

**THREE-DIMENSIONAL MODELING OF DRIVER SPEED
BEHAVIOR ON HORIZONTAL CURVES FOR TWO-LANE
TWO-WAY RURAL ROADS**

By

Eng. Hatem Mahmoud Ahmed Abdel-Aty

**A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of The
Requirements for the Degree of
MASTER OF SCIENCE
In
CIVIL ENGINEERING - PUBLIC WORKS**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

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Title of Thesis:

Three-Dimensional Modeling of Driver Speed Behavior on Horizontal Curves for Two-Lane Two-Way Rural Roads.

Key Words:

Operating speed; Acceleration/Deceleration Rates; Horizontal curves; Vertical grades; Two-lane rural highway.

Summary:

This study presents three-dimensional and two-dimensional models developed to predict the 85th percentile operating speed and the 85th percentile deceleration/acceleration rates on horizontal curves for two-lane two-way rural highways. The operating speed was determined along the horizontal curves by using in-vehicle GPS equipment which allowed continuous collecting and processing of speed data. GPS second by second speed data helped to obtain more accurate continuous speed profiles which enabled getting accurate deceleration and acceleration rates measurements. This method enabled capturing driver speed behaviour along horizontal curves and determining accurately the minimum speeds on horizontal curves which were used as a key factor in determining the practical value for operating speed. Twenty six volunteers were chosen and asked to drive a GPS equipped passenger car on a two-lane rural highway near south of Cairo, Egypt. Twenty-four horizontal curves with different lengths, radii, and grades were tested. The geometric features such as radius and vertical grades were found to be the most significant explanatory variables to study the effect of 85th percentile operating speed and deceleration/acceleration rates on horizontal curves. These models will make an influential change in the considering design consistency for horizontal curve design when used in Egyptian guidelines.

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DEDICATION

To my parents who supported me during this work and still supports me during my life, without your loyal prayers, I cannot achieve anything in my life.

To my lovely sisters, lovely brothers, and the best friends Ahmed Abdelsadek, Karem Hassan, and Amr Ali Gamal.

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TABLE OF CONTENTS

ACKNOWLEDGMENT	i
DEDICATION	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
ABSTRACT	viii
CHAPTER ONE: INTRODUCTION	1
1.1. Background.....	1
1.2. Research Objectives.....	2
1.3. Thesis Outline.....	2
CHAPTER TWO: LITERATURE REVIEW	4
2.1. Road Alignments Features.....	4
2.1.1. Horizontal Alignment.....	5
2.1.1.1. Horizontal Curve Radius (R).....	6
2.1.1.2. Degree of Curvature (D).....	6
2.1.1.3. Curvature Change Rate (CCR).....	6
2.1.1.4. Deflection Angle (DF).....	7
2.1.1.5. Horizontal Curve Length (CL).....	7
2.1.1.6. Horizontal Tangent Length (L).....	7
2.1.1.7. Superelevation (e).....	7
2.1.1.8. Sight Distance (SD).....	8
2.1.2. Vertical Alignment.....	8
2.1.2.1. Rate of Vertical Curvature (K).....	8
2.1.2.2. Grade (G).....	9
2.1.3. Combination of Horizontal and Vertical Alignments.....	9
2.2. The Previous Predictor and Explanatory Variables.....	9
2.3. Previous Predicted Models.....	14
2.3.1. The Previous Variables.....	14
2.3.2. The Previous Developed Models.....	15
2.4. Summary.....	27
CHAPTER THREE: RESEARCH METHODOLOGY	28
3.1. Test Road Selection.....	29
3.2. Volunteer Selection.....	30
3.3. Data Collection Equipment.....	31
3.3.1. GPS Basic Concept.....	31
3.3.2. The Research Device.....	32
3.4. Data Preparation.....	34
3.4.1. Trimble Geomatics Office ^(R)	34
3.4.2. Excel Sheets for Calculating the Speed.....	38
3.4.3. AutoCAD Civil 3D.....	39

