Evaluating the Impacts of Pavement Surface Defects on Traffic Safety: A Case Study Between Arba Minch To Zeyise Wozeka Road, Ethiopia

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Abstract: Traffic accidents are increasing enormously in the entire global day to day. In the developing countries like Ethiopia, these road traffic accidents are making economic, social and political problems. Numerous amounts of research had been carried out on traffic accidents. The number of researchers identified a lot of factors that might increase the traffic accidents. The most critical factors were drivers, vehicle condition, roadway conditions and environmental conditions. The hardness to maneuver, the problem to take and give lane for other vehicles, discomfort of drivers and so on are the main factors of the road surface defects causing various road traffic accidents.

This research is initiated to evaluate the correlation of road surface condition to road traffic accidents. The severity of the surface defects is collected from condition survey and the number of accident data of study area has been collected from Gamo Gofa zone road and transport office and Arba Minch zuria traffic police directive. The multiple linear regression model is developed for analysis by taking the rate of road traffic accidents as dependent variable and the road surface defects as independent variables. The major road surface defects that causes the accidents are identified as Edge break, Potholes, Rutting and Roughness. In addition to this the pavement condition index (PCI) is calculated in order to distinguish the category of the road pavement current condition. Pavement condition score (PCS) which is the quantitative form of road pavement condition is also determined. A Multiple Linear Regression modal is developed to evaluate the rate of accidents by considering these surface defects. The statistical indicators of the developed modal are found to be good fitting. The results and analysis of the study may bring some guide lines to know the relationship between the accident rate and the surface defects. The study would help to find some engineering solutions to recommend for traffic authorities for the improvement of traffic safety. The results and analysis of the study shows that the rate of accidents is highly correlated with severity of surface defects and pavement condition. It was concluded that the increase in pavement defects also increases the rate of traffic accidents. Finally, the study forwarded engineering solutions and recommendations for the improvement of traffic safety.

Index Terms **- Traffic Safety, Pavement Surface Defects, Pavement Condition Index, Pavement Condition Score, Multiple Linear Regression, Zeyise Wozeka, Correlation Matrix.**

1. INTRODUCTION

Accidents are unwanted incidents that makes huge loss for the personal and community as a whole. The economic and social status of the country will decline due to the increase in road accidents. The impact can be reduced by suitable corrections made by both management techniques and pavement condition. Road traffic safety is one of the major primary for the transportation agencies. In Ethiopia, the road management system gives greater primacy to new roads. Because of that now a days aged road was over used with a lot of defects. Pavement defects directly affect riding quality, vehicle operation and contribute to driver distraction and accidents. A pavement with a bad record of defects can cause a vehicle to lose control when braking or turning, especially under adverse environmental conditions. As other major contributing factor to occurrence of accidents, road surface condition is also a serious hazard.

Major causes of crash in Ethiopia as reported by police is driver's negligence and over confidence. This is mainly due to the lack of awareness in driving and in maintaining discipline on roads. The lack of training for drivers, traffic police monitoring and enforcement measures are some of the responsible factors for the occurrence of more accidents in Ethiopia. The road characteristics have a great influence on traffic accidents. Improving poor road infrastructure would reduce road accidents [1]. There is a clear correlation between crash rate and pavement conditions. Worsening pavement conditions can lead to more accidents in a normal driving environment [2].

1.1 General Objective

The main objective of this study is to evaluate the impacts of road pavement surface defects on traffic safety by determining the correlation between them. This identifies hazardous pavement conditions, pavement defects and locations which is very important for pavement management strategies.

1.2 Specific Objectives

1. To investigate the road pavement surface condition
2. To correlate the accident rate with road pavement surface defects.
3. To determine pavement condition index and pavement condition score
4. To model the correlation of accident rate on pavement surface defect
5. To forward engineering solutions and recommendations for road traffic safety

1.3 Statement of The Problem

Road traffic accidents are a global problem resulting in deaths, physical injuries, psychological problems and financial losses. Road safety is one of the most seen problems in developing countries. Road pavement in Ethiopia continuously deteriorates the

safety over time due to the combined actions of traffic loading, environmental conditions and weak or non-existing pavement management systems.

