Methodology to Identify Hazardous Locations for Highways in Puerto Rico

By

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ABSTRACT

The main purpose of this research was to establish a procedure for the identification of hazardous road sections with high incidence of fatalities. The fatal accident database of the Puerto Rico Traffic Safety Commission (TSC) was evaluated during the period of 1995 through 2003 with emphasis on those accidents associated with highways in the west region of Puerto Rico. The original database was filtered using descriptive statistical analysis. The Puerto Rico fatal database was compared with the United States Department of Transporatation (USDOT) Fatal Analysis Reporting System (FARS) and trends were established. Pareto Analysis Tecnique was then applied for the identification and selection of hazardous segments. This procedure allowed identifying the few vital problems and dividing them from the many trivial. A hazardous index was computed using the fatal crash rate, severity and frequency of fatalities for each road section. The methodology allowed identifying and discriminating segments from intersections. Field inspections were also performed for the calibration and validation of the analysis based on the standard procedures described on the Manual on Uniform Traffic Control Devices (MUTCD), the American Association of State Highway and Transportation Officials (AASHTO) Policy on Geometric Design of Highways and Streets, Roadside Design Guide (RDG), and the Puerto Rico Highway and Transportation Authority (PRHTA) Specifications, Standard Drawings and Design Directives. The Accident Modification Factors (AMF) and the Crash Reduction Factors (CRF) were used for the different countermeasures recommended.

Annual Average Daily Traffic (AADT) data from the PRHTA were used for taffic forecasting of all highway segments and years under study. Then, the Rate per Hundred Million Vehicles Miles (RMVM) was computed. The Pareto diagram technique using the variable RMVM allowed to identify the most hazardous road segments in the western region of the island. These were highway PR-2 from km. 154.8 to 155.3 at Mayagüez, PR-115 from km. 7.0

to 7.1 at Añasco, PR-459 from km. 4.0 to 4.1 at Aguadilla, PR-100 from km 9.0 to 9.3 at Cabo Rojo, and PR-2 from km. 172.0 to 172.1 at San Germán. The results showed that although human behavior is the major cause for fatal crashes, road segments with safety deficiencies higher incidence of fatalities. The PR-2 segments had in common the fatalities that occurred mostly on weekends at night and were related to driving over the speed limit. The segments located near universities have fatalities occurring mainly at night and are related to alcohol consumption and speed. The segments located near tourist areas have high incidence of fatalities although they were registered at different times during a given day.

The recommendations of this research study included improvements in the data recollection process, educational campaigns, law enforcement, installation of lighting systems, median barriers, pavement markings, raised pavement markers, guardrail upgrade, geometric and operation improvements in horizontal and vertical alignment, and prohibit motor vehicle parking on shoulders.

RESUMEN

El propósito principal de esta investigación fue establecer un procedimiento para la identificación de secciones de carretera peligrosas con alta incidencia de fatalidades. La base de datos de accidentes fatales de la Comisión para la Seguridad en el Tránsito fue evaluada durante el periodo de 1995 al 2003 con énfasis en los accidentes asociados con carreteras en la región oeste de Puerto Rico. La base de datos original fue filtrada mediante un proceso de análisis estadístico descriptivo. La base de datos fatales de Puerto Rico fue comparada con la base de datos de FARS (Fatal Analysis Reporting System) del Departamento de Transportación de Estados Unidos y se establecieron tendencias. La técnica de análisis de Pareto se aplicó posteriormente para la selección de los segmentos peligrosos. Este procedimiento permitió identificar los pocos problemas vitales y dividirlos de los muchos triviales. Un Índice de Peligrosidad fue calculado la razón de choques, severidad y frecuencia de fatalidades para cada sección de carretera. La metodología permitió identificar y diferenciar segmentos de intersecciones. Se realizaron inspecciones de campo para la calibración y validación del análisis basado en las normas y procedimientos descritos en el Manual de Dispositivos Uniformes para el Control del Tráfico (MUTCD, por sus siglas en inglés), la Política de Diseño Geométrico de Carreteras y Calles, las Guías de Diseño de Elementos de Seguridad Aledaños a la Carretera (RDG, por sus siglas en inglés), las especificaciones de la Autoridad de Carreteras y Transportación (ACT) de Puerto Rico, los Planos Modelos y las Directrices de Diseño. Los Factores de Modificación de Accidentes (AMF, por sus sigals en inglés) y los Factores de Reducción de Accidentes (CRF, por sus siglas en inglés) fueron utilizados para diferentes medidas correctivas recomendadas para los segmentos peligrosos identificados en este estudio.

Los datos del Promedio Anual de Tráfico Diario (AADT, por sus siglas en inglés) de la ACT fueron utilizados para pronosticar los valores de AADT correspondientes a los segmentos y

años bajo estudio. Luego, la Razón por Cien Millones de Vehículos Millas (RMVM, por sus siglas en inglés) fue calculada. La técnica del diagrama de Pareto utilizando la variable de RMVM permitió identificar los segmentos de carretera más peligrosos en la región oeste de la isla. Estos son la carretera PR-2 del km.154.8 al 155.3 en Mayagüez, la PR-115 del km. 7.0 al 7.1 en Añasco, la PR-459 del km. 4.0 al 4.1 en Aguadilla, la PR-100 del km 9.0 al 9.3 en Cabo Rojo, y la PR-2 del km. 172.0 al 172.1 en San Germán. Los resultados demuestran que aunque el comportamiento del usuario es la mayor causa de accidentes fatales, los segmentos de carretera con deficiencias de seguridad tienen mayor incidencia de fatalidades. Los segmentos en la PR-2 tienen en común que las fatalidades ocurrieron en su mayoría durante los fines de semana en la noche y están relacionados a conducir en exceso de velocidad. Los segmentos localizados cerca de universidades tienen fatalidades que ocurren principalmente durante la noche y están relacionadas al consumo de alcohol y a la velocidad. Los segmentos que se encuentran cerca de zonas turísticas tiene alta incidencia de fatalidades aunque se registraron a diversas horas del día.

Las recomendaciones de este trabajo de investigación incluyen mejoras en el proceso de recopilación de datos, campañas educativas, refuerzo en el cumplimiento de la ley, instalación de sistema de iluminación, barreras en la mediana, marcado de pavimento, marcadores con relieve sobre el pavimento, actualizar las barreras de seguridad, mejoras geométricas y de operaciones en la alineación horizontal y vertical, y prohibir el estacionamiento de vehículos de motor en los paseos.

Les dedico este trabajo a mis padres que siempre han estado a mi lado ayudándome, dándome todo lo que pueden y más, porque gracias a su amor y apoyo de siempre es que soy la persona que soy y que he llegado a donde estoy, logrando todas mis metas.

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TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS (CONT.)

PAGE

LIST OF TABLES

PAGE

LIST OF TABLES (CONT.) PAGE

LIST OF FIGURES

PAGE

LIST OF FIGURES (CONT.) **PAGE**

LIST OF ACRONYMS

AADT	:	Annual Average Daily Traffic
AASHTO	:	American Association of State Highway and Transportation Officials
ACAA	:	Administración para la Compensación por Accidentes Automovilísticos
AMF	:	Accident Modification Factor
BAC	:	Blood Alcohol Content
CRF	:	Crash Reduction Factor
DTPW	:	Department of Transportation and Public Works
EPDO	:	equivalent Property Damage Only
FARS	:	Fatal Analysis Reporting System
FI_f	:	Frequency Index
FHWA	:	Federal Highway Administration
HDM	:	Highway Design Manual
HI_f	:	Hazardous Index
HSIP	:	Highway Safety Improvement Program
ISTEA	:	Intermodal Surface Transportation Efficiency Act of 1991
ITS	:	Intelligent Transportation Systems
IV	:	Indicator Values
MUTCD	:	Manual on Uniform Traffic Control Devices
NCHRP	:	National Cooperative Highway Research Program
NHI	:	National Highway Institute
NHS	:	National Highway System
NHTSA	:	National Highway Traffic Safety Administration

LIST OF ACRONYMS (CONT.)

PDO	:	Property Damage Only
PR	:	Puerto Rico
PRHTA	:	Puerto Rico Highway and Transportation Authority
RDG	:	Roadside Design Guide
RI_f	:	Crash Rate Index
RMVM	:	Rate per 100 Million Vehicle Miles
RSA	:	Road Safety Audit
RSAR	:	Road Safety Audit Review
SAFETEA-LU	:	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SI_f	:	Severity Index
SPIS	:	Safety Priority Index System
TEA-21	:	Transportation Equity Act for the 21st Century
TRB	:	Transportation Research Board
TSC	:	Traffic Safety Commission
USA	:	United States of America
USDOT	:	United States Department of Transportation
UVC	:	Uniform Vehicle Code
VMT	:	Vehicle Miles Traveled

LIST OF APPENDIXES

1. Introduction

1.1. Problem Statement

Highway safety has become a priority in all aspects, and a real concern for all road users. Drivers, occupants, pedestrians as road users are continuously exposed to the probability of suffering an accident anytime. Most common accidents are motor vehicle crashes, vehicle-pedestrian crashes and run-off the road crashes with fixed objects [1]. In the last five years a new trend of motorcycle crashes is observed in our island highways [2]. In Puerto Rico, the high population density and motorization rate make this problem an every day fact.

According to the data obtained from the Puerto Rico Traffic Safety Commission (TSC), in the island, 44% of the population has a driver's license; there are 12 vehicles for each driver, and a vehicle for every 34 feet of road [3]. The socio-economical costs associated with crashes on our roads amounts to $300 millions each year [3]. The objective of Highway Safety is to reduce fatalities, injuries and economic losses related to traffic accidents.

The continuous construction and widening of roadways has provided Puerto Rico with a practical and efficient network of roads that has attracted a higher number of road users and has reduced the use of regional airports for trips from Mayagüez to San Juan or from Ponce to San Juan. As a result, the number of motor vehicles on our roads increases continuously, what also causes an increase in traffic accidents.

Motor vehicles constitute the principal mode of transportation, as well as traffic crashes are the main cause of deaths for people between 4 and 33 years of age, according to data from the Fatal Analysis Reporting System (FARS), census of fatal crashes in the 50 states, the District of Columbia and Puerto Rico. In comparison with the United States, Puerto Rico practically doubles the fatality rate per Vehicle Miles Traveled (VMT). During the study period of this research (1995 to 2003) about 250,000 crashes were registered, from which 50,000 were injuries and more than 500 were fatalities due to traffic accidents on our roads. Forty two percentage of the fatalities were drivers, passengers constituted a 20%, cyclists and motorcyclists added to 3%, and near 35% were pedestrians [1]. Since 2003, the amount decreased to 453 in 2005. This reduction contrasts with the remarkable increase in motorcyclists fatalities which in 2005 added to 20% of all fatalities [2].

Campaigns in favor of seatbelt use and against drinking and driving on our roads, as well as the allowed blood alcohol content (BAC) reduction to 0.08% and 0.02% for heavy vehicles drivers, and the increase on penalties according to Puerto Rico Vehicle and Traffic Law 22, effective since January 7, 2001, with amendments, are part of the efforts made by the government to reduce fatality numbers. However, negligent drivers and pedestrians are only one of the contributing factors of fatalities on the island road network. In many cases, the geometric design of the roadways and the combination of other factors, amongst them, traffic control and weather conditions, could also be a contributor. Moreover, throughout the island, there are roads that are commonly referred to as "death roads" because of the many dangers they present to the road users.

From 2003 to 2005 nearly 500 lives were lost due to traffic accidents on our roads. Although during recent years a significant reduction occurred, the total fatality numbers used to be 550 to 600 for more than 25 years, and in 2006 it reached more than 500 again [3]. About a third of motor vehicle deaths involve vehicles leaving the roadway and hitting fixed objects [1]. These kinds of crashes occur most commonly in rural roads, on curves, and/or downhill road sections.

Everyday on the news, kids, teenagers, or entire families die on our roads. Each death that occurs constitutes an unquantifiable loss.

There is a need to develop a research that studies existing data about traffic crashes in Puerto Rico related to road geometry and roadside features. It is imperative to continue working on improving the safety of our roads applying adequate countermeasures designed specifically to each particular site.

1.2. Objectives and Scope of the Research

The objectives of this research project are:

- To identify hazardous road sections in the western region of Puerto Rico.
- To analyze five actual sites after ranking the hazardous road sections identified in the western region of the island.
- To study and identify possible causes of crashes on road sections with higher incidence of fatalities.
- To identify and apply statistical models that will suit Puerto Rico's particular conditions and characteristics. The Pareto diagram will be applied to establish priority associated with traffic volume and frequency of fatalitites by identifying hazardous segments in the 80^{th} percentile.
- To provide recommendations for the application of geometric, operational, educational, and legislative strategies with the purpose of attenuating crashes on the sites of the study cases.

This research considers fatal accidents in the highway segments under the western region of Puerto Rico during the period of 1995 through 2003. Crash data was provided by the office of the TSC, from the PRHTA. Only data from fatal accidents in state roads was considered, other type of crashes, such as, property damage only or injury crashes, were excluded from this research. The western region was determined as the 18 municipalities included as part of the Western Region Office of the PRHTA.

1.3. Expected Benefits

The main benefits of this research include the characterization of fatal accidents in the west region of Puerto Rico, the development of a procedure to identify hazardous locations with high incidence of fatalities through the use of the Puerto Rico Traffic Safety Commission (TSC) data base, and to create awareness about the importance of an efficient data recollection process and the valuable information that can be obtained out of it. At the present, this database is used only for in-house statistical purposes and periodic press release at critical times of the year (Thanksgiving, Christmas, New Year's Eve, Holy Week and major holidays), but there is no procedure established by any agency that considers it in the process of planning, design and construction of new or maintenance projects. It is also expected that this research will contribute:

- To extend the knowledge to the *Administración para la Compensación por Accidentes Automovilísticos* (ACAA) and other agencies in Puerto Rico.
- To create general guidelines that will assist the Puerto Rico Highway and Transportation Authority (PRHTA), the Puerto Rico Department of Transportation and Public Works (PRDTPW) and the Puerto Rico Police in the decision-making process associated with crash evaluation and prevention.
- To be a starting point to establish a public policy associated with the analysis of historical highway crash data to improve the roadside safety on our roads.

