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

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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.

Thank you.

Hatem Mahmoud

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 85^{th} percentile operating speed and the 85^{th} 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 85^{th} 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 85^{th} 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 85^{th} 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 85^{th} percentile operating speed on horizontal curves. All specifications of the two-dimensional and three-dimensional predicted models used to develop the 85^{th} percentile operating speed on horizontal curves are explained.

Chapter five shows the developed models relating both the 85^{th} 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.