Arba Minch to Zeyise Wozeka road is asphalt paved highway with extremely defected pavement surface. The vehicle crash, injure and fatalities are the usual road accidents in the selected road segments. Because the road traffic accidents occur as a result of several factors, less attention is given to road pavement surface defects by the authorities. The main purpose of this study is to determine the correlation between road pavement surface defects and traffic safety and to recommend the road authorities and responsible engineering offices for roadway safety improvements. It is the hope of the study that the finding could stimulate discussion and inform the responsible bodies in pavement management systems.

1.4 Scope of The Study

This research study is carried out on Arba Minch to Zeyise Wozeka roadway network. The Arba Minch to Zeyise Wozeka roadway network is almost 33 km from initial point until Gidole junction. The road segment was in use from commencement day of March 18, 2005 GC. The most usual defect types of roads such as cracking, potholes, patching, rutting, and raveling are considered in the study area. The vehicle crash, injure and fatalities are also the usual road accidents in the selected road segments.

2 REVIEW OF THE LITERATURE

According to [3] report, The African Region which remains the least motorized of the rest world regions has the highest road fatality rates of all the world's regions. [4] reported that road crash fatality rate in Ethiopia was 23,837 deaths per 100,000 inhabitant per year and recorded as the highest death rate. According to [5] conclusion, the reason behind this highest rate of traffic fatalities per vehicle in Ethiopia is due to various factors such as poor maintenance of roads, inadequate marking, poor street lighting, un-licensed drivers, traffic violations, over speed and overtaking.

Road traffic accidents are a huge public health and development problem in Ethiopia. Its current situation requires a high-level political commitment, immediate decisions and actions in order to curb the growing problem. Otherwise, it will get worse from day-to-day as motorization and population increase rapidly [6]. As [7] reported, in most African countries, urbanization is growing and road infrastructure is expanding. Safety consideration in land-use planning and road design is not adequate to serve the mixed traffic that exists in the region.

Pavement deterioration is a serious problem for road traffic safety. Road deterioration is very common in developing countries. Roads networks built at great expense, have been heavily used without maintained and abused than expected. As this neglect continues, the deterioration of roads is accelerated [8].

To examine the effect of pavement condition on road crashes most research studies investigated the effect of pavement characteristics on accident occurrences, in particular, the effect of pavement condition individually or in combination with other factors of the road environment. [9] investigated the effect of pavement roughness measured by the international roughness index (IRI) and rut depth on accident rate. Collecting data from different sources and developing regression models, the researcher related pavement condition to rate of accidents at different severity levels and concluded that there is a good correlation between IRI and rut depth with crash rate.

The claims of a relationship between incident number and road quality was statistically tested using Negative Binomial Regression. Combining data such as location, crash date, severity of crash, crash type, road characteristics, road design, and weather condition, pavement roughness, surface distress information, AADT and percent truck on each segment, concluded that good road quality is negatively and correlated with property damage crashes [10].

In Ethiopian the pavement condition rating system is classified only according to the Ethiopian Road Authority pavement management System (ERA's PMS) developed in 2011. The system uses the Pavement Condition Index (PCI) to represent the average condition of the paved road network for a specific year to simulate the deterioration process of road pavements and forecast their condition over time. The system developed the Pavement Condition index (PCI), that combines, in a systematic manner, severity levels of the distress types occurring within a given road section into a scale of 0 to 100, where 0 represents a very poor pavement and 100 represents a pavement in excellent condition. As pavement condition index is qualitative, [11] assigned the Values from 0 to 5 to the score to make it quantitative as their rating score system is qualitative.

Table 1: The pavement condition index scale [12]

Pavement condition categories	Pavement condition index
Very Good	86% to 100%
Good	71% to 85%
Fair	51% to 70%
Poor	36% to 50%
Very Poor	0% to 35%

3 METHODOLOGY OF THE RESEARCH

3.1 Data Collection Method for the Pavement Surface Defects

In order to have precise amount of data for analysis, the road stretches had been divided into smaller of 3 segments of 11 km each. The condition survey to investigate the pavement defect types of roads in Ethiopia such as cracking, potholes, patching, rutting, raveling and edge damage had been done and the severity of pavement surface defects had been measured manually by blocks of 500 meter length for each segment. During the detailed surface condition survey, the nature, extent, severity and position of the following defects are recorded.

1. **Cracking:** The width of each types of crack was measured separately to distinguish the narrow cracks and wide cracks and recorded and the total surface area affected by each crack was measured for each block of 500 m length.
2. **Raveling:** The total surface area affected by ravelling was measured and recorded for each block of 500 m length.

