work related activity on the roads could also help in reduction of crashes. In addition to the above mentioned safety measures, it could be recommended for transportation agencies like MoDOT to use modern safety devices like flagger audible warning devices, highly mobile barrier systems, and worker-activated panic button warning systems which are worn by all personnel in the work area. [11] This kind of modern safety devices could alert the working personnel's near the work zones and avert from any kind of mishaps, or, several crashes.

From case II analysis it could be summarized that considered predictor variables (e.g., "season," "color," "manufacturer," and "age group") have shown statistical significance on the luminous intensities of LED traffic signal lights. Therefore, these predictor variables could be analyzed on a timely manner to study the pattern of degradation of the luminous intensity of LED luminaires. From this study "color" (one of the four predictor variables) was also showing a significant impact on the intensity, therefore, individually different color (such as green, red, yellow, yellow arrow etc.,) traffic LED luminaries could be studied further in-depth for their effects on the degradation factor of luminous intensities. Through such a study which colored light degrades faster on the factor of intensity could be determined. The life of the LED traffic luminaire and its luminous intensity could also vary from manufacturer to manufacturer. Therefore, transportation agencies such as MoDOT should be cautious in buying the lights only from reliable and quality driven manufacturers. LED luminaries such as Dialight, GE, LTEK, and Philips manufactured lights were used for the data analysis. So buying LED luminaries from those manufactures could be recommended for MoDOT, or, any other transportation agencies.

BIBLIOGRAPHY

[1] The role of Statistics in Science, http://www.bcps.org/offices/lis/researchcourse/statistics_role.html, Accessed May 25, 2014.

[2] Daniel, J., K. Dixon, and D. Jared, “Analysis of Fatal Crashes in Georgia Work Zones,” Transportation Research Record, Vol. 1715, 2000, pp. 18-23.

[3] Bryden, J.E., and D.J. Mace, Guidelines for Design and Operation of Nighttime Traffic Control for Highway Maintenance and Construction, NCHRP Report 476, Transportation Research Board of the National Academies, Washington, DC, 2002.

[4] Garber, N., and M. Zhao, “Distribution and Characteristics of Crashes at Different Work Zone Locations in Virginia,” Transportation Research Record, Vol. 1794, 2002, pp.17-25.

[5] Mohan, S., and W.C. Zech “Characteristics of Worker Accidents on NYSDOT Construction Projects,” Journal of Safety Research, Vol. 36, 2005, pp. 353-360.

[6] Harb, R., E. Radwan, X. Yan, A. Pande, and M. Abdel-Aty, “Freeway Work-Zone Crash Analysis and Risk Identification Using Multiple and Conditional Logistic Regression,” Journal of Transportation Engineering, Vol. 134, No. 5, 2008, pp. 203-214.

[7] Krammes, R.A., and C. Hayden, “Making Two-Lane Roads Safer,” Federal Highway Administration, 2003, http://www.tfhrc.gov/pubrds/03jan/04.htm, accessed June 2, 2014.

[8] Khaled El-Rayes, Liang Liu, and Tarek Elghamrawy,” Studying and Minimizing Traffic-Related Work Zone Crashes in Illinois”, April 2013.

[9] Mahoney, K.M., R.J. Porter, D.R. Taylor, B.T. Kulakowski, and G. Ullman, Design of Construction Work Zones on High-Speed Highways, NCHRP Report No. 581, Transportation Research Board, Washington, DC, 2007.

[10] T., J.N. Ivan, and C. Zhang, “Crash Prediction Models for Intersections on Rural Multilane Highways,” Transportation Research Record, Vol. 2019, 2007, pp. 91-98.

[11] Steven D. Schrock, Gerald L. Ullman, A. Scott Cothron, Edgar Kraus, and Anthony P. Voigt, An Analysis of Fatal Work zone Crashes in Texas, October 2004, Texas Transportation institute.[12]

[12] Missouri STARS Committee (2012) *Missouri Uniform Accident Report Preparation Manual*. (Statewide Traffic Accident Records System (STARS) Manual). January 1

[13] Lewin , L. Corbin, M. Janoff., 1995, " The application of Light Emitting Diodes to Traffic Signals", IESNA Annual Conference.

[14] John, Vines, "Aging of LED Traffic Signal lights", website http://www.imsasafety.org/journal/mj10/22.pdf, Accessed, 20 January 2014.

[15] Replacement Processes for Light Emitting Diode (LED) Traffic Signals. NCHRP Web-only Document 146, Aug 2009.

[16] Behura, N (2007 April). A Survey of Maintenance Practices of Light-Emitting Diode Traffic Signals and Some Recommended Guidelines. ITE Journal.

[17] Institute of Transportation Engineers (2005, June 27). Vehicle Traffic Control Signal Heads—Light Emitting Diode Circular Signal Supplement. Washington, D.C

[18] Institute of Transportation Engineers (2007, July 1). Vehicle Traffic Control Signal Heads—Light Emitting Diode Circular Signal Supplement. Washington, D.C.

[19] Bullogh, J.D. (2009). Replacement Process for Light Emitting Diodes for Traffic Signals. Contactor's Final report, NCHRP Web Only Document 146, Transportation Research board. pp 26-30.

[20] Urbanik.T (2008). LED Traffic Signal Monitoring, Maintenance and Replacement issues. A Synthesis of Highway Practice. NCHRP (Synthesis 387). Washington, D.C.

[21] Evaluation of life expectancy of LED traffic signals and development of a replacement schedule in the District of Columbia. Available from Internet: *app.ocp.**dc**.gov/pdf/DCKA-2012-B-0112_Amd4att2.pdf*. (Accessed January 2014).

[22] Long, S. et al. 2010. "Life Expectancy Evaluation and Replacement Schedule Development for LED Traffic Signals." Rolla, USA: Missouri University of Science and Technology.

[23] Long, S. et al. 2014. “Longitudnal and useful Life Analysis and Replacement statergiesfor LED Traffic luminaries.” Rolla, USA: Missouri University of Science and Technology.

[24] Graph pad Statistics guide, http://www.graphpad.com/guides/prism/6/statistics/index.htm?f_ratio_and_anova_table_(one-way_anova).htm (Accessed May 2014).

VITA

Venkat Sravan Kothapalli was born on 07th September 1986 in the town of Vijayawada, India. He received his Bachelors of Technology degree in Mechanical Engineering from Jawaharlal Nehru Technological University, Hyderabad in 2008. After completion of his bachelors, he worked as a Quality Engineer at De Dietrich Process Systems India (Pvt) Ltd, Hyderabad. In August, 2014 he received his Master's degree in Engineering Management at the Missouri University of Science and Technology, Rolla.