1.4. Organization of Thesis

This thesis is organized in seven chapters and five appendixes. A literature review about fatal crashes and highway safety in the United States and Puerto Rico is included in Chapter 2. The literature review includes road geometry and human factors in highway safety, manuals and legislations associated with highway safety, and Puerto Rico's budget distribution for highway safety programs. Chapter 3 explains the methodology followed to develop the research, summarized through a flowchart. Databases used for the research were described in Chapter 4. This chapter also describes the Police report form for crashes, the management of the database for the research and possible sources of error are mentioned. Chapter 5 presents the data analysis process including the AADT computations, the Pareto Diagram analysis and the results obtained. Chapter 6 includes the conclusions, recommendations, countermeasures for specific segments studied during the research, and possible future research concerning fatal crashes in Puerto Rico. Chapter 7 provides the references consulted for the research. Appendixes include the Police crash report form, computation tables for AADT, Frequency graphics, Pareto Diagrams, AMF tables, and CRF tables.

2. Literature Review

2.1. Introduction

The literature review included searches in the internet, newspapers, manuals and guides related to road safety design, roadside features, Road Safety Audits, procedures for hazardous locations identification, and legislations applicable to Highway Safety: ISTEA, TEA-21, SAFETEA-LU. The literature review was focused on Puerto Rico's and USA's crash databases, statistical methods and procedures for the identification and analysis of hazardous locations, and previous publications from USA, Australia and Great Britain. Figure 2.1 shows a flowchart that explains the literature review process, which consists of five major areas.

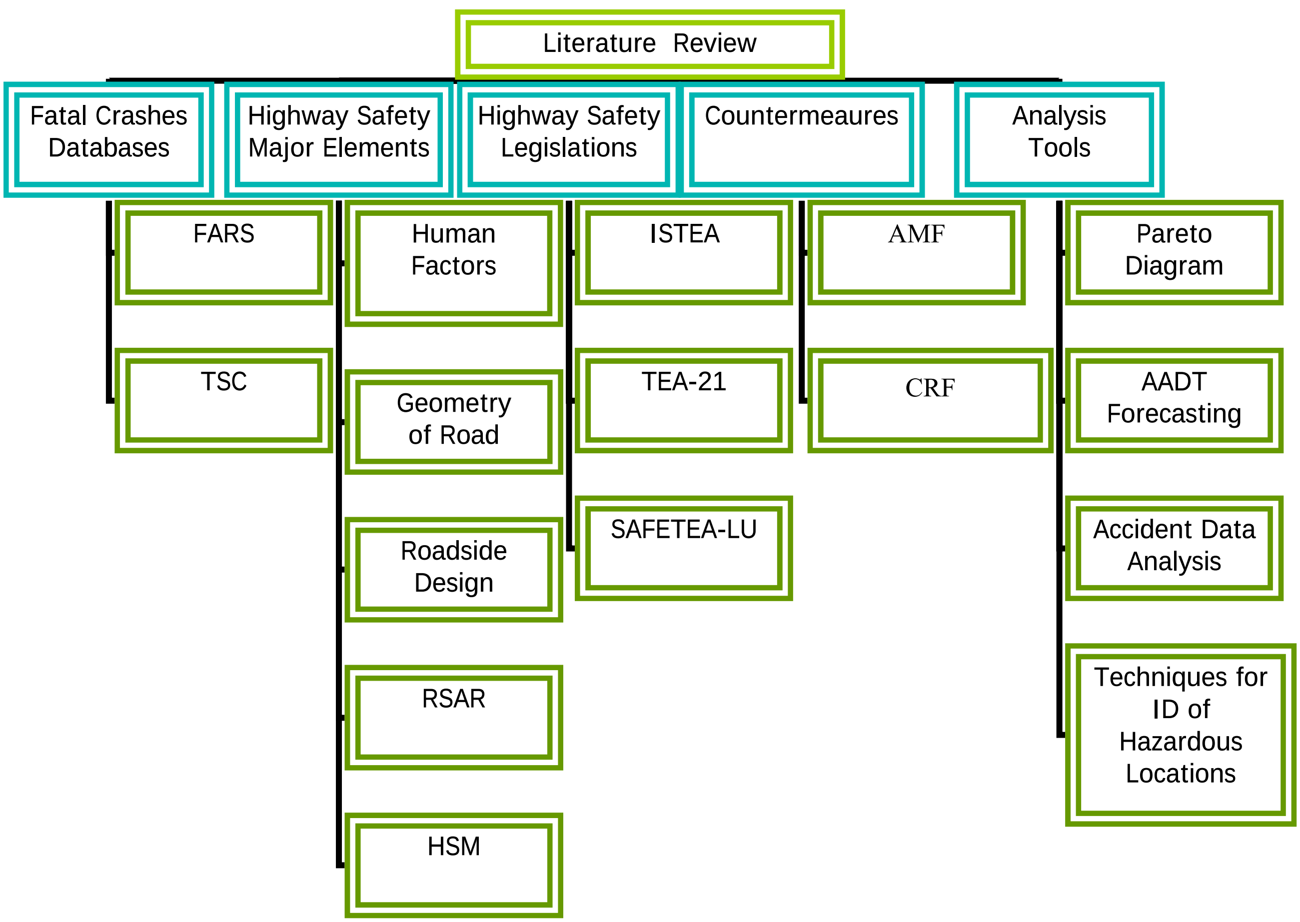

Figure 2.1: Literature Review Process

2.2. Fata Crashes Databases

2.2.1. Fatal Crashes in the United States

In the United States, according to FARS, the most common fatal crashes involves drivers, followed by passengers. Pedestrians, motor and non-motor cyclists are the smaller groups. Figure 2.2 shows the percentage distribution of fatalities per group type for the year 2003.

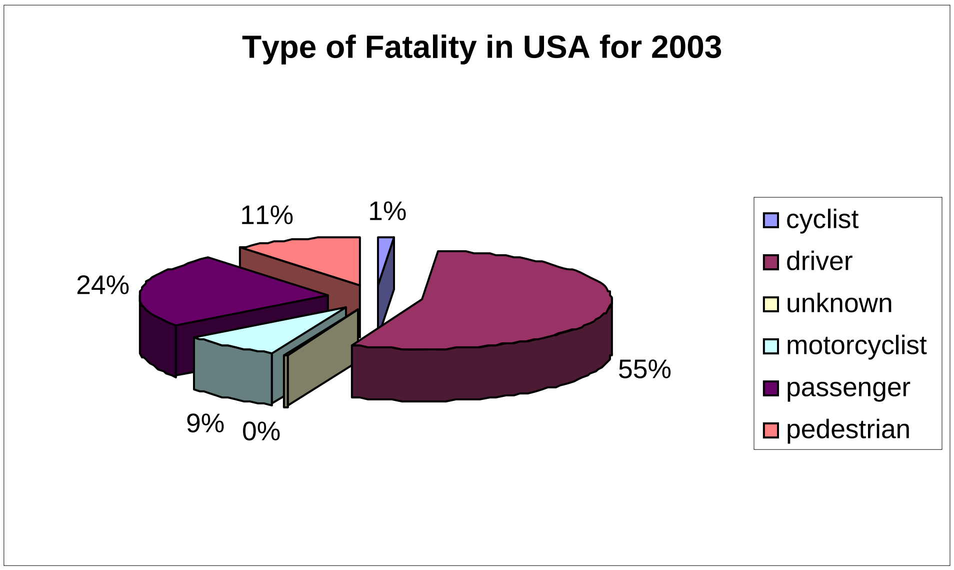

Figure 2.2: Percentage of fatalities per group in USA for 2003 [1]

2.2.2. Fatal Crashes in Puerto Rico

During the period of 1995 through 2003, drivers and pedestrian were the largest groups involved in fatal accidents, followed by passengers. Motorcyclists and cyclist represented the smaller groups with an average of 6% and 3%, respectively. While in the last three years fatalities have been starting to reduce, there is one group of road users that is increasing its fatality numbers, which are motorcyclists. This fact coincides with the recent major increase in the use of these vehicles. From 1997 to 2005 the fatalities associated with motorcyclis increased by 233% [4]. Average fatalities for user groups distribution are shown in Figure 2.3.

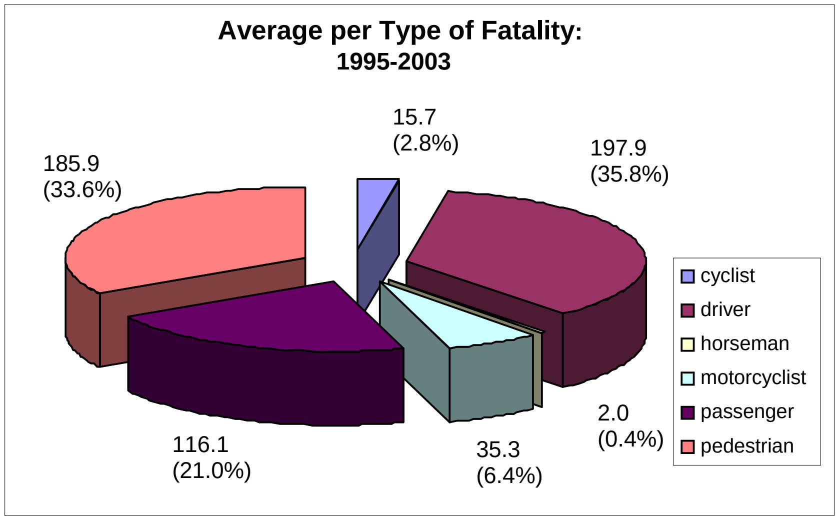

Figure 2.3: Average number of fatalities per group in PR, 1995-2003 [4]

2.3. Highway Safety Major Elements

2.3.1. Human Factors in Crashes

Human factor is the main cause of traffic crashes by 95%. Traffic Engineering discipline characterizes drivers by two principal factors: perception-reaction time and visual acuity [5]. The perception time is the time it takes a driver to detect, identify and decide as a response to a stimulus. The reaction time is the time it takes the driver to begin the physical response. The reaction time depends on three basic concepts: complexity of the task, event is expected or unexpected, and 85th-percentile. The AASHTO recommends a typical value of reaction time of 1.5 seconds taken from the 85-percentile due to the fact that median values are much lower. The following formula relates reaction distance, speed and perception-reaction time.

$$d_r = 1.468\ S\ t \tag{2.1}$$

Where:

d_r = reaction distance, feet
S = speed, mph
t = perception-reaction time, seconds
1.468 = conversion factor from mph to fps

Visual acuity considers two main areas: static acuity and dynamic visual acuity. The static acuity refers to the ability of reading letters at specific distances in order to assure that traffic signs can be seen and read. Other important vision factors are: dynamic acuity, depth perception, glare recovery, and peripheral vision. These characteristics deal with the standardization of colors, sizes and shapes of traffic signs. Although these are of great importance in driving, only static acuity is tested.

The following figure illustrates the fields of vision: clear or acute vision which discerns characters and legends, fairly clear vision which perceives shape and color but not legend, and peripheral vision detects motion.

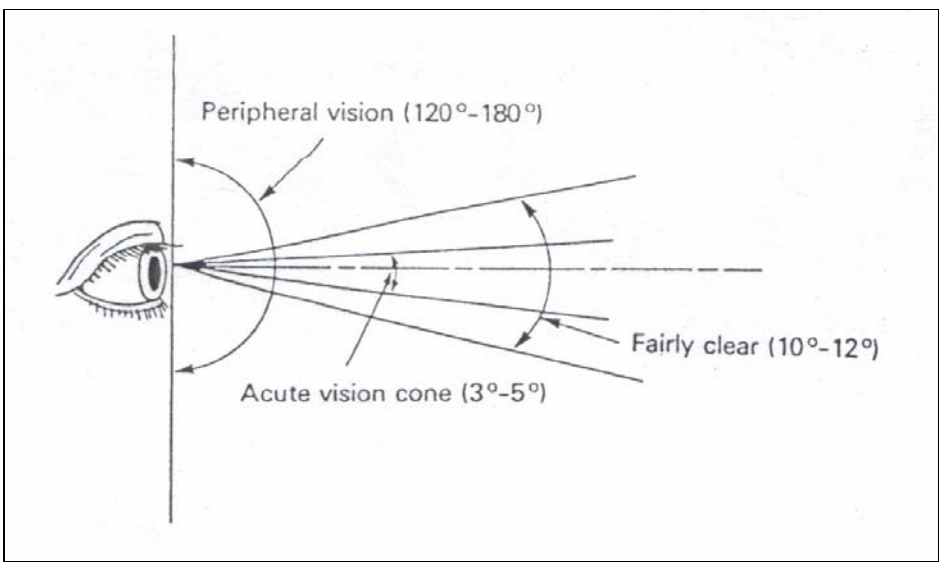

Figure 2.4: Drivers Field of Vision (Reproduced from Roess, McShane and Prassas)

There are many other factors that affect human performance while driving. Some of these are age, fatigue, consumption of alcohol and/or drugs. Also driving over the speed limit, and reckless behavior leading to forbidden maneuvers.

2.3.2. Geometry of Road as a Factor in Crashes

Major considerations in the geometric design of a road are: horizontal alignment, vertical alignment, water drainage, and cross section (lane width, shoulder, and median design) [5].

The horizontal alignment consists of a series of tangents and straight sections connected by curves. Its design is directly related to design speed, curvature, superelevation and side friction. Superelevation will diminish the tendency of the vehicle to go outward the center of the curve due to a centrifugal force. This centrifugal force is counterbalanced by the weight component of the vehicle which develops a side friction between the pavement and the tires [6,7].