3.4.3.1. Curve Radius.....	39
3.4.3.2. Vertical Grade.....	45
CHAPTER FOUR: MODEL DEVELOPMENT.....	46
4.1. Regression Techniques.....	46
4.1.1. Types of Linear Regression.....	46
4.1.1.1. Simple Linear Regression Model.....	46
4.1.1.2. Multiple Linear Regression Model.....	47
4.1.2. Linear Regression Model Parameters.....	48
4.1.3. Important Assumptions for Regression Analysis Validity.....	48
4.1.3.1. Linearity.....	48
4.1.3.2. Normality.....	49
4.1.3.3. Homoscedasticity.....	50
4.1.3.4. Transformations.....	50
4.1.4. Tests for Model Validity.....	50
4.1.4.1. T – Test.....	50
4.1.4.2. F – Test.....	51
4.1.4.3. Coefficient of Determination (R^2).....	51
4.2. The Research Statistics Program.....	51
4.2.1. IBM SPSS Statistics.....	51
4.3. Operating Speed Model Development.....	52
4.3.1. Dependent Variables.....	52
4.3.2. Independent Variables.....	56
4.3.3. Two-Dimensional Model.....	58
4.3.4. Three-Dimensional Model.....	62
CHAPTER FIVE: DECELERATION AND ACCELERATION MODELS.....	69
5.1. Data Preparation.....	69
5.1.1. Horizontal Curves Features.....	69
5.1.2. Deceleration and Acceleration Rates.....	71
5.2. Data Analysis.....	77
5.2.1. Calculation of 85 th Percentiles.....	77
5.2.2. Explanatory Variables.....	78
5.3. Model Development.....	80
5.3.1. Two-Dimensional Model.....	80
5.3.1.1. Two-Dimensional Deceleration Model.....	80
5.3.1.2. Two-Dimensional Acceleration Model.....	85
5.3.2. Three-Dimensional Model.....	89
5.3.2.1. Three-Dimensional Deceleration Model.....	90
5.3.2.2. Three-Dimensional Acceleration Model.....	93
CHAPTER SIX: CONCLUSION.....	98
6.1. Summary.....	98
6.2. Finding of This Research.....	99
6.3. Recommendations.....	101
REFERENCES.....	102

LIST OF TABLES

Table 2.1: The Dependent and Independent Variables Due to Previous Research.....	14
Table 3.1: The Different Geometric Characteristics for Each Curve.....	30
Table 3.2: The Value of Radii Estimated From the Volunteers Paths.....	41
Table 3.3: The Average Value Used to Measure the Final Radius.....	43
Table 4.1: The Operating Speed Values for All Volunteers at Each Curve.....	53
Table 4.2: Descriptive Analysis for Minimum Operating Speed on Horizontal Curves.....	55
Table 4.3: Two-Dimensional Models Depending on Horizontal Curve Radius.....	58
Table 4.4: Two-Dimensional Models Depending on Horizontal Curve Radius and Horizontal Curve Length.....	59
Table 4.5: Three-Dimensional Models Depending on Horizontal Curve Radius and Vertical Grades.....	63
Table 5.1: The Horizontal Curves Geometric Features Used for Modeling.....	70
Table 5.2: The Deceleration Rates Values for All Volunteers at Each Curve.....	73
Table 5.3: The Acceleration Rates Values for All Volunteers at Each Curve.....	75
Table 5.4: Descriptive Analysis for Deceleration Rates on Horizontal Curves.....	77
Table 5.5: Descriptive Analysis for Acceleration Rates on Horizontal Curves.....	78
Table 5.6: Two-Dimensional Models for Predicting the 85 th Deceleration Rates (The Mean Variable is Horizontal Curve Radius).....	80
Table 5.7: Two-Dimensional Models Predicted for the 85 th Deceleration Rates. (The Mean Variable is Horizontal Curve Length).....	81
Table 5.8: Two-Dimensional Models for Predicting the 85 th Acceleration Rates. (The Mean Variable is Horizontal Curve Radius).....	85
Table 5.9: Two-Dimensional Model Depending on Horizontal Curve Length.....	86
Table 5.10: New Two-Dimensional Predicted Model for Acceleration Rates.....	87
Table 5.11: Three-Dimensional Models for Predicting the 85 th Deceleration Rates. (The Mean Variables are Horizontal Radius and Vertical Grade).....	90
Table 5.12: Three-Dimensional Models for Predicting the 85 th Acceleration Rates. (The Mean Variables are Horizontal Radius and Vertical Grade).....	93