3. **Pot holes:** the approximate dimension of each potholes was measured and recorded for travelled roadway segment or sample for each separate 500m length of block.
4. **Edge failures**: the approximate dimension of edge breaks from each road sides have been measured and recorded for each separate 500m length of block.
5. **Side drain:** the surface area covered by the silt and scour defects was measured and recorded for each separate 500m length of block.
6. **Rut depth:** the depth of deformation along the wheel path has been measured and recorded for ach separate 500m length of block.
7. **Roughness:** the cumulative measure of vertical undulations (humps and sags) of a pavement surface was measured manually by using steel measuring tape and straight edge as other methods were unavailable and recorded for each separate 500m length of block of road.

3.2 Calculation of Pavement Condition Index (PCI)

Pavement Condition Index (PCI) represents the average condition of the paved road network for a specific year to simulate the deterioration process of road pavements and forecast their condition over time. The Calculation of Pavement Condition Index (PCI) for this study has been done as Per ERA's PMS. Pavement Condition Index (PCI) has been calculated for each surveyed over 500m stretch. This helps to determine the current road condition for each study block.

3.3 Data Collection Tools

During the data collection the tools such as printed forms, clip boards, digital photograph (camera), notebook, 3m steel measuring tape, 2m straight edge and ball point pen and pencil has been used. Walking the whole length is unconvinced so that motor bike was used.

3.4 Road Traffic Accident Data Collection

Road traffic accident data containing basic accidents, roadway location, roadway condition and environmental and climate condition was collected from Gamo Gofa zone road and transport office and Arba Minch zuria traffic police directive. The following data shows the accident frequency for the past 10 years at the selected Arba Minch to Zeyise Wozeka road segment.

Table 2: The road traffic accident on Arba Minch to Zeyise Wozeka road for 10 Years

Year	Fatality	Major	Minor	Property damage
2007/08	10	15	20	9
2008/09	15	19	28	5
2009/10	14	13	27	10
2010/11	13	21	25	15
2011/12	27	20	30	14
2012/13	29	37	26	11
2013/14	21	31	27	20
2014/15	30	29	27	12
2015/16	27	39	30	8
2016/17	35	45	33	10

Table 3: Total accident for the year 2016/17

Segments	Fatality	major Injury	Minor Injury	Property Damage
segment 1	8	9	7	8
segment 2	18	23	17	15
segment 3	9	13	9	9
Total	35	45	33	32

3.5. Method of Data Analysis

The collected accident data was entered into M.S.excel for the purpose of analysis and the correlation study for both the severity and extent has been taken place using Excel 2016. The PCI is then calculated using Microsoft excel by following the procedure of calculating Pavement Condition Index (PCI) as Per ERA's PMS. The pavement condition score (PCS) which is the quantitative expression of the qualitative PCI is determined as per Mohammed, et al. (2015). Multiple linear regression model is developed by using SPSS and excel is used to solve the accident rate with PCI and pavement defects.

4 RESULTS AND DISCUSSIONS

4.1 The Correlation between Road Surface defects and Total Rate of Accident

The correlation matrix for both severity and extent condition of road segments has been checked and the result of correlation indicates total cracks, edge break, potholes, raveling, rutting and roughness are strongly correlated with rate of accidents as indicated in table 4.

Table 4: The correlation matrix of severity of distress with rate accident

	Total cracks	Edge Break	Potholes	Raveling	Rutting	Roughness	Fatality	Major Injury	Minor Injury
Total cracks	1								
Edge Break	0.331	1							
Potholes	0.380	0.826	1						
Raveling	0.533	0.451	0.502	1					
Rutting	0.396	0.597	0.659	0.474	1				
Roughness	0.305	0.551	0.692	0.340	0.553	1			
Fatality	0.291	0.773	0.816	0.434	0.643	0.679	1		
Major Injury	0.236	0.707	0.775	0.418	0.612	0.672	0.949	1	
Minor Injury	0.298	0.762	0.821	0.429	0.622	0.632	0.967	0.906	1

As for the precision of the data the total stretch was subdivided into three segments. The correlation matrix is done for each segments of 11 km. The multiple regression modal is developed by considering total cracks, edge break, potholes, raveling, rutting and roughness with rate of accidents. The influence of cracks and raveling are neglected due to their poor significance in the modal. The goodness of fit (R^2) for the model is found to be 0.896968094, 0.837090609 and 0.83668159 for Fatality, Major Injuries and Minor Injuries Vs Surface Defects respectively. The strong correlation of the modal is indicated from the values of R2 close to 1, which further reinforces the view that there is correlation between road surface defects and number of traffic accidents. The multiple regression modals between the severity of road surface defects and the rate of all types of accidents are developed by considering 75% of selected road segment (25 km) data and are as follows. The remaining 25% of collected data is kept for the purpose of testing the modals.