The vertical alignment refers to the changes in the roadway profile elevation. Vertical curves are parabolic and result form the need to connect adjacent grades with transition curves. There are two types of vertical curves: crest curves and sag curves. Sight distance is a critical factor in the design of these curves. Crest curves go to a lower grade, and are limited by the line of sight over the hill. Sag curves go to a higher grade, and are limited by night visibility for which the headlight range is determinant. [6,7]

Water drainage is very important for the good maintenance of the pavement and to avoid a safety risk. Roads always provide slopes to allow water run to the side of the road to gutters and finally to catch basins and culverts [7]

Number of lanes and width besides providing for volume of vehicles and sometimes extra space in curves, are also intended to minimize confusion, and errors by drivers.

There are many other components to take into consideration in the road design. Some examples are: (1) traffic separation devices such as barriers, median barriers and traffic cushions, (2) traffic controls: signs, traffic signals, pavement markings, and (3) provision of pedestrian and bicycle facilities [5].

2.3.3. Roadside Safety Design

Roadside safety design which deals with the design of the area between the outside shoulder edge and the right-of-way limits, is one the most important aspects to evaluate and to implement [5]. This concept has two main purposes: to make every reasonable effort to keep the vehicles on the roadway, and that roadside should be reasonably forgiving to allow errant vehicles to recover, stop safely, return to the roadway, or reduce the severity of the crash. Roadside safety can be applied at any stage: planning, design, construction or maintenance.

The main concern in roadside safety is the presence of fixed objects, critical slopes, and non-traversable slopes. Some of the most commonly known fixed objects are trees, lighting posts, signs, drainage structures, traffic devices, truck-mounted attenuators, mailbox supports, fire hydrants, and emergency call box supports, among others. There are a few options to consider if a roadside feature represents a hazard to the safety for the users of the road. In order of preferences, these are: (1) remove the obstacle, (2) redesign, (3) relocation (4) reduce impact severity (5) shielding, and (6) delineation of the obstacle [8]. During the selection of roadside safety features, it is important to consider field experience, constraints of the site, constructability appearance, and the cost and difficulty of maintenance.

There has been three main time periods in Roadside Safety Programs: [8]

- Prior to 1936: efforts by individual offices; appeared the first Manual on Uniform Traffic Control Devices (MUTCD), first Uniform Vehicle Code (UVC), and development of programs for driving licensing and enforcement.
- 1936 to 1966: different legislations and design guides where developed
- 1966 to the present: every state had to develop a highway safety program, authorization on funding for these programs, safety standards were established, and creation of a management system.

The five missions documented in the literature for obtaining an improved roadside safety are: (1) Increase the awareness of roadside safety and support for it. (2) Build and maintain information resources and analysis procedures to support continued improvements in roadside safety. (3) Keep vehicles from leaving the roadway. (4) Keep vehicles from overturning or striking objects on the roadside when they do leave the roadway. (5) Minimize injuries and fatalities when overturns occur or objects are struck in the roadside [8].

2.3.3.1. Roadside Design Guide (RDG)

The Roadside Design Guide compiles current information and operating practices associated to roadside safety. The guide mainly provides information on roadside safety treatments to minimize crash severity. The RDG has six chapters. The main topics discussed are:

1. Methods for selecting the appropriate alternative roadside safety enhancements, including a cost benefit analysis for ranking of alternatives.
2. Clear roadside concept, clear zone values and related design guidance.
3. Treatment of roadside drainage features.
4. Sign and luminaries supports, breakaway and non-breakaway supports.
5. Miscellaneous roadside features such as: mailbox supports and utility poles.
6. Guardrails
7. Median barriers.
8. Crash tests

2.3.3.1.1. National Cooperative Highway Research Program (NCHRP) Report 350

There are many deficiencies that can be found on our roads that represent a hazard and attempt to the safety of the users. The Federal Highway Administration (FHWA) determined that all roadside safety hardware in the National Highway System (NHS) must meet the National Cooperative Highway Research Program (NCHRP) Report 350 criteria.

The NCHRP 350 brought many changes to the acceptance criteria for safety artifacts or installation arrangements. The NCHRP 350 criteria consider structural adequacy, occupant risk, and post impact vehicle response. Crash testing level of roadside features, such as barriers and end treatments is a critical factor due to the changes in the vehicle flow [8]. In adopting NCHRP 350, the FHWA is assuring through the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 that the trend of an increase in the vehicle fleet of sport and utility vehicles, vans and pickups is considered in the highway safety features design. The PRHTA has the policy that all design directives and the Standard Drawings shall meet the criteria of the NCHRP 350 and keep up to date with the changes.

According to the Federal Highway Administration (FHWA), the w-beam guardrail block-out used in guardrails does not meet the NCHRP 350 criteria. Most of the metal barriers in Puerto Rico, if not all of them, have this type of block-out. For that reason, since 1999, Design Directive Number 407 requires designers to use wood or rubber block-outs in new installations in the National Highway System (NHS) [9].

2.3.3.2.Manual on Uniform Traffic Control Devices (MUTCD)

The MUTCD defines and standardizes the installation of traffic control devices on all roadways [10]. The manual offers standards that shall be meet, guidance, and optional recommendations. The Manual has ten chapters, these are:

Part 1 : General

Part 2 : Signs

Part 3 : Markings

Part 4 : Highway Traffic Signals

Part 5 : Traffic Control devices for Low-Volume Roads

Part 6 : Temporary Traffic Control

Part 7 : Traffic Controls for School Areas

Part 8 : Traffic Controls for Highway-Rail Grade Crossings

Part 9 : Traffic Controls for Bicycle Facilities

Part 10 : Traffic Controls for Highway-Light Rail Transit Grade Crossings

2.3.4. Road Safety Audit Reviews (RSAR)

In order to identify treatments, first the hazards have to be identified, and it is done through Road Safety Audits (RSA). The National Highway Institute (NHI) defines a RSA as an examination of a future roadway by an independent, qualified team who then reports on potential safety issues [11]. Austroads has a wider definition: a RSA is a formal examination of a future road or traffic project or an existing road in which an independent, qualified team reports on the project's crash potential and safety performance [12]. The concept of RSA was developed in Great Britain in the 1980's, and has been an efficient and cost effective approach to transportation safety. The concept must be implemented not only on existing sites (RSAR), but on projects at their design and construction stages. RSA considers the safety of all road users, especially vulnerable ones, such as the visually and mobility impaired, cyclists, pedestrians, equestrians, motorcyclists, children and the elderly. Through these audits, the problem can be defined and the most fitting countermeasures applied. In our case, the Audit review will be applied. After the review has been done, the selection process begins to identify accident-prone locations, commonly known as black spots.

RSA and RSAR are conducted in the following manner [13]:

1. Select team
2. Provide relevant data and documentation.
3. Hold kick-off meeting.
4. Assess data and documents.
5. Inspect site

6. Discuss safety issues with designer or internal client
7. Write audit report.
8. Hold completion meeting.
9. Respond to the report.
10. Implement agreed-on-changes.
11. Share lessons learned.

Six checklists are documented in the literature that are applicable to different stages, namely, feasibility, preliminary design, detailed design, pre-opening, roadwork traffic scheme, and existing roads. This research project will study existing roads, for which Checklist 6: Existing Roads: Road Safety Audit, applies. This checklist has 14 major areas [12]:

1. Road alignment and cross section
2. Auxiliary lanes
3. Intersections
4. Signs and lighting
5. Markings and delineation
6. Crash barriers and clear zones
7. Traffic signals
8. Pedestrian and cyclists
9. Bridges and culverts
10. Pavement
11. Parking
12. Provision of heavy vehicles

13. Floodways and causeways

14. Miscellaneous

Checklists are only a tool and should be consider a guide of features to evaluate, but each site is unique and will present particular configurations or situations that should also be considered in the audit.

RSA's provide significant benefits at a low cost and can be generally produced in two days. It should take one day to conduct the audit and another day to write the report. Among the RSA benefits are [11]:

- Provide safety beyond established standards.
- Identify additional improvements that can be incorporated into the projects.
- Create consistency among all projects.
- Encourage personnel to think about safety in the course of their normal activities, throughout all stages of a project.
- Invite interdisciplinary input.
- Enhance the quality of field reviews.
- Become learning experiences for the audit team members.
- Provide feedback to highway designers that they can apply to other projects as appropriate. That feedback also helps to confirm decisions taken and work through outstanding issues.
- Ensure quality is maintained throughout a project's lifecycle.

2.3.5. Highway Safety Manual (HSM)

According to the Transportation Research Board, one reason for a lack of safety emphasis in decision-making within the profession is the absence of a single authoritative document to use for estimating safety impacts [14]. The main purpose of the HSM is to make safety consequences a priority for roadway planning, design, operations, and maintenance decisions. The manual will include: (1) synthesis of validated highway research, (2) procedures that are adapted and integrated to practice, and (3) analytical tools for predicting impact on road safety. The HSM is divided in five major parts listed below, and a Glossary of Terms.

Part I. Introduction and Fundamentals

1. Introduction and Overview
2. Fundamentals

Part II. Knowledge

3. Roadway Segments
4. Intersections
5. Interchanges
6. Special Facilities and Geometric Situations
7. Road Networks

Part III. Predictive Methods

8. Rural, Two-Lane Roads
9. Rural, Multi-lane Highways
10. Urban and Suburban Arterial Highways

Part IV. Safety Management of a Roadway System Purpose Background

11. Roadway Safety Network Screening

12. Diagnosis of the Nature of Safety Concerns at Specific Sites

13. Selection of Countermeasures

14. Economic Appraisal

15. Priorization

Part V. Safety Evaluation

16. Overview of estimating the Safety Effect of Implemented Interventions

Glossary of Terms

2.4. Highway Safety Legislations

2.4.1. Intermodal Surface Transportation Efficiency Act (ISTEA)

The ISTEA was approved in 1991 and requires that all agencies take under consideration social issues in their planning processes. It also requires public participation in the decision-making process about the community transportation needs.

ISTEA emphasized on intermodalism, higher occupancies and transit use. The legislation was urban oriented and made a great effort in the intelligent transportation systems implementation. ISTEA required states to have a statewide transportation planning process. It also recognized the incorporation of the interstate system into the National Highway System (NHS).

The Act gave the states flexibility in the funds distribution allowing the shifting of funds to Surface Transportation Program highway or transit projects. Funds came from the Highway Trust Fund through 1999. During the ISTEA legislation validity, funds for highway programs increased by 63% and for transit by 91% .

2.4.2. Transportation Equity Act for the 21st Century (TEA-21)

The TEA-21 was made law in 1998. The TEA-21 Restoration Act provides technical corrections for the original Act. TEA-21 had four specific objectives [15]:

1. Rebuilding America: $198 billion for investments in highways , transit, intermodal projects, and technologies

2. Improving safety: goal to increase set-belt use and reduce drunk-driving through the adoption of 0.08 blood alcohol concentration standards. Also improvements in truck safety, pipeline safety, and making roads, and rail-highway grade crossings safer.

3. Protecting the environment: addresses issues such as congestion mitigation, air quality improvement, development of clean and fuel efficient trucks, encouragement of transit rideship, and programs for bicycle and pedestrian paths, recreational trails, and roadside planting, among others.

4. Creating opportunity: programs for moving from welfare to work, effective Disadvantage Business Enterprise program, and labor protections fro transportation workers.

2.4.3. Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)

In 2005, President George W. Bush signed into law the SAFETEA-LU. The SAFETEA-LU represents the largest in history in the USA for highways, highway safety and public transportation. It addresses the main problems the transportation system has: improving safety, reducing traffic congestion, improving efficiency in freight movement, increasing intermodal connectivity, protecting the environment, and preparing the way for future challenges [16]. This program establishes a new HSIP, an equity Bonus program that ensures a minimum of 90.5% of contributions return to the Highway Trust Fund by each state. This percent is from gas and other highway taxes and the minimum will increase to 92% by the year 2008. SAFETEA-LU also brings innovative finance programs to attract private investors. The traffic congestion is managed by each State through road pricing and real-time management. The interregional and international freight transportation is addressed through planning, financing, and infrastructure improvements. Also, a pilot program named LIFE is conducted for the development of longer-lasting highways applying new technologies to accelerate construction without reducing efficiency. SAFETEA-LU increases funds for environmental programs of TEA-21 and adds new ones while restructuring all the environmental requirements.

Puerto Rico receives funds through the SAFETEA-LU. The TSC recommended budget for the fiscal year 2007 is $17,604,000, from which $15,800,000 come from Federal Funds and $1,804,000 from the Administration of Compensations for Vehicle Crashes. Figureb 2.5 presents the TSC's budget distribution [17].