LIST OF FIGURES

Figure 3.1: Image from Google Earth Shows the Test Road Form.....	29
Figure 3.2: The Distribution of the Driver's Ages.....	31
Figure 3.3: (a) The Antenna and (b) The Receiver for Trimble R3 GPS Equipment.....	33
Figure 3.4: (a) The Rover Station on the Passenger Car and (b) The Base Station at the Control Point.....	33
Figure 3.5: The Points Coordinates before the Processing Stage.....	34
Figure 3.6: The Baselines between Base and Rover Stations for a Section on the Test Road.....	35
Figure 3.7: The Timeline for the Satellites Signals for Base and Rover Antenna.....	36
Figure 3.8: Processed 3D Positions for All Points for One Volunteer Path.....	37
Figure 3.9: Summary for the Steps of Coordinates Processing Operation.....	37
Figure 3.10: Using Microsoft Excel ^(R) Sheets in Calculating the Speed for One Volunteer.....	38
Figure 3.11: Continuous Speed Profiles for All Volunteers Paths.....	39
Figure 3.12: Identification the Radius in AutoCAD Civil 3D ^(R) Program.....	44
Figure 3.13: The Relation between Radius and Speed.....	44
Figure 3.14: Estimation of Grades on Civil 3D ^(R) Program.....	45
Figure 3.15: Microsoft Excel ^(R) Sheet Showing the Grades Properties Estimated from AutoCAD Civil 3D ^(R) Program.....	45
Figure 4.1: Scatterplot Shows the Relation between the Speed and the Curve Radius.....	47
Figure 4.2: A Practical Example from the Thesis Shows the Linearity between the Residuals and Predicted Dependent Variable.....	49
Figure 4.3: The Normally Distribution of Variables Data.....	49
Figure 4.4: Practical Example from the Thesis Representing the Normally Distribution of Variables Data.....	50
Figure 4.5: Histogram Shows Normally Distribution for Speed Sample on One Curve.....	56
Figure 4.6: All Forms of Independent Variables Used in the Models from the IBM SPSS ^(R) Program.....	57
Figure 4.7: Scatterplot Shows the Linear Relation between the Speed and the Inverse Radius.....	60
Figure 4.8: The Normally Distribution of Variables Data in Two-Dimensional Model.....	60
Figure 4.9: The Normal Probability Plot Confirms Normally Distribution of Variables Data.....	61
Figure 4.10: The Relation between the Observed V_{85} and Curves Radii.....	61
Figure 4.11: Relation between Operating Speed and Radius Due to Two-Dimensional Model.....	62
Figure 4.12: Fitting between Actual Speed and Predicted Speed.....	62
Figure 4.13: The Normally Distribution of Variables Data in Three-Dimensional Upgrade Model.....	65
Figure 4.14: The Normal Probability Plot Confirms Normally Distribution of Variables Data.....	66
Figure 4.15: The Relation between Speed and Radius at Zero Grade Value.....	66
Figure 4.16: The Relation between Speed and Radius at Grade 2%.....	67