$$\text{Fatality} = -0.57053 + 0.02385(\text{EB}) + 0.08693(\text{Ph}) + 0.01582(\text{Ru}) + 0.38161(\text{Ro}) \quad (4.1)$$

$$\text{Major Injury} = -0.55871 + 0.02404(\text{EB}) + 0.02844(\text{Ph}) + 0.01565(\text{Ru}) + 0.57495(Ro) \quad (4.2)$$

$$\text{Minor Injury} = -0.59957 + 0.02289(\text{EB}) + 0.15879(\text{Ph}) + 0.01055(\text{Ru}) + 0.22953(Ro) \quad (4.3)$$

Where, EB is for edge brake, Ph is for pothole, Ru is for rutting and Ro is for roughness. The models are then validated with the rest of 25% of collected data and are found to be good as shown in figures 1 to 3

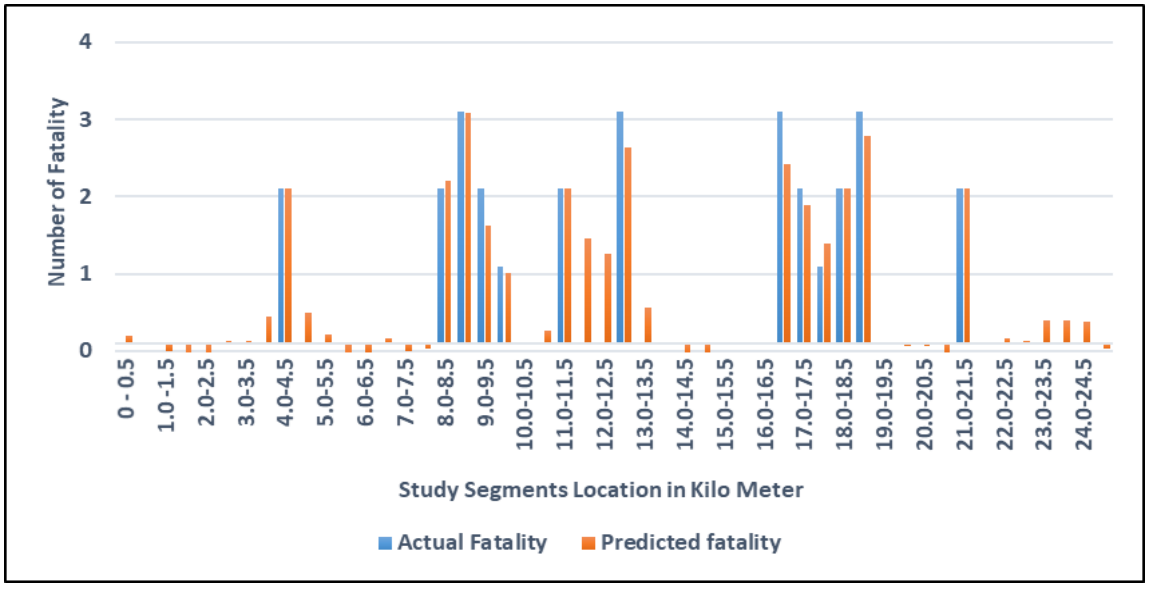

Figure-1 1: Observed and predicted number of fatalities

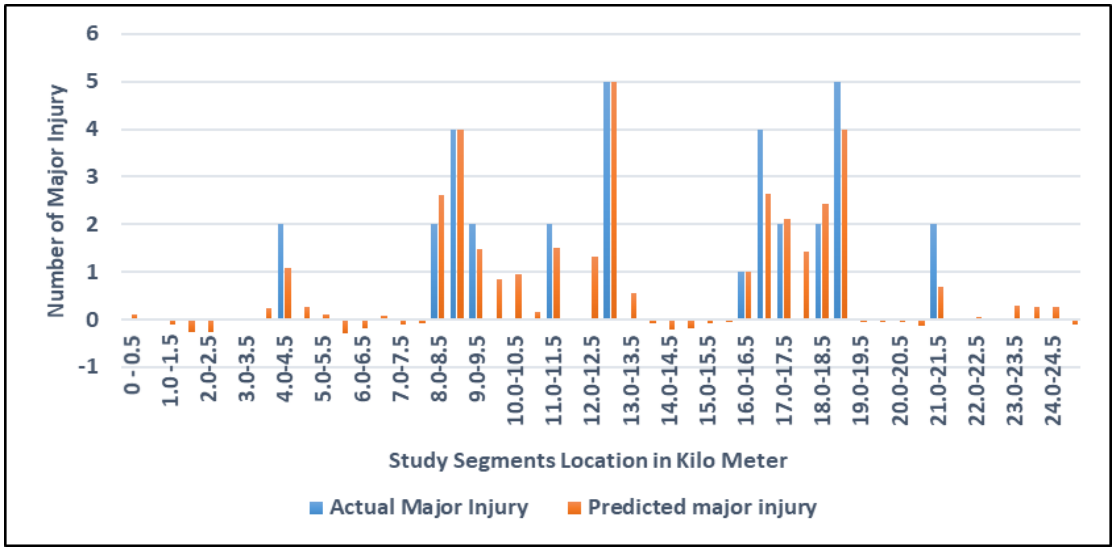

Figure 2: Observed and predicted number of major injuries

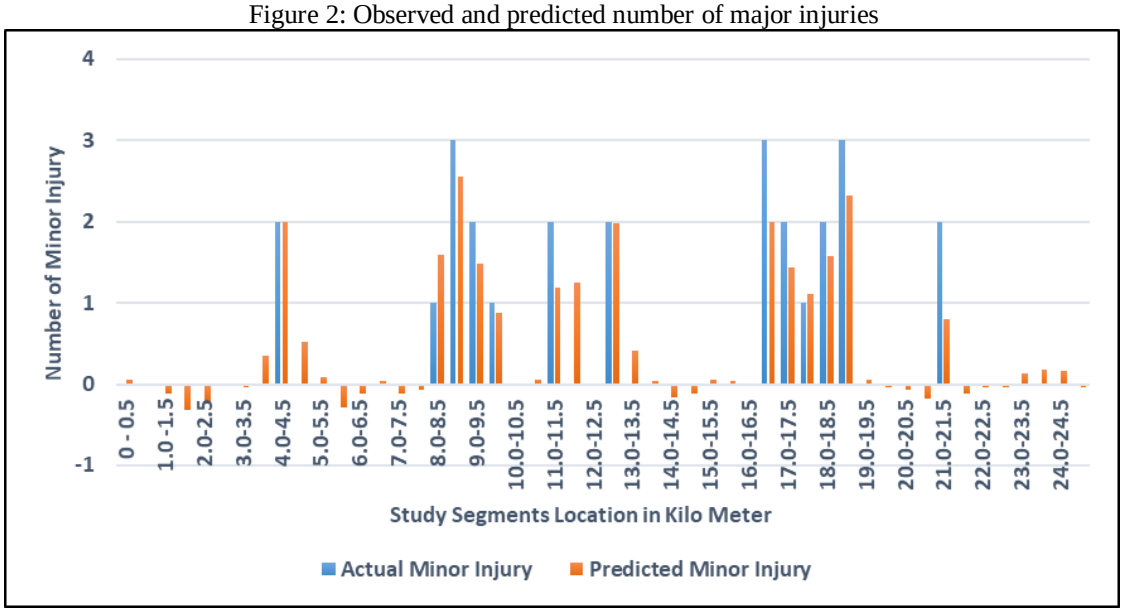

Figure 3: Observed and predicted number of minor injuries

4.2 Pavement Condition Index Rating and Pavement Condition Scoring

After the accomplishment of the condition survey, all the collected data was entered into M.S. excel and Pavement Condition index (PCI) and Pavement Condition Scoring (PCS) are calculated for each segment as indicated in table 5.

Table 5: The condition categories of each segment

Segments	Length (Km)	Very Good (Km)	Good (Km)	Fair (Km)	Poor (Km)	Very Poor (Km)	PCS
1	11	0	0.5	2.0	2	6.5	1.285
2	11	0	0	0.5	1.5	9	0.379
3	11	0	0	2.5	1	7.5	0.909

The pavement condition categories were qualitative that expresses from very good to very poor scale of pavement condition. In order to get the correlation between the accident number and pavement surface condition, the pavement surface condition data has been quantified from 0 to 5 which assigned to the pavement condition score. The scoring system used by Mohammed et al. (2015) give 5 to the highest pavement condition categories and o to lowest pavement condition categories of the study relatively. In the present analysis, highest pavement condition category is considered to be good and the lowest is considered to be very poor. Mohammed et al. used direct interpolation for the scoring system units as shown in the following table.