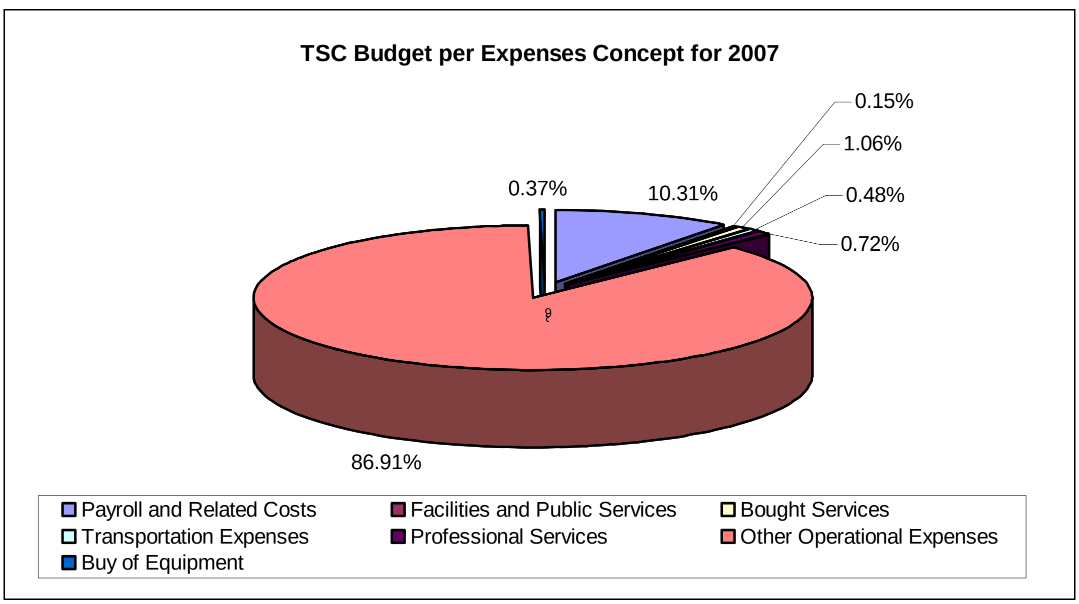

Figure 2.5: Budget Distribution of the Puerto Rico Traffic Safety Commission in Percentage for 2007

Most of the Federal Funds come from the SAFETEA-LU. In order to qualify for these incentives Puerto Rico must meet the following requirements: to have a mandatory law for the use of seatbelts and protection car seats, and to have a law that makes illegal to drive a vehicle having a blood alcohol content (BAC) of 0.08 or more. Also, there are the 402 recurrent funds which are approved by the Federal Congress. These are distributed among the proposals received from government agencies, townships, universities, and non-lucrative entities for the development of traffic safety programs, educative campaigns, engineering improvements, enforcement of traffic law, and improvement in the response time of the medical emergency system.

2.5. Crash Reduction Factors (CRF) and Accident Modification Factors (AMF)

2.5.1. Crash Reduction Factor (CRF)

CRFs are used by many states to estimate the safety impacts of different improvements. These factors consider if the area is rural or urban, and are subdivided in the following types of countermeasures: Barrier, Channelization, Geometric improvements, Markings, signs, and delineation, Median, Roadside, Roadway cross section, Signing, Unsignalized intersection, and Vertical alignment. The CRFs are computed by making before and after comparisons. Also, cross sectional comparisons are applied.

CRFs are a tool usually applied for short term project programming, but have the disadvantage of being based on limited data [18]. CRFs have four major weaknesses:

- Inconsistency from state to state.
- Not developed for many ITS improvements or other operational strategies.
- Designed for individual improvements.

- Impacts of improvements are usually exaggerated.

Appendix D shows CRF tables [19].

2.5.2. Accident Modification Factors (AMF)

AMF represent the safety impact of particular geometric design and traffic control features in the accident prediction algorithm. AMF nominal or base value for each feature is 1.0. Values greater than 1 are related to features with higher accident experience than the base condition. Similarly, values less than 1 are related to features with lower accident experience.

AMF were developed for roadway sections and for at-grade intersections by two expert committees [20]. Committees developed the AMF based on before and after accident evaluations, parameters from regression models, expert judgment, and sensitivity analysis.

AMF are organized as follows:

1. Roadway Segments
    - Lane width
    - Shoulder width
    - Shoulder type
    - Horizontal curves: length, radius, presence or absence of spiral transitions, superelevation
    - Grades
    - Driveway density
    - Two-way left-turn lanes
    - Passing lanes / short four-lane sections

- Roadside design

2. At-grade Intersections

- Skew angle
- Traffic control
- Exclusive left-turn lanes
- Exclusive right-turn lanes
- Intersection sight distance

Each feature mentioned before is computed through a graphic that considers the Average Daily Traffic (ADT) Volume and then the value is adjusted to total accidents with a formula. Some AMFs tables may be found in Appendix E [21].

2.6. Highway Safety and Accident Associated Countermeasures

Diverse treatments for safety deficiencies have been developed by government agencies. There are standards and guides to be followed at the planning, design, and construction stages. Usually, there is more than one solution for a particular problem. Engineering judgment is the key element in choosing the best solution or the best combination of alternatives. The decision is based on economic feasibility, and constructability.

Examples of possible roadside improvements are [8]:

- Installation of shoulder rumble strips to alert drivers
- Remove or shield trees or utility poles located close to the roadway
- Public service announcements and citizen initiatives to increase awareness
- Improvement of safety management systems

- Implement proactive highway maintenance programs
- Improvement of driver education programs
- Increase of speed enforcement at locations with known roadside safety problems
- Promote development of innovative technologies to keep vehicles on the road
- Improve the proficiency of persons responsible of roadside safety
- Improve vehicle design to increase compatibility with roadside hardware
- Improve hardware design

On Table 2.1, countermeasures for different types of crashes are provided [5].

Table 2.1: Summary of Accident Countermeasures (Reproduced from Roess, McShane and Prassas)

Accident Pattern	Probable Cause[1]	Possible Countermeasures[2]
Left-turn head-on	A	1-11
	B	3, 6, 12-15
	C	16, 17
	D	3
	E	15
Rear-end at unsignalized intersection	A	4, 13, 18
	E	15
	F	14
	G	15, 19-22
	H	23
	I	10, 24
	J	25
Rear-end at signalized intersection	A	3, 4, 13, 18
	G	15, 19-22
	H	23
	J	25, 26
	K	12, 14, 15, 27-32
	L	16, 17, 33
	M	34
Right angle at signalized intersection	B	6, 12, 14, 15 35, 36
	E	15, 16, 37
	H	23
	K	14, 27-32, 38
	L	11, 16, 17, 33, 39, 40
	N	14
	O	2, 11
Right angle at unsignalized intersection	B	6, 10, 12, 14, 15 24, 35, 36, 41, 42
	E	15, 16, 37
	H	23
	N	14
	O	10, 43
	P	44, 45
Pedestrian-vehicle	B	12, 25, 35, 46
	E	14, 15, 45, 47
	H	23
	I	10, 25, 26
	L	11
	P	26
	Q	47, 48
	R	49
	S	14, 15, 47, 50
	T	51-53
Wet pavement	G	15, 19-22
	T	53
Ran off roadway	E	15
	G	15, 19-22
	H	23
	K	54
	U	55-58
	V	14, 53, 59
	W	60
	X	6
	Y	61
Fixed object	E	15
	G	20, 22, 55, 62
	H	23
	T	53
	U	14, 63
	Z	58, 64-67
	AA	68
Parked or parking vehicle	E	15
	T	69
	BB	35
	CC	70
	DD	45, 50, 71
	EE	1, 43
Sideswipe or head-on	E	15, 72, 73
	T	53
	U	1, 55
	W	60
	X	6, 13, 74
	Y	61
	FF	38, 75
Driveway-related	A	13, 18, 35, 55 72, 76
	B	12, 15, 23, 35
	E	15
	H	23
	GG	77-81
	HH	43, 79, 82
	H	6, 10, 74
Train-vehicle	B	12, 14, 24, 83-85
	E	15
	G	62
	K	23, 54
	T	36, 42, 53
	JJ	11
	KK	86
	LL	87
	MM	88
Night	K	14, 23, 59
	V	14, 59, 89
	X	14, 53, 59, 89
	FF	44, 90

Table 2.1: Summary of Accident Countermeasures (continued)

[1]Key to probable causes:

A	Large turn volume	U	Inadequate roadway design for traffic conditions
B	Restricted sight distance	V	Inadequate delineation
C	Amber phase too short	W	Inadequate shoulder
D	Absence of left-turn phase	X	Inadequate channnelization
E	Excessive speed	Y	Inadequate pavement maintenance
F	Driver unaware of intersection	Z	Fixed object in or too close to roadway
G	Slippery surface	AA	Inadequate TCDs and guardrail
H	Inadequate road lighting	BB	Inadequate parking clearance at driveway
I	Lack of adequate gaps	CC	Angle parking
J	Crossing pedestrian	DD	Ilegal parking
K	Poor traffic control device (TCD) visibility	EE	Large parking turnover
L	Inadequate signal timing	FF	Inadequate signing
M	Unwarranted signal	GG	Improperly located driveway
N	Inadequate advance intersection warning signs	HH	Large through traffic volume
O	Large total intersection volume	II	Large driveway traffic volume
P	Inadequate TCDs	JJ	Improper traffic signal preemption timing
Q	Inadequate pedestrian protection	KK	Improper signal or gate warning time
R	School crossing area	LL	Rough crossing surface
S	Drivers have inadequate warning of frequent midblock crossings	MM	Sharp crossing angle
T	Inadequate or improper pavement markings		

[2]Key to possible countermeasures:

1	Create one-way street	46	Reroute pedestrian path
2	Add lane	47	Install pedestrian barrier
3	Provide left-turn signal phase	48	Install pedestrian refuge island
4	Prohibit turn	49	Use crossing guard at school crossing area
5	Reroute left-turn traffic	50	Prohibit parking
6	Provide adequate channelization	51	Install thermoplastic markings
7	Install stop sign	52	Provide signs to supplement markings
8	Revise signal phase sequence	53	Improve or install pavement markings
9	Provide turning guidelines for multiple left-turn lanes	54	Increase sign size
10	Provide traffic signal	55	Widen lane
11	Retime signal	56	Relocate island
12	Remove sight obstruction	57	Close curb lane
13	Provide turn lane	58	Install guardrail
14	Install or improve warning sign	59	Improve or install delineation
15	Reduce speed limit	60	Upgrade roadway shoulder
16	Adjust amber phase	61	Repair road surface
17	Provide all-red phase	62	Improve skid resistance
18	Increase curb radii	63	Provide proper superelevation
19	Overlay pavement	64	Remove fixed object
20	Provide adequate drainage	65	Install barrier curb
21	Groove pavement	66	Install breakaway posts
22	Provide "slippery when wet" sign	67	Install crsh cushioning device
23	Improve roadway lighting	68	Paint or install reflectors on obstruction
24	Provide stop sign	69	Mark parking stall limits
25	Install or improve pedestrian crosswalk TCDs	70	Convert angle to parallel parking
26	Provide pedestrian signal	71	Create off-street parking
27	Install overhead signal	72	Install median barrier
28	Install 12-inch signal lenses	73	Remove constriction such as parked vehicle
29	Install signal visors	74	Install acceleration or deceleration lane
30	Install signal back plates	75	Install advance guide sign
31	Relocate signal	76	Increase driveway width
32	Add signal heads	77	Regulate minimum driveway spacing
33	Provide progression through a set of signalized intersections	78	Regulate minimum corner clearance
34	Remove signal	79	Move driveway to side street
35	Restrict parking near corner/crosswalk/driveway	80	Install curb to define driveway location
36	Provide markings to supplement signs	81	Consolidate adjacent driveways
37	Install rumble strips	82	Construct a local service road
38	Install illuminated street name sign	83	Reduce grade
39	Install multidial signal controller	84	Install train-actuated signal
40	Install signal actuation	85	Install automatic flashers or flashers with gates
41	Install yield sign	86	Retime automatic flashers or flashers with gates
42	Install limit lines	87	Improve crossing surface
43	Reroute through traffic	88	Rebuild crossing with proper angle
44	Upgrade TCDs	89	Provide raised markings
45	Increase enforcement	90	Provide illuminated sign

Source: FHWA 1981.
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2.7. Analysis Tools

2.7.1. Pareto Analysis

The Pareto Diagram is a graphical technique that allows the user to discriminate important problems from those that are trivial, in order to establish priorities. In other words, through this principle relevant problems associated with a particular variable are identified [22].

The origin of the Pareto is attributed to Dr. Joseph Juran in honor to Vilfredo Pareto, an Italian economist who conducted a study on the wealth distribution in society. Pareto concluded that the minority of the population had most of the wealth whereas the majority had the smallest part. The study also concluded that economy inequality is inevitable in any society [23]. Dr. Juran made many applications of this concept leading to the 80/20 rule. This rule establishes that 20% of the causes solve 80% of the problems and 80% of the causes solve only 20% of the problems. Usually, one major cause will be associated with 80% of the problems; in other cases 2 or 3 elements will cause that 80%.

Pareto Diagram organizes various data classifications by descending order. Data elements are arranged from left to right in bars. The vital minority which is typically 20% of the elements appear at the left side of the graphic. (See example in Figure 2.6.)

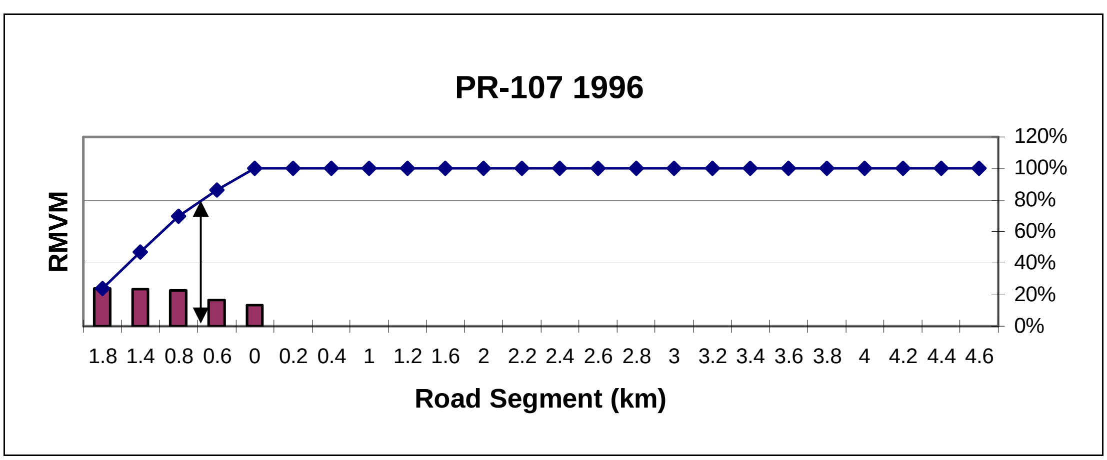


Figure 2.6: Pareto diagram for PR-107, km 0.0 to 4.6, Mun.icipality of Aguadilla, 1996.