Figure 4.17: The Relation between Speed and Radius at Grade 4%.....	67
Figure 4.18: The Relation between Speed and Radius at Grade 6%.....	67
Figure 4.19: Relation between Operating Speed and Radius with Grades Due to Three-Dimensional Model.....	68
Figure 5.1: Speed Profile for All Drivers on Curve C21 (R=194.26m).....	70
Figure 5.2: Speed Profile for One Driver on Curve C21 (R=194.26m).....	72
Figure 5.3: The Explanatory Variables Used in the Models from the IBM SPSS ^(R) Program.....	79
Figure 5.4: Scatterplot Shows the Linear Relation between Model's Variables Due to Models 4 and 6 Respectively.....	82
Figure 5.5: The Normally Distribution of Variables Data in the Developed Models 4 and 6 Respectively.....	83
Figure 5.6: The Normal Probability Plot for Developed Models 4 and 6 Respectively.....	83
Figure 5.7: Fitting between Actual Deceleration and Predicted Deceleration Rates Due to the Final Developed Model.....	84
Figure 5.8: Fitting between Actual Deceleration and Predicted Deceleration Rates Due to Model No.6.....	84
Figure 5.9: Comparison between the Developed Two-Dimensional Models 4 and 6.....	85
Figure 5.10: Scatterplot Shows the Linear Relation between Model's Variables Due to Models 4 and 9 Respectively.....	87
Figure 5.11: The Normally Distribution of Variables Data in the Developed Models 4 and 9 Respectively.....	88
Figure 5.12: The Normal Probability Plot for Predicted Models 4 and 9 Respectively.....	88
Figure 5.13: Fitting between Actual Acceleration and Predicted Acceleration Rates Due to the Developed Model.....	89
Figure 5.14: Fitting between Actual Acceleration and Predicted Acceleration Rates Using Model No. 9.....	89
Figure 5.15: The Normally Distribution of Variables Data in the Developed Models 1 and 2 Respectively.....	92
Figure 5.16: The Normal Probability Plot for Three-Dimensional Models 1 and 2 Respectively.....	92
Figure 5.17: The Final Three-Dimensional Deceleration Downgrade Model.....	93
Figure 5.18: The Normally Distribution of Variables Data in the Final Developed Models for Upgrade and Downgrade Respectively.....	96
Figure 5.19: The Normal Probability Plot for the Final Developed Models for Upgrade and Downgrade Respectively.....	96
Figure 5.20: The Acceleration Rates Due to the Final Three-Dimensional Upgrade Model.....	97
Figure 5.21: The Acceleration Rates Due to the Final Three-Dimensional Downgrade Model.....	97

ABSTRACT

Highway design practice in many countries in North America and Europe is adopting the operating speed approach in design instead of the traditional design speed approach. Subsequently, over the past years considerable research was performed worldwide in this area to predict operating speed. Different approaches were used to measure the speeds and to model explanatory variables. Considerable research used spot speeds in predicting operating speeds, making the measurements subjected to bias or human error. This study presents three-dimensional and two-dimensional models developed to predict the 85th percentile operating speed and the 85th percentile deceleration/acceleration rates on horizontal curves for two-lane two-way rural highways. The operating speed was determined along the horizontal curves by using in-vehicle GPS equipment which allows continuous collecting and processing of speed data. GPS second by second speed data helped to obtain more accurate continuous speed profiles which enabled getting accurate deceleration and acceleration rates measurements. This method enabled capturing driver speed behaviour along horizontal curves and determining accurately the minimum speeds on horizontal curves which were used as a key factor in determining the practical value for operating speed. Twenty six volunteers were chosen and asked to drive a GPS equipped passenger car on a two-lane rural highway near south of Cairo, Egypt. Twenty-four horizontal curves with different lengths, radii, and grades were tested. The geometric features such as radius and vertical grades were found to be the most significant explanatory variables to study the effect of 85th percentile operating speed and deceleration/acceleration rates on horizontal curves. These models will make an influential change in the considering design consistency for horizontal curve design when used in Egyptian guidelines.

Key Words: Operating speed – Acceleration/Deceleration Rates – Horizontal curves – Vertical grades – Two-lane rural highway.

CHAPTER ONE: INTRODUCTION

1.1. Background

The American Association of State Highway and Transportation Officials (AASHTO 2001) defined the operating speed as “the speed at which drivers are observed operating their vehicles during free flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.” AASHTO (2001) considered the 85th percentile speed from speed distribution on the road under free flow conditions as the operating speed. The operating speed on two-lane two-way rural highways depends on several factors related to:

1. Environmental characteristics such as residential areas (exist on both sides of the road or not), lighting condition (daylight or dark), asphalt condition (dry or wet), heavy rain, and snow.
2. Vehicle characteristics such as vehicle type (passenger cars, buses, or heavy trucks), handling, and stopping.
3. The driver behavior such as speed selection, preset experience with the road, well prediction of the road.
4. Road characteristics such as traffic on road, radius, curvature change rate, vertical grades, horizontal curve length, tangent length, vertical curve length, lane width, superelevation, deflection angle, sight distance, etc.