Table 6: Scoring system used in the study **Invalid source specified.**

Number	Pavement Condition Categories	Scoring System Units
1	Good	5
2	Fair	3.333333
3	Poor	1.666667
4	Very Poor	0

In each segment, the fair, poor and very poor road condition is converted to single quantitative known as pavement condition score (PCS) as indicated in the table 7. For instance, as Mohammed et al. (2015) the PCS for each segment was determined as the summation of scoring system units times by condition category coverage distance per total segment length.

4.3 Relation between the Accident severity and Road Condition Score

Table 7 shows the number of road traffic accidents in the year 2016/17 and total road traffic accident per segment and the pavement condition scores (PCS). Lower PCS value indicates that the effect of surface defects is more and the highest PCS value indicates that the effect is less.

Table 7: Road traffic crash per each segment and PCS in the year 2016/17

Segments	Fatality	Major Injury	Minor Injury	Property Damage	PCS
segment 1	8	9	7	8	1.285
segment 2	18	23	17	15	0.379
segment 3	9	13	9	9	0.909

The effects of pavement surface defects on the road traffic safety (fatalities, major injuries, minor injuries and property damages) are correlated as shown in the figures Figure 4 to 6 which clearly indicates the correlation of road traffic crashes with pavement condition scores (PCS) in the year 2016-17.

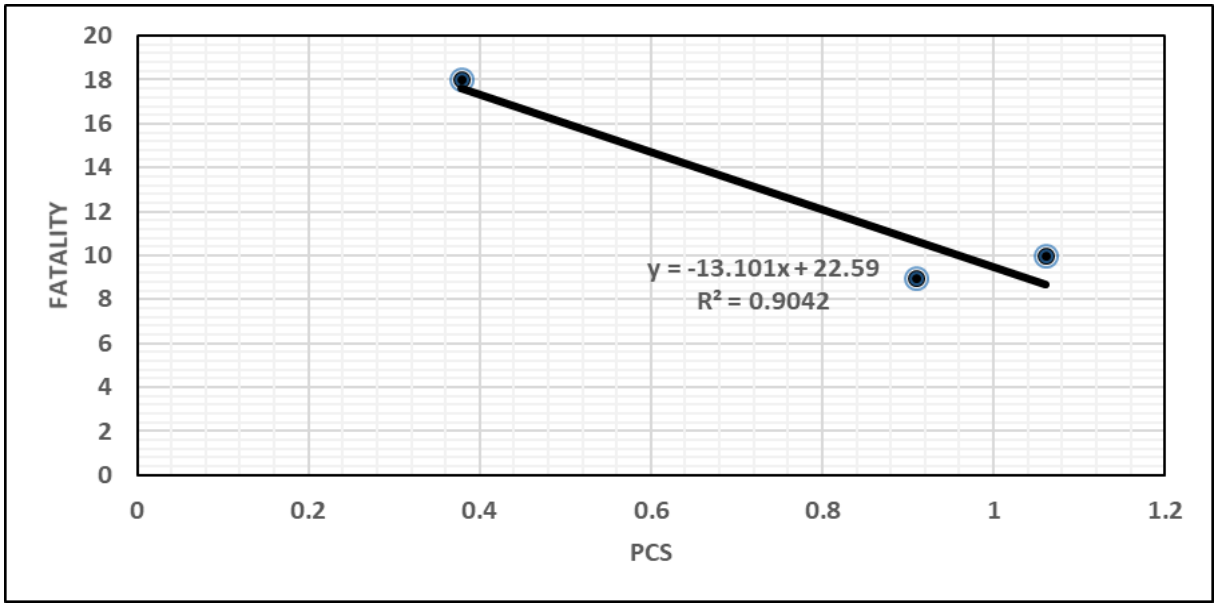

Figure 4: Relationship between number of fatalities and pavement condition score (PCS)