Pareto diagrams have been applied in other transportation areas. For example, for identification of deficiencies in subsystems during the maintenance process of aircraft [24], and for the identification of the fastest and safest routes of a determined area during an earthquake [25].

2.7.2. Forecasting of Average Annual Daily Traffic (AADT)

Average Annual Daily Traffic, AADT, is the average 24-hour traffic volume at a given location over a full 365-day year. AADT is a useful indicator of demand. In Puerto Rico, the Department of Transportation and Public Works collects AADT data. Unfortunately, it is not available for every highway segment in the island and it is not necessarily colleted on a yearly basis. Transportation and Public Works agencies collect AADT for planning purposes and it doesn't necessarily fit the needs for research studies of this nature.

AADT growth is influenced by many factors such as changes in land use, economy, population, and fuel price. When AADT data is unavailable for particular highway segments there are several methods to obtain an approximate value. Growth rate, formula using single compounding, lineal and multiple regression techniques are usually applied to historical AADT to estimate current AADT on a particular segment. The growth rate method is most commonly used on highway safety applications.

2.7.3. Analysis of Accident Data

Analysis of Accident data is important and necessary for three main reasons: (1) to identify accident patterns, (2) to determine probable causes, and (3) to develop countermeasures. There are accident rates that can be computed to facilitate the comparison of results. Important parameters for these calculations are: traffic volume and length of road section. The most common used rates are Rate per Million of Entering Vehicles (RMEV), commonly used for intersection data, and Rate per 100 Million Vehicle Miles (RMVM), applied to roadway sections with similar traffic and geometric characteristics. These are presented in equations 2.2 and 2.3.

$$RMEV = \frac{A \times 1{,}000{,}000}{V} \qquad (2.2)$$

Where:

RMEV = accident rate per million entering vehicles
A = number of accidents by type occurring in 1 year at the location
V= average daily traffic (ADT) * 365

$$RMVM = \frac{A \times 100{,}000{,}000}{VMT} \qquad (2.3)$$

Where:

RMVM = rate per 100 million vehicle miles
A = number of total accidents by type at the study location, during a given period
VMT = total vehicle miles of travel during the given period
= ADT x (number of days in study period) x (length of road)

There are five main elements for summarizing accident data [26]:

- Type of accident: rear-end, right-angle, left-turn, fixed object, sideswipes, pedestrian-related, run off road, head-on, parked vehicle, and/or bicycle-related.
- Severity: fatality, personal injury, or property damage only. Scale: 12, 3, and 1, respectively. This scale may be adjusted based on engineering judgment depending on the particular behavior of a site.
- Contributing circumstances: human factors, environmental factors, and vehicle-related factors. This information can be obtained from the accident report.
- Environmental conditions: Lighting condition and roadway surface condition.
- Time periods: hour, day and month.

2.7.4. Techniques for the Identification of Hazardous Road Segments

A hazardous location is defined as a site where the accident frequency is higher than the expected value for other similar locations and conditions, computed based on the same exposure data. This finding must be confirmed by a statistical test. Traffic accidents are random and rare events, what makes it impossible to identify hazardous locations based only on the number of accidents.

The basis for determining accident patterns is frequency. Because frequencies differ from site to site, it is difficult to assign discrete values that can be used to identify the patterns. For that matter, it is very important to use exposure data, such as traffic volumes, to define these patterns. Accident patterns are commonly determined by two techniques: Expected Value Analysis and Cluster Analysis.

If the number of a particular type of collision at the study site is higher than the expected value for the control locations, that type of crash is overrepresented at the study site for that confidence level. Cluster Analysis concentrates on the identification of a particular characteristic of the crash based on the data taken from the accident site.

$$EV = x \pm ZS \tag{2.4}$$

Where:

EV = expected range of accident frequency
X = average number of accidents per location
S = estimated standard deviation of accident frequencies
Z = number of Standard deviations corresponding to the required confidence level

The Highway Safety Improvement Program (HSIP) consists of the planning, implementation, and evaluation of safety programs and projects. Each component is subdivided in processes. The process this research project will focus on is Process 2 of the

Planning Component: Identify Hazardous Locations and Elements. This process comprehends seven procedures. The first five are merely based on accident data, the sixth is based both on accident data and physical roadway information, and the last one is based solely on physical roadway information. These procedures are [27]:

1. Frequency Method: used to identify and rank locations based on number of accidents.

2. Accident Rate Method: considers both accident frequency and volume of traffic.

3. Frequency Rate Method: computes accident rates and ranks hazardous locations.

4. Rate Quality Control Method: statistically determines if the accident rate of a given location is significantly higher than the average rate for similar locations. Based on the assumption that Poisson distribution fits occurrence of crashes.

5. Accident Severity Method: used by some states for the identification and priority ranking of hazardous locations.

6. Hazard Index Method: allows the development of a rating index for each site that is likely to be identified as a hazardous location.

7. Hazardous Roadway Features Inventory Method: helps in choosing sites that are potentially hazardous locations. Mainly based on the comparison of existing roadway features with safety and design standards.

One of the most common techniques is the Critical Accident Rate Factor Method. The Critical Rate Factor is calculated by applying the standard deviation and then this rate is divided by the statewide average crash rate. Locations with a CRF of 1.0 or higher and with a minimum of 8 crashes in a 3 year period are considered High Crash Locations [26].

$$CR = AVR + 0.5 / TB + TF\ (AVR / TB)^{1/2} \qquad (2.5)$$

Where:
CR = critical accident rate, per 100 million vehicle-miles or per million entering vehicles
AVR = average accident rate for the facility type (PDO equivalent)
TF = test factor, Standard deviation at a given confidence level (S in EV equation)

TB = traffic base, 100 million vehicle-miles or million entering vehicles

$$= \frac{\text{Years} * \text{AADT} * \text{segment length} * 365 \text{ days per year}}{100 \text{ million}}$$

$$\text{Segment accident history} = \frac{\text{PDO equivalent}}{\text{TB}} \tag{2.6}$$

$$\text{Accident ratio} = \frac{\text{segment accident history}}{\text{statewide accident history (=CR)}} \tag{2.7}$$

Other methods used for the identification of high collision locations are [28]:

- Identified on an annual basis
- Use of collision frequency, collision rate or a combination of the two for identifying hazardous locations.
- Use of hazard index based on collision frequency/rate and sometimes severity.
- Combined ranking index seems to implicitly recognize the problems in using collision frequency or rate alone.
- Statistical basis.
- Empirical Bayes technique and a technique that lists locations with an accident frequency higher than the Poisson distributed mean for that class of road. The Empirical Bayesian technique is based on an average number of crashes, while the Poisson Regression concentrates on identifying one characteristic of the crash based on data taken from the crash site.
- Hazard index calculated dividing number of fatal and injury collisions by total number of collisions. Used to rank hazardous sites identified by a combination of collision rate and frequency.
- Comparing 5-year moving average accident rate to the 5-year moving average for all highway sections in the province for the same highway class.

2.7.4.1. Iowa

The Department of Transportation of Iowa has a crash location system represented by nodes and links [29]. Elements identified as nodes are: intersections, ramp terminals railroad crossings, grade separation structures, bridges, road ends, county lines, turn at 90 degrees if each leg is at least 0.25 mi, and major signalized commercial entrances. The distances between nodes are identified as links. High crash locations are ranked annually from 1 to 100 based on 5-year crash data. To enter in the analysis process, the location must fulfill at least one of three requirements: 1 fatal crash, 4 injury crashes or 8 total crashes. Locations with this characteristic undergo further analysis they are ranked by crash frequency, crash rate and crash financial loss according to the type of crashes. These rankings are added, and the lowest value will receive the first place in the final ranking.

2.7.4.2. Ohio

The Ohio Department of Transportation uses the Ohio Enhanced Crash Location Identification System (OECLIS) software for the identification of hazardous locations [30]. Intersections with 14 crashes and segments with 20 crashes are considered initially for the analysis. Three years of crash data, signal, volume and road inventory files are analyzed to calculate: crash frequency, crash density, crash rate, delta-change, equivalent property damage only (EPDO), EPDO rate, and relative severity index (RSI) for each specific type of crash. The hazard index method is used to determine the ranking of freeway ad non-freeway locations separately. A Priority Hazard Index is computed based on assigned weights for the categories. Finally, the locations are ranked by the Priority Hazard Index and the highest 5% are identified.

2.7.4.3. Oregon

The Oregon Department of Transportation developed a Safety Priority Index System (SPIS) for the evaluation of state highway segments with high crash history [31]. The SPIS considers crash frequency, crash rate and crash severity. The study period is three years and highway sections are 0.10 mi long. Locations having at least three crashes or at least 1 fatal crash are chosen for the SPIS analysis. The three analyzed variables are given different weights, named Indicator Values (IV), in the SPIS: 255 for crash frequency , 25% for crash rate and 50% for crash severity.

2.8. Summary

This chapter presents an overview of the principal elements to consider for the identification and evaluation of hazardous locations. A brief description of human factors and geometry elements relevant to the occurrence and severity of crashes is provided. Also, the existent highway safety related legislations and the budget distribution for road safety programs in Puerto Rico are described. Finally, highway safety manuals, crash analysis methods and countermeasures are summarized. The next chapter will described the methodology used through the research process.

3. Methodology

3.1. Introduction

The following chapter will briefly describe the procedure followed for the development of this thesis. First, a literature review was performed to study the existing procedures applied by different agencies in the United States, Australia, and the United Kingdom for the identification of hazardous locations. Then, the CST database was obtained, filtered and statically analyzed for characterization of fatal crashes and the preliminary selection of hazardous locations. Field inspections were performed for the validation of preliminary results and final selection of hazardous locations.

3.2. Methodology Description

3.2.1. Segment Definition

In this research study, segment is defined as a discreet 0.2 km element that can be continuous through a highway and can cross traditional segments or intersections as used in traffic engineering. The word element will be used interchangeably with the word segment. In same manner, due to variations in the literature, the words accident and crash will be used interchangeably also. Figure 3.1 shows a schematic representation division of a road segment in elements.

3.2.2. Methodology Flowchart

Figure 3.2 shows a flowchart to summarize the development of the research project.

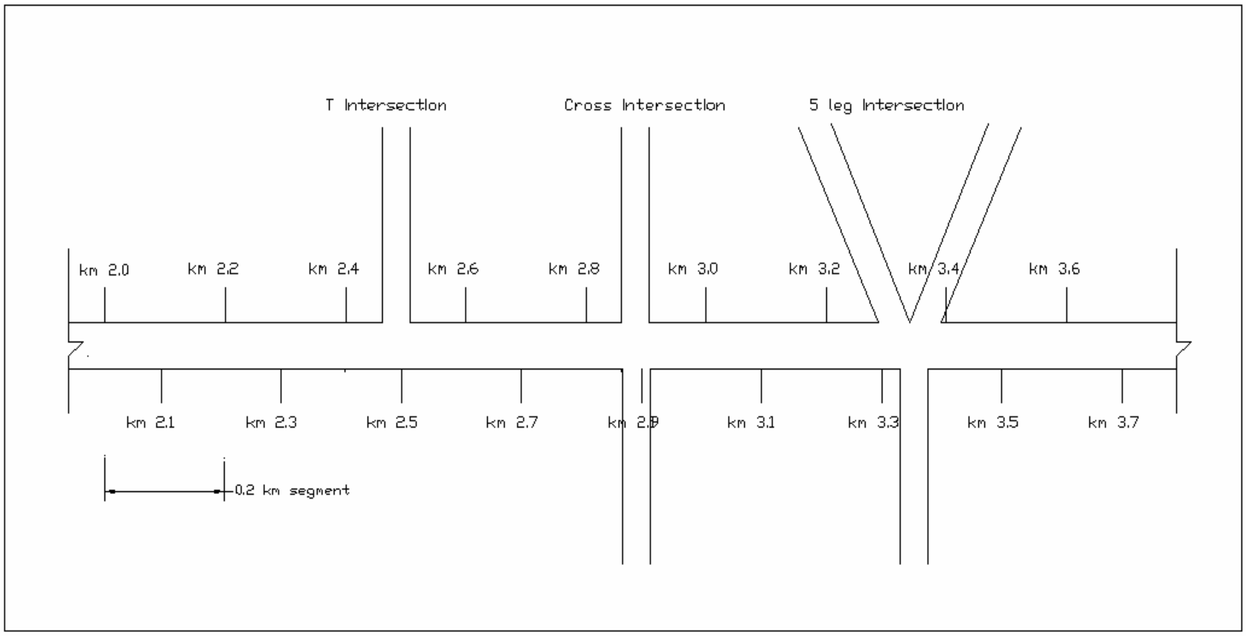


Figure 3.1: Conceptual Sketch of road section subdivision in 0.2 km elements.