In previous research, most of the models developed were based on spot-speed data using speed trap recording, video camera recording, laser gun, or stop watch. Spot speed data were collected at the beginning, midpoint, and end of curve, and at certain points on the approach and departure tangents to calculate the deceleration and acceleration rates. Recent research used the Global Position System GPS – VBOX equipment at specific locations (Memon et. al (2008). This enabled drawing speed profiles, and therefore finding exact points where drivers begin to change their speed behaviour to enter and exit the horizontal curves. However, most of the operating speed models developed from these profiles were two-dimensional, and therefore grades of the highways were not considered (Nie and Hassan 2007, Cafiso and Cerni 2012).

This thesis presents a procedure in collecting driver speed profiles in a naturalistic way through an in-vehicle GPS system. This procedure has two main advantages to overcome two drawbacks:

1. This procedure avoids any bias or human errors that may occur when spot speeds are collected. This is because usually the spot speeds are collected at the mid-tangent and curve, which is not necessarily the representative speed of the horizontal element. It is also subjective to the cosine errors induced by lidar or radar guns for example providing less accurate readings. It also avoids the change in driving speed behavior due to perception of the test equipment along the road side.
2. The second advantage is that this procedure enables capturing all driver speed behavior through a continuous speed profile. This enables capturing the exact

point and value of minimum speed on the horizontal curve to be represented in the model.

1.2. Research Objectives

The objective of this thesis is to find the relation between the highway geometric characteristics and driver speed behaviour. To do so, a field experiment was designed using a GPS instrumented vehicle. Twenty six volunteers were asked to drive the instrumented vehicle on a rural two-lane two-way rural road. The GPS equipment collected coordinate data at a time interval of 5 readings/ second. This enabled collecting speed behaviour of drivers on horizontal curves and finding the relation between them. The more specific objectives of this thesis are:

1. Developing continuous speed profiles along horizontal curves to find the driver speed behaviour at curve entrance, during the curve, and at the curve exit. This helps determine exact point of minimum speed and the deceleration and acceleration rates along the horizontal curve with different radii and vertical grades.
2. Develop models for predicting operating speeds on two-lane two-way rural highways. The models will depend on the relation between operating speeds and geometric features for horizontal alignments including curve radius and curve length and vertical characteristics including vertical grades.
3. Develop models for predicting the deceleration and acceleration rates on two-lane two-way rural highways when approaching and departing horizontal curves. The models will depend on the relation between the acceleration and deceleration and the different road geometric features.

The overall result of these models will be to provide a useful tool for road designers to consider highway design consistency in the initial phases of design.

1.3. Thesis Outline

Chapter one is an introduction to the thesis presenting the background on the topic of the research then describes the purposes of the research and its goals.

Chapter two is a comprehensive review of previous studies relating driver speed behavior to the road geometric features in several countries for different road types especially two-lane two-way rural highways. Most of the previous research measured the variation of speed at a specific point on the road and without developing speed profiles which enables determining the driver behavior accurately. Collecting different speed data with various methods are listed in this chapter. The road alignment' geometric features which are expected to affect the speed behavior are described. Previous research models for deceleration and acceleration rates are explained briefly.

Chapter three explains the efforts used in this experimental program to measure the speed. This chapter also explains the geometric characteristics of the selected test road and the specification of the volunteers. The GPS second by second equipment used in this research is explained in details. The programs used in processing GPS data, calculating the operating speeds, and estimating different road geometric features such as curve radius, curve length, and vertical grades are described.

Chapter four describes the different regression analysis techniques and the models developed to relate the 85th percentile operating speed on horizontal curves. All specifications of the two-dimensional and three-dimensional predicted models used to develop the 85th percentile operating speed on horizontal curves are explained.

Chapter five shows the developed models relating both the 85th percentile deceleration and acceleration rates when approaching or departing the horizontal curves to the geometric characteristics of the curve. A comparison is also made with previous research results.

Chapter six describes the conclusion reached by this research and the recommendation for the future research that can be applied.