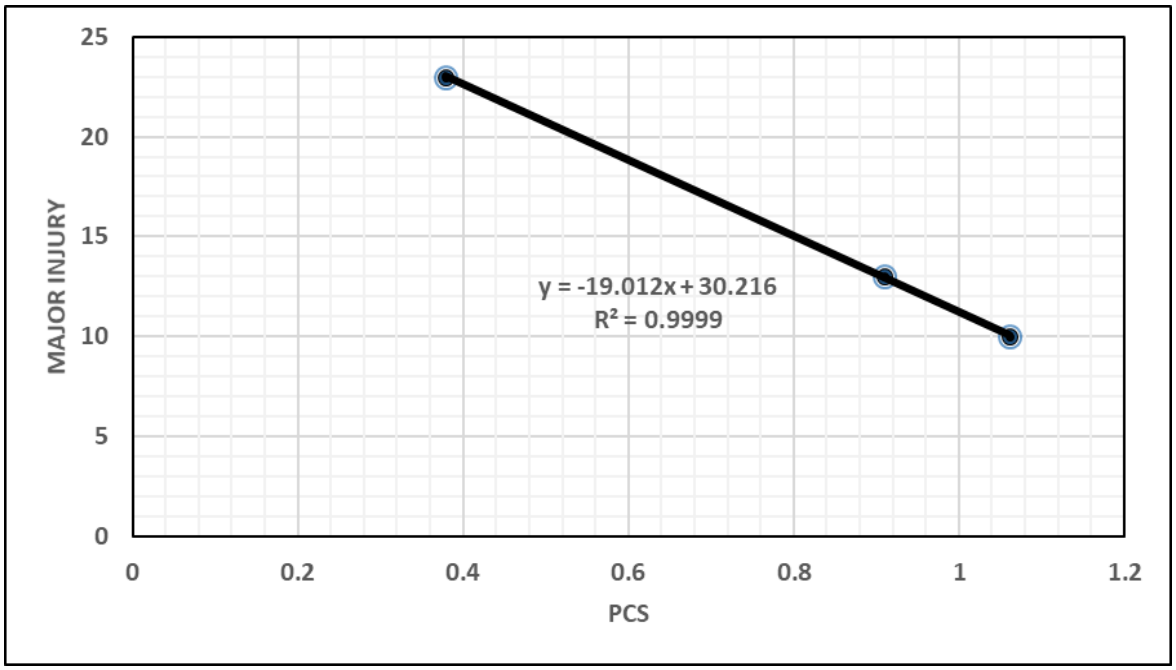

Figure 5: Relationship between of major injuries and pavement condition score (PCS)

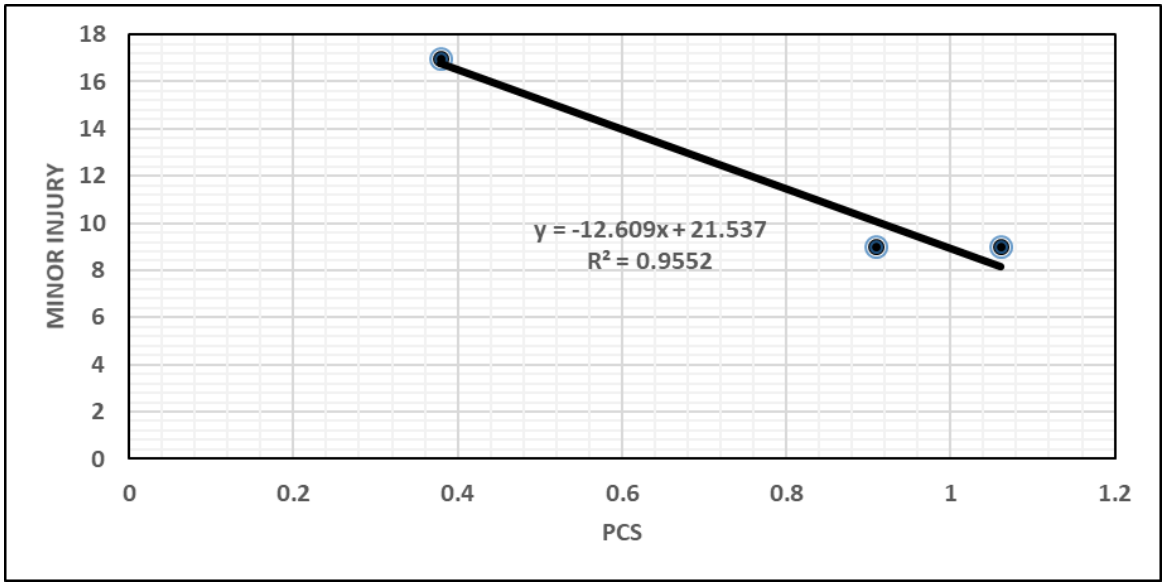

Figure 6: Relationship between of minor injuries and pavement condition score (PCS)

Figure 7 indicates the variation of traffic accidents in each segment in the selected area. This clearly shows that the rate of accidents are more in Segment 2 as compared to other two segments.