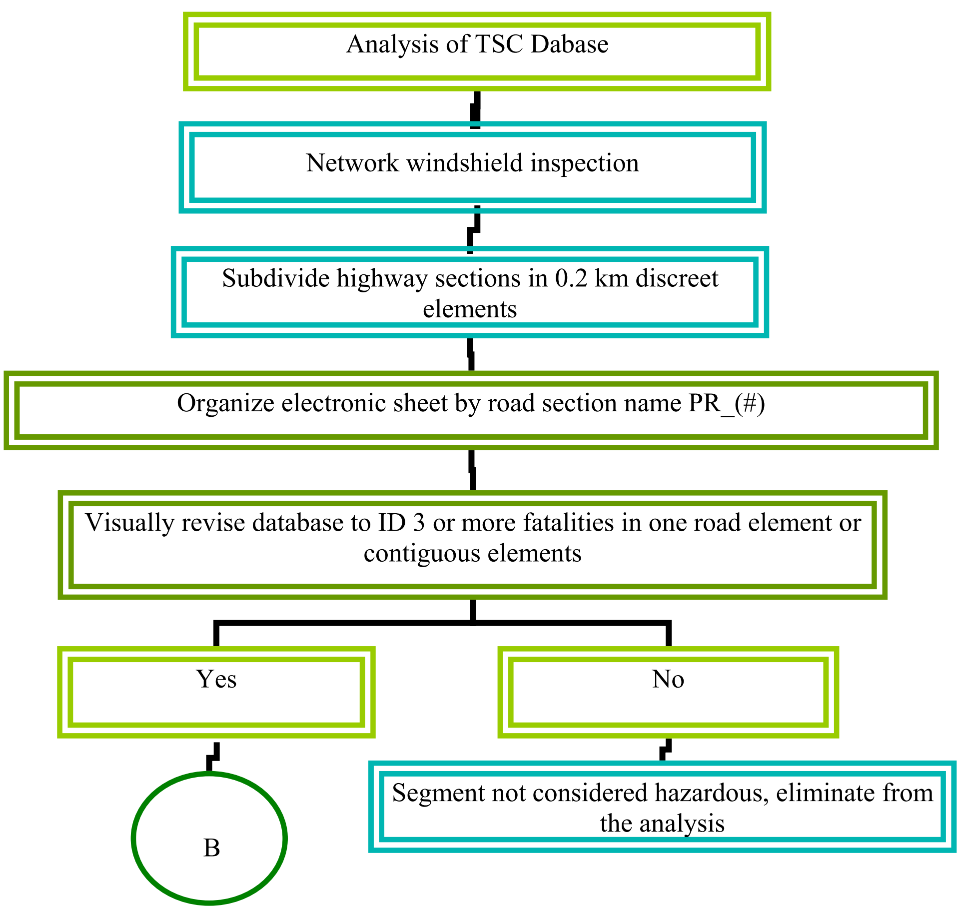


Figure 3.2 a: Research Flowchart

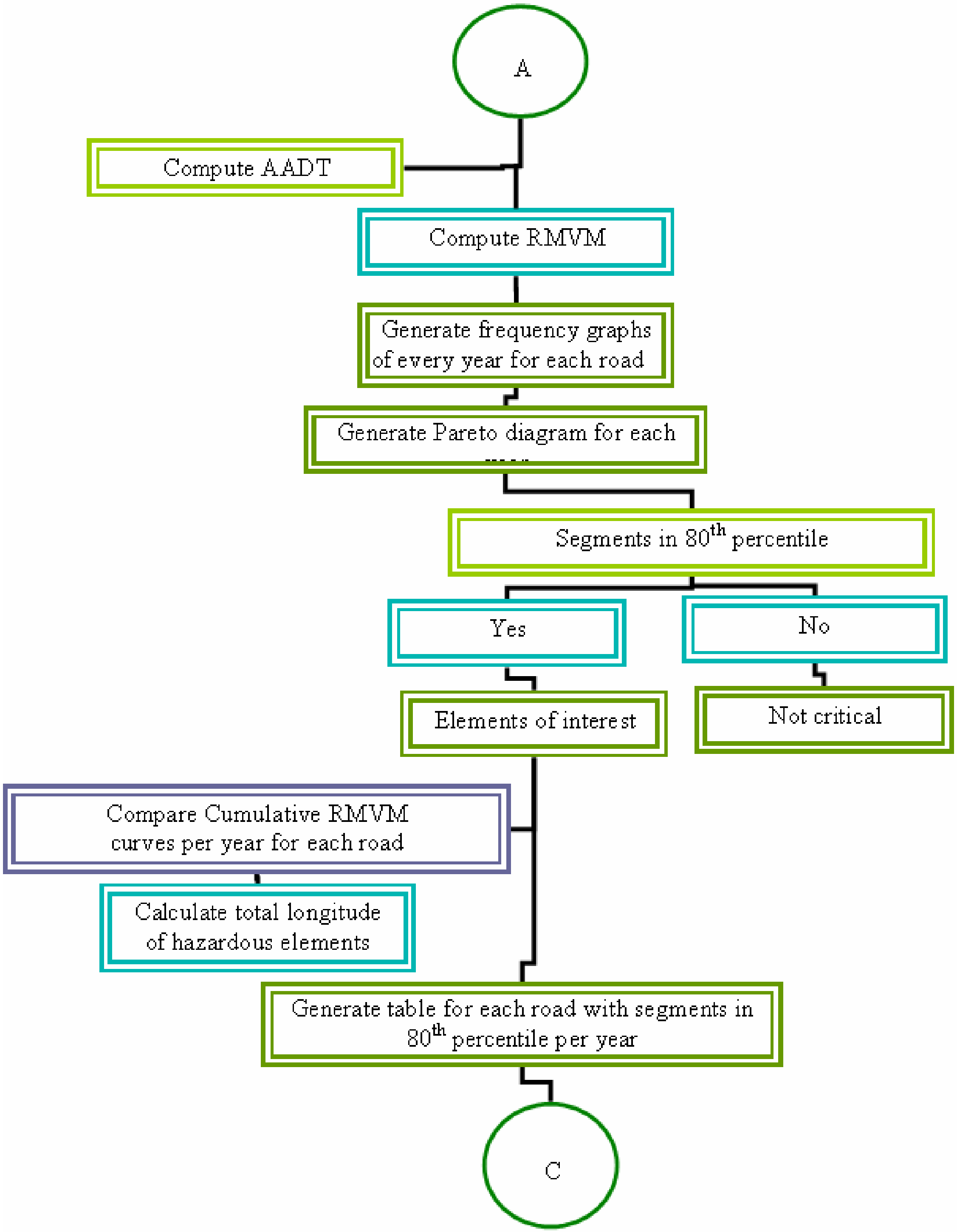


Figure 3.2 b: Research Methodology

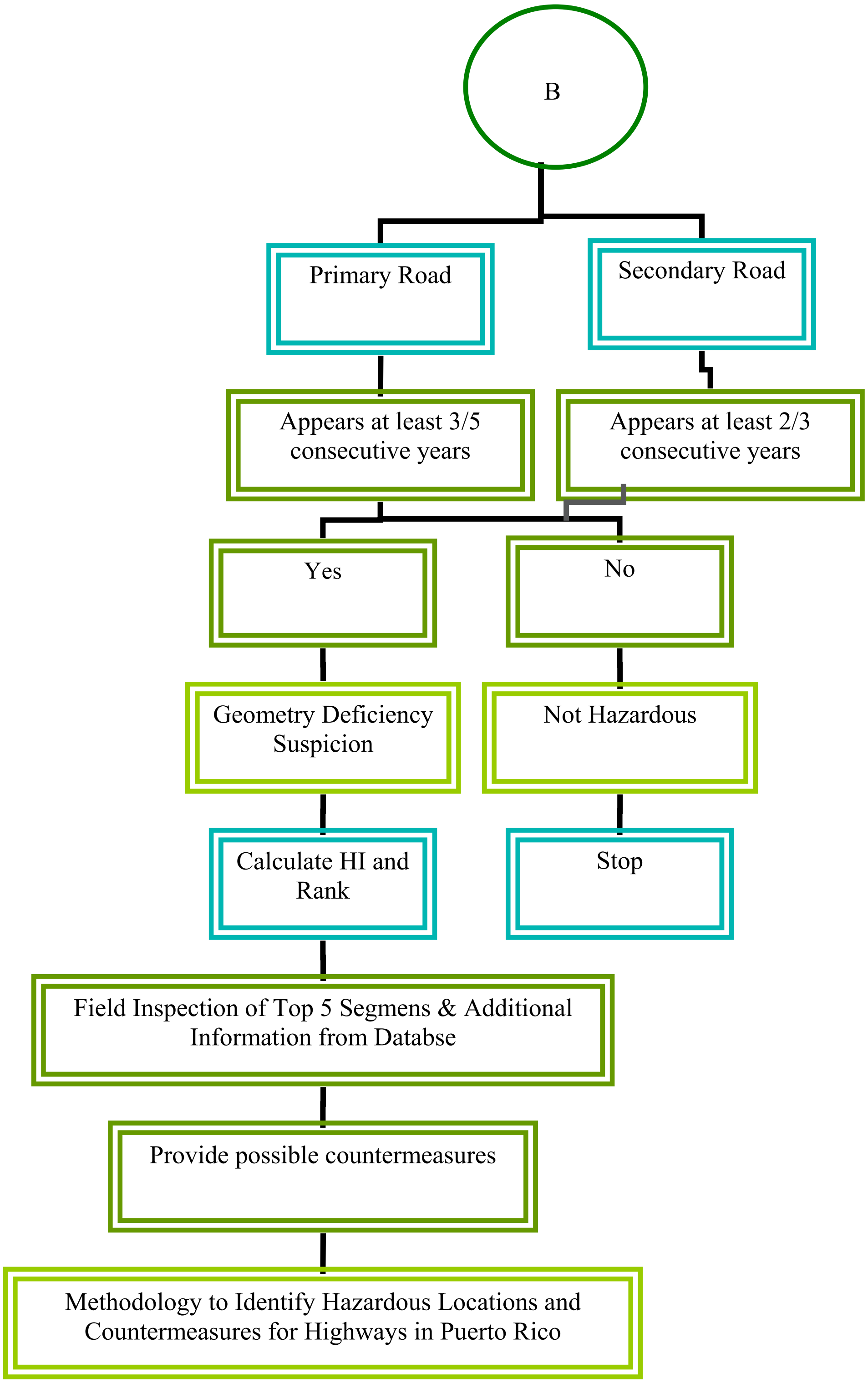


Figure 3.2 c: Research Methodology

3.2.3. Literature Review

The literature review was the first step in the development of the research. This included searches in the Internet, newspapers, safety related manuals, previous publications on the subject, and procedures applied and/or developed by other agencies. The literature review includes: review of databases of both external and internal sources, and historical data.

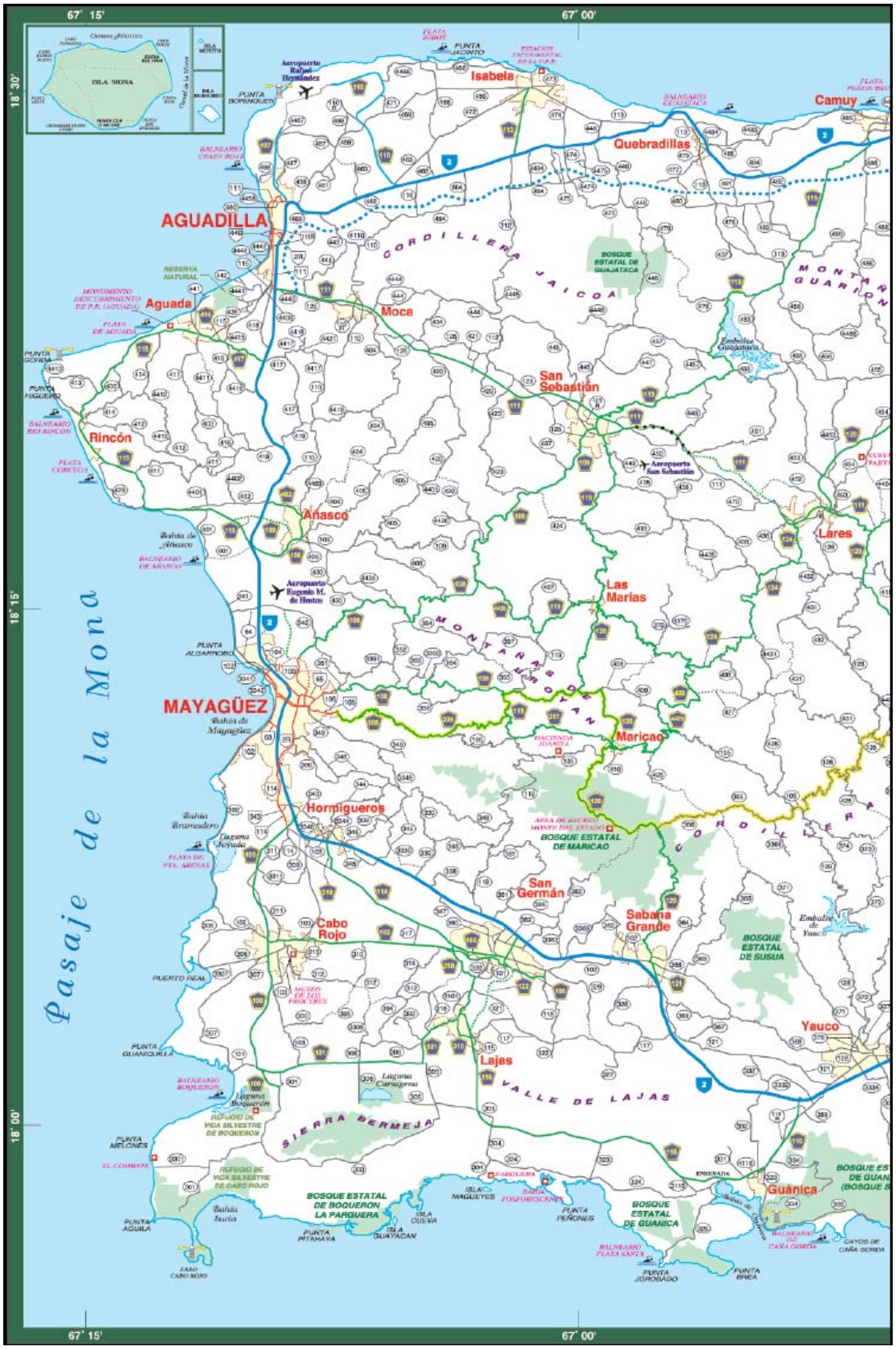
3.2.4. Gathering of Data Bases

At the beginning of the research process, both databases from *FARS* and the *Traffic Safety Commission* were obtained and analyzed for the characterization of fatal accidents in Puerto Rico and comparison with the United States. For the scope of the research itself, only the *TSC* database was used. Data that were not clear, possibly erroneous, were eliminated. Locations were mostly given by number of road and kilometer, but intersections of two roads had to be converted to this format, assigning the datum on the main road from the two intersecting ones. Queries were developed for the filtering and grouping of data. A more detailed description of the database is included in the next chapter.