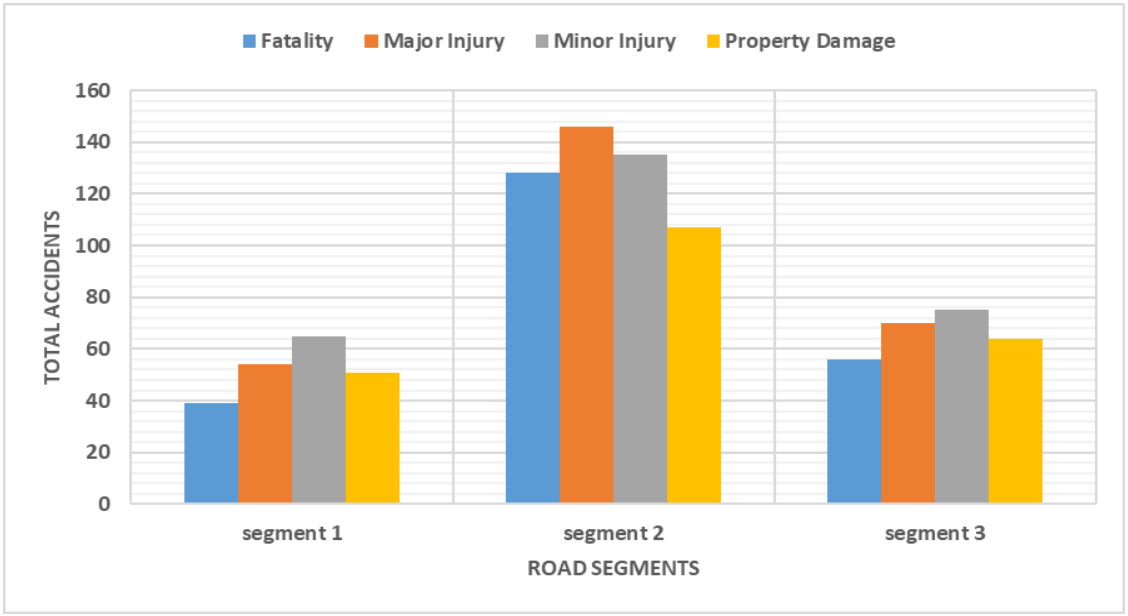

Figure 7: Total number of accidents on each road segments

5 SUMMARY AND CONCLUSIONS

The study is conducted to evaluate the effect of road surface defects on traffic safety between Arba Minch town to Zeyise Wozeka road in Ethiopia. The total length of the road considered is 33 kms. The selected road is divided into 3 segments of 11 kms each for the purpose of analysis. The various surface defects such as Cracking, Raveling, Pot holes, Edge failure, Side drain, Rutting and Roughness are considered as major sources of accidents in all the segments. The surface defects are measured in the field. Meanwhile, the accident data in the study area from 2007 to 2016 is collected from the respective Engineering departments and traffic police stations. Multiple linear regression models are developed by considering the surface defects as independent variables and the rate of accidents as dependent variable. It is found that the influence of Cracking, Raveling and Side drain is very less and are neglected. The models are developed for all the segments by considering Edge failure, Pot holes, Rutting and Roughness with rate of accidents and are found to be good fitting. The pavement condition index (PCI) and Pavement Condition Scores are determined for each segment. It is concluded that there is a greater detrition of the pavement with road surface defects. The PCS for segment 1 is reported as1.285 followed by 0.379 and 0.909 for segments 2 and 3. This clearly indicates that the surface defects in Segment 2 are more effective in the occurrence of various types of accidents as compared to other two segments.

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6 RECCOMENDATIONS

- The surface defects on pavement in the selected area are to be minimized by good management system
- The road authority should take care of the maintenance of pavements in a regular basis
- Immediate measures are essential for segment 2 in the selected area and needs an overlaying for the entire stretch

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