3.2.5. Descriptive Statistical Analysis

The TSC database was initially analyzed for the characterization of fatal crashes in Puerto Rico and in the West Region of Puerto Rico, separately. Microsoft Access and Excel programs were used for this task.

Western Region was defined based on the eighteen municipalities pertaining to the PRHTA. These are: Aguada, Aguadilla, Añasco, Cabo Rojo, Guánica, Hormigueros, Isabela, Lajas, Las Marías, Maricao, Mayagüez, Moca, Quebradillas, Rincón, Sabana Grande, San Germán, San Sebastián, and Yauco. A map of the region is shown in Figure 3.3.



Main Highways	Start Km	End Km	Main Highways	Start Km	End Km	Main Highways	Start Km	End Km
PR-100	0.0	14.6	PR-109	0.0	29.0	PR-116	0.0	26.6
PR-101	0.0	19.4	PR-111	0.0	33.0	PR-402	0.0	9.0
PR-102	0.0	41.0	PR-114	0.0	15.0	PR-417	0.0	8.7
PR-107	0.0	4.6	PR-115	0.0	28.0	PR-2	96.0	200.8

Figure 3.3: Area of Study: Western Region of Puerto Rico

Trends for municipality, type of person (driver, passenger, pedestrian, motorcyclist, bicyclist), and period of time (month, day of the week, hour) were determined from the database. These were done for each year of the database from 1995 to 2003, and the average of these. Trends were established for these segments of road too.

3.2.6. Initial Screening of Hazardous Locations

The initial selection of hazardous highway segments was made based on probabilities and descriptive statistics. Eight road segments were chosen for further study and analysis. The road segments were divided in 0.2 km segments according to the km post markers located on the roadside. The 0.2 km division also has the benefit that allows the user to discriminate segments from intersections. The analysis period for this study was nine years (1995-2003). Out of the 119 roads, 45 of them had only one fatality for the nine-year period, and 28 roads had only two fatalities in the nine-year period of time. Thirteen roads having three or more fatalities occurred in the same or adjacent segments were identified. These were: PR-2, PR-100, PR-107, PR-109, PR-111, PR-114, PR-115, PR-116, PR-121, PR-413, PR-444, PR-459, and PR-485. Once frequency tables for specifying fatality frequency for each year for the segments were done, roads having segments with at least three years of fatality occurrence remained in the analysis: these were PR-2, PR-100, PR-107, PR-109, PR-111, PR-115, PR-116, and PR-459.

3.2.6.1. Pareto Analysis

The Pareto analysis technique was applied using as a variable the Fatality Rate per Hundred Million Vehicle Miles Traveled. This variable was used to identify the few vital hazardous segments from the many trivial. This variable was chosen because it considers the fatality occurrence of a given segment relatively to its traffic volume. A

Pareto diagram was made for each year and for each road. The few vital segments for every road were determined using the 80th percentile. Repetitive segments in each road during the nine-year period were then analyzed computing a hazardous index which was then ranked to establish the most hazardous segments of the network.

3.2.6.2.AADT Forecasting

AADT data for the primary highway network from the PRHTA was obtained. Due to the fact that PRHTA collects the data primarily for planning purposes, it is not collected routinely on a yearly basis nor is taken in a consistent distance interval. This research data is analyzed by sections for which AADT values were obtained from the PRTHA. They were assigned each year to every 0.2 km segment. If AADT were not available for a particular site, they were calculated or approximated values using growth rates, and/or weighted averages of the length and AADT prior and after to a particular 0.2 km site. Computation criteria were established to maintain the uniformity in the calculations. A flowchart for AADT forescasting in shown in Figure 3.3.

The first step was to compute the growth rate for each 0.2 km segment between any PRHTA data for the segment. This step results in one or more growth rates for that particular segment. Equation 3.1 shows the formula used in this process.

$$E_{t+n} = E_t \times (1+g)^n \tag{3.1}$$

where:
E_t = base year AADT value observed during t year
g = annual AADT growth rate
n = number of years between the first and the last AADT data value
E_{t+n} = forecasted year AADT value

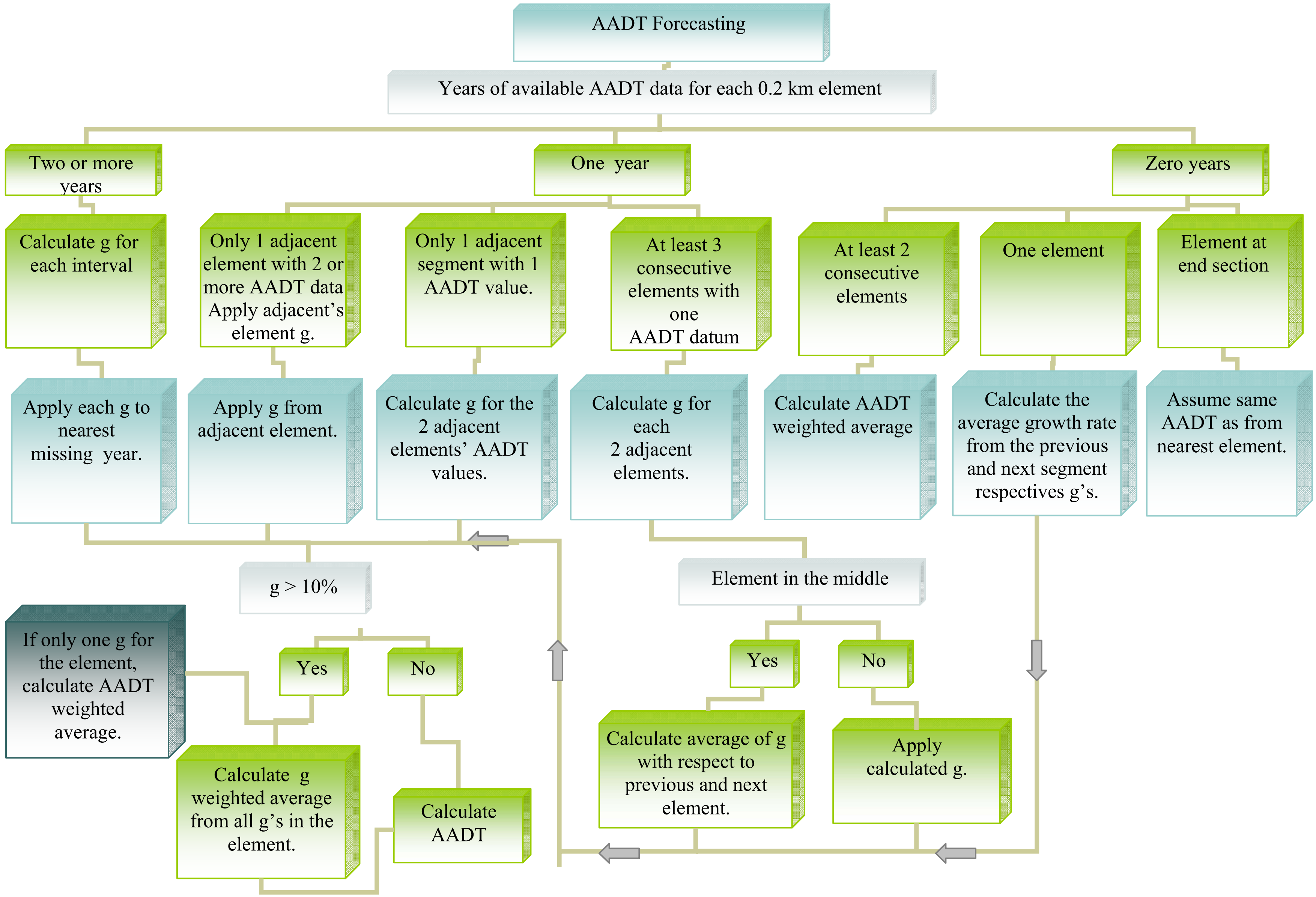


Figure 3.4: Methodology for AADT Forecasting

$$g = \sqrt[k]{\frac{E_t}{E_{t-k}}} - 1, \tag{3.2}$$

where: g = annual AADT growth rate
k = a number of years between the first and the last AADT data value
E_t = base year AADT value observed during t year
E_{t+k} = forecasted year AADT value

If the segment has only one AADT datum, the growth rate from the adjacent segment (previous or next segment) is assigned to that segment. If both growth rates from the previous and next segment are available, the average growth rate of both segments will then be used. If there are one or more segments with no AADT data for any year, the AADT will be calculated using a weighted average as follows:

$$\overline{AADT} = \frac{[\, AADT_1(L_2) + AADT_2\,(L_1)\,]}{(L_1+L_2)} \tag{3.3}$$

where: $\overline{AADT}$ = AADT weighted average
$AADT_1$ = previous AADT value available
$AADT_2$ = next AADT value available
L_1 = previous segment longitude in kilometers
L_2 = next segment longitude in kilometers

If there is only one year AADT datum for a segment and only one AADT datum for the next segment, given that the segments are adjacent to each other, the growth rate will be computed using the two AADT values, and applied to both segments. However, if there is one AADT value for the segment through three or more segments, the growth rates for the segments that are in the middle, will be calculated as the average of the growth rate for the segment with respect to the previous segment and the growth for the segment with the next segment. On the other hand, if there is no data for the segments at the beginning of a road, they will be assumed to be the same as the nearest segments. This criterion is based on the assumption that there are no significant AADT variations between the site of interest and the nearest segment in which AADT data is available. Similarly, if there is no data available for the end section of the road, the AADT data will be assumed to be the same as the nearest previous AADT data, measured or calculated. If limited AADT data for the last section and those at different km which have no difference in description, AADT weighted average and growth rates will be computed, and then missing AADT values will be calculated based on those growth rates. If a segment has more than one growth rate, when calculating the AADT for a particular year at the beginning or the end of the study period, the nearest growth rate will be used. If it is more than 10%, a weighted average of all the growth rates for that segment will be used. If any segment has only one growth rate, and it is 10% or more for one year period, the growth rate will not be used to calculate the AADT values for the rest of the segment, and equation 3.3 will be used. Tables with AADT forecasted values are in Appendix B.

3.2.6.3.Hazardous Index

A hazardous index (HI_f) was developed by modifying the original parameters of the components of the index. The hazardous index is the sum of frequency index (FI_f), accident rate index (RI_f), and severity index (SI_f).

Since this research only considers fatal crashes, the calculation of the SI was modified to reflect this fact. The SI_f usually is computed by assigning one value if it is a fatal crash, another value if it is injury, and another one if it is property damage only (PDO). This research only considers fatal crashes, so everything involved in each fatal crash was accounted to determine the degree of severity in the fatal crash. The fields of number of deaths and number of injured from the database were used. The values assigned were 9 for each death and 3 for each injured involved in the fatal crash.

RI is computed using the RMVM. The number of crashes refers to each type of crash. For example, lateral crash, rear-end crash, against a fixed object, among others. The only type of crash considered in the research is fatal.

3.2.7. Site Inspection

After the Pareto diagram and HI were done, a site inspection was performed for each one of the segments in both directions. Inspections were documented by digital pictures and video recording. Sites inspected were: PR-2 km 154.8-155.3, PR-115 km 7.0-7.1, PR-459 km 4.0-4.1, PR-100 km 9.0-9.3, and PR-2 Km 172.0-172.1. From these inspections some relevant information was gathered: geometry, pavement marking, signing, traffic control, presence of accesses, type of development (commercial or residential), safety devices, lighting system, and visibility, among others.

3.2.8. Data Analysis

Based on the MUTCD, RSDG, the Green Book, NCHRP 350, PRHTA Specifications, Standards and Directives, data taken in the field was verified for the fulfillment of minimum and maximum distances required, deficiencies were identified.

Excel program was used for the analysis of the *TSC* database. Information obtained from the database was complemented along with field data, to establish trends in fatal crashes occurrence.

3.2.9. Conclusions

After analyzing all the data gathered from the preliminary statistical analysis and selection of segments, and then analyzing the field inspections, some conclusions were reached about the characteristics of hazardous locations and possible contributors to make a road segment prone to fatal accidents. Research conclusions are discussed in Chapter 6.

3.2.10. Proposed Countermeasures

Based on the knowledge acquired during the research, literature review, database analysis and data obtained from site inspections and plans, important recommendations were presented. These are oriented to minimize fatal crashes occurrence, in other words, to the reduction of quantity and magnitude of crashes not only for the study sites, but applicable to any road segment identified as a hazardous location.

Also, recommendations directed to the agencies related to the data collection process, law creation and enforcement, planning, design and any other related to road safety in any way, were made.

3.3. Summary

This chapter explained in detail the methodoly followed for the development of this research project, including the management and filtering of the databases, the study area, the division of road segments, the selection of road segments, the procedure for AADT forecasting computations, the Pareto analysis, and the computation of the SI, RI, FI, and HI. Results are presented in Chapter 5. Next chapter will describe the databases, their composition, and possible sources of error.

4. Description of Data Base

4.1. Introduction

At the initial stage of the research, two databases were analyzed to obtain a general overview of crashes in the USA and fatal crashes in the island. These were the TSC database and FARS. The FARS database was analyzed with the purpose of comparing the trends in the USA with Puerto Rico's. Databases are done for each year. For this research, TSC databases from 1995 to 2003 were analyzed, and years 2001 and 2003 of FARS.

4.2. Traffic Safety Commission Database

The TSC database is built for each year from data obtained from the reports the Police Department fills out when a car accident occurs. The information is transcribed in ASCII format, in eighteen different fields, where some of the information is number coded. The fields are:

Id : Identification numbering of each fatality entry.

Numyr : number of death in the year

Nummes : number of death in the month

Nombre : name of the person that died

Relmt: classification of the person that died (driver, passenger, pedestrian, cyclist, or motorcyclist)

Edad : age

Municipio : municipality

Carr-Km : road and kilometer, or two roads intersection

Mes : month

Dia : number of day in the month

Hora : hour in military format

Bac : blood alcohol content

Nummt : number of death people in that particular fatal crash

Infrc : type of infraction

Sexo : gender

Diasem : day of the week

Numher : number of injured people involved in the crash

Usodrg : positive or negative for use of drugs by the person that died

The infraction code had nineteen alternatives up to year 2001. In 2002, ten new alternatives were added.

4.3. Fatality Analysis Reporting System (FARS)

FARS is an annual census of fatal crashes occurred in the fifty states of the United States, the District of Columbia and Puerto Rico. This system was initiated in 1975 by NHSTA. Official data for each state is obtained from: Police Accident Reports, State Vehicle Registration Files, State Driving Licensing Files, State Highway Department Data, Vital Statistics, Death Certificates, Coroner / Medical Examiners Reports, Hospital Medical Reports, Emergency Medical Service Reports, and other state records.

FARS recollection of data consists of two types of elements identified as crash level and vehicle level. Crash level data comprehends data about the atmospheric and physical conditions of the crash site, people involved in the crash, causes of the crash, traffic control devices, and the emergency medical services report. The vehicle level data includes physical and design features of the vehicle, people aboard it, and physical condition of the vehicle after the crash.

4.4. Police Reports

Police Reports are the only source of data for the TSC database. The Police Department prepares reports based on the Traffic Accident Report and the Dead Person Report.

The Traffic Accident Report consists of three pages. The first page has four parts that collect information about the place and time of occurrence, vehicle 1, vehicle 2, and the fourth part contains the codes for some of the blanks. The second page collects data about the people involved in the crash (it has space for up to five entries), the condition of the road, information of witness, and information of the police officer that made the report. The third and last page provides space for the sketching of the crash and then a narrative that includes the versions of the witnesses and the judge's resolution, if any.

4.5. Selected Data for Analysis

For the preliminary analysis all the data from the TSC database was used to characterize fatal crashes in Puerto Rico. Then, due to the purpose of this particular research, only data for the West Region of the island was considered from the TSC database. Databases for each year from 1995 to 2003 were analyzed. Data for alleys or municipal roads was eliminated, only state roads were considered.

The databases were managed by creating queries in order to select the required data for each type of analysis executed. For the identification of hazardous locations the fields of municipality, road and kilometer, were used. Other queries created were: category of person resulting dead on the crash, blood alcohol content based on the percentage limit, use of drugs, type of infraction, day of the week and time, and period of time during the year analyzed first by

2 week periods, and finally by a month period composed of the last 2 weeks of the first one and the two first weeks of the next.

4.6. Sources of Error

The first possible source of error is the police officer judgment at the site of the crash. The police officer may interpret the information based on his / her experience instead of reporting just the facts. Fields in the police accident report that may have more than one applicable answer may result in incomplete information or left blank, for example items 108: Contributive Circumstances, and 109: Driver's Maneuvers. Also, if the officer does not understand all the fields, these may be left blank. For example, item 8: Functional and Federal Classifications. Item 173, Roadway Defects, only has three types of defects, when there are many other defects that may contribute to the occurrence of a traffic accident, such as shoulder edge drop-off, bleeding, and polished aggregate.

Another field that is prone to errors is the location of the crash. In some entries of the database, the location was identified only by referencing to a store instead of writing the road and kilometer numbers. In the cases of crashes at intersections, the numbers of the roads are given, but no kilometer of either one is identified. Intersections with avenues do not provide if the avenue has a road number. Also, the smallest unit in the signing of the longitude of a road is the hectometer, and in many cases the kilometer markers are missing. This may cause that the information is not provided in the report or the officer may provide the kilometer number of the nearest marker regardless of its accuracy. Also, some roads have more than one intersection with a same road, but the database does not provide enough information to identify at which one of the intersections the crash occurred.

Other errors in the data can occur due to human error in the process of transcribing the Police Report into the TSC database. Some errors found were cells left blank or filled with a period, and in the field of number of injured people, in some cases the entry said 98.

4.7. Summary

This Chapter describes the FARS and the TSC databases. The TSC is described in more detailed for being the main source of data for this research. All the fields in the database are mentioned and explained. The Police accident report form is described also. Problems encountered with the database, the selection of data, and possible sources of error are summarized. Next chapter includes field inspections, data analysis and results.

5. Field Inspections and Data Analysis

5.1. Introduction

Data analysis comprised the following sources: TSC database, and field inspections. Through the statistical analysis of the database, and physical finding in the field, the fatalities occurrence in the western region of Puerto Rico was characterized and analyzed reaching conclusions and recommendations for their improvement.

5.2. Management and Filtering of Data Base

Fatalities data from the Commission for Traffic Safety was obtained for the years 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, and 2003. The files were in ASCII format and were transferred first to Microsoft Access and then to a spreadsheet format.

Initially, all the data from those six years were combined to make a preliminary descriptive statistics analysis.

The process began by subdividing each road in the western area in 2 kilometers segments and then fatalities were account for those segments. This was done for each road in the western region. For the preliminary process of determining dangerous segments, 5 segments were identified, but important information was lost in combining the six years of data. There is a table for each road pertained to the West Region Office of the PRTHA. Ninety tables were made from which 17 were chosen for having 2 or more fatalities in any of its segments. Initially, for each of the 90 tables, segments having a fatality total equal or higher than the average for that road were identified. Finally, the selection was narrowed down to 15 segments ranked by fatality frequency. This process led to the conclusion that important data was lost due to the longitude of the segment. Two-kilometer segments were not separating segments from intersections; therefore the process was reinitiated with 0.2 km segments. Thirteen roads with 3 or more fatalities in a segment or contiguous segments during the 9-year study period were identified. Frequency tables were done for these roads and nine were chosen to make graphics and evaluate them for further analysis applying the Pareto diagram. Five roads were eliminated because the fatalities were a one time event, seven years had pass before another fatality occurred in the same segment, or none other fatalities occurred in that road at any segment nor any other year.

Figure 5.1 shows the fataity frequency graphic for PR-2 from 1995 to 2003. The graphic shows the highest frequency throughout the 9-year period at Mayagüez, and the lowest at Sabana Grande. It also shows a higher concentration of fatalities at urban and commercial areas of PR-2 from Quebradillas to San Germán. Suburban section of PR-2, namely, Sabana Grande, Guánica and Yauco have low occurrence of fatalities, and most of them had only one fatality occurrence in the 9-year study period.

5.3. Selection of Hazardous Road Segments

Due to the fact that there are many roads in the western region of the island generates a significant amount of data as a result of subdividing it in 0.2 km road segments, a ranking process was established in order to narrow down the amount of segments and be able to identify the most hazardous road segments in a practical, and cost-efficient manner.

5.3.1. Pareto Analysis

The Pareto Analysis was applied to the variable RMVM and the corresponding diagram for each data year for each road was generated. In general, segments in the 80^{th} percentile are the most critical for a particular year, with respect to the RMVM which considers the AADT. Segments in the 80^{th} percentile that are repeated at least once, were identified.

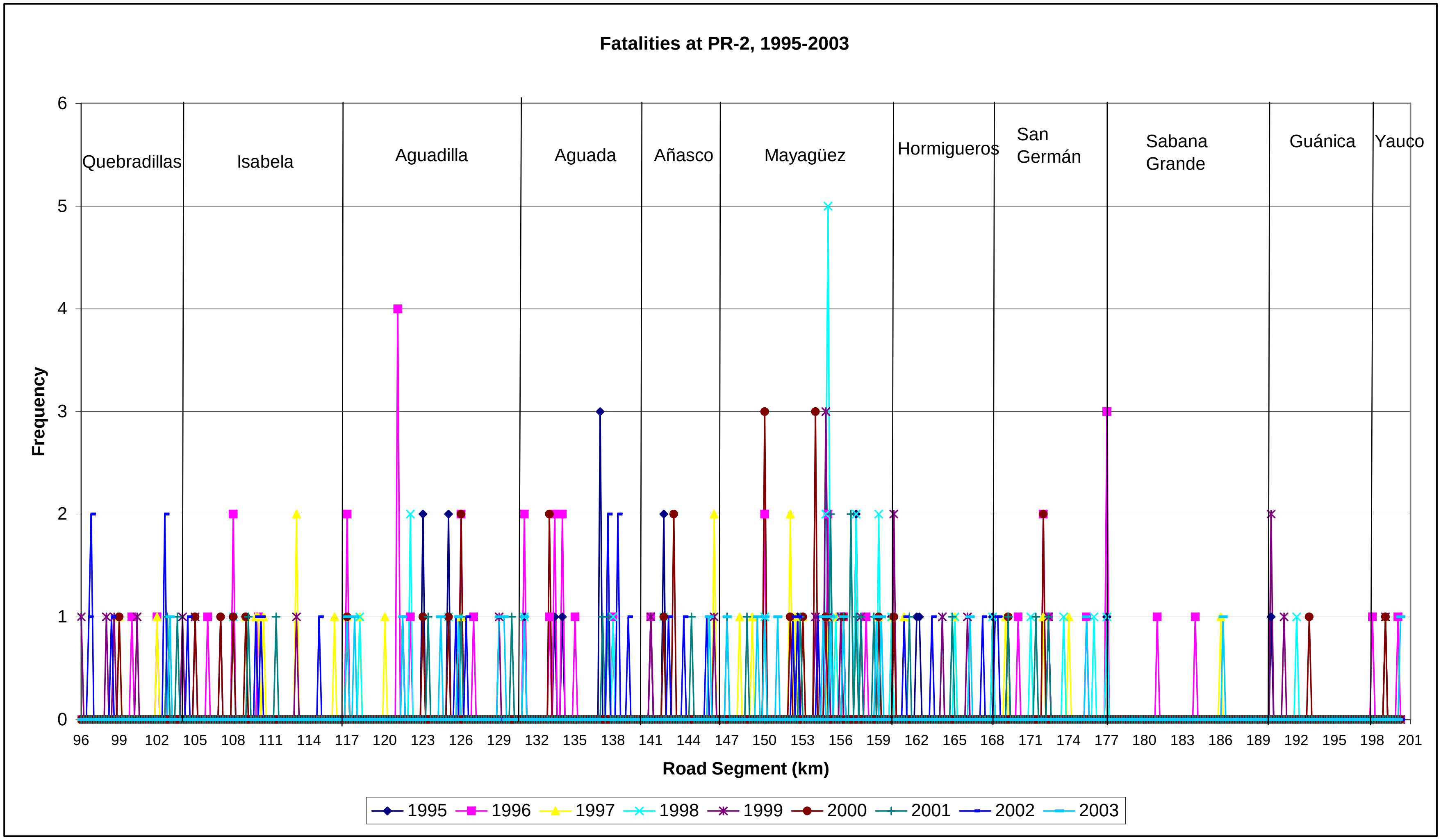


Figure 5.1: Fatality Frquency fo PR-2, 1995 to 2003, km. 96 to 200.8

This section will describe the Pareto Diagram results. Pareto diagrams can be found in Appendix C. For easy interpretation segments were identified by its starting km. For example, km 2 includes data for occurrences at km 2.0 and 2.1. Physically, the segment would start at Km 2.0 and would end at km 2.2, without including data for km 2.2, as seen in Figure 5.2.

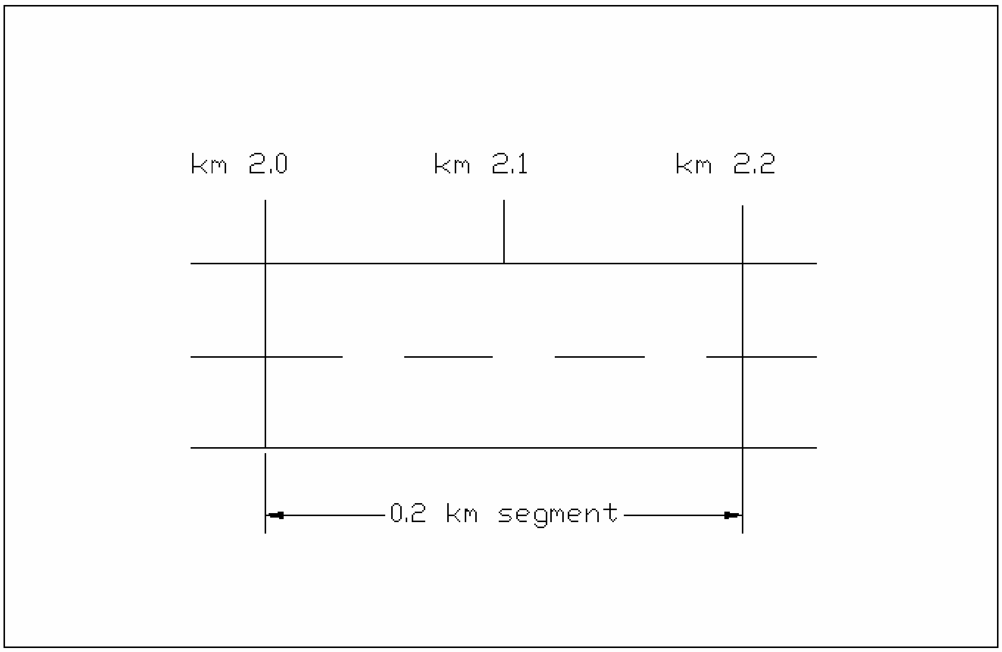


Figure 5.2: Conceptual Sketch of Segment definition

Figure 5.3 shows an example of a Pareto Diagram used for the analysis. The Pareto diagram consists of a series of bars representing the segments' RMVM arranged in descending order, and a cumulative curve of the RMVM's. To obtain the segments of interest, the segments that are contained in the 80th percentile are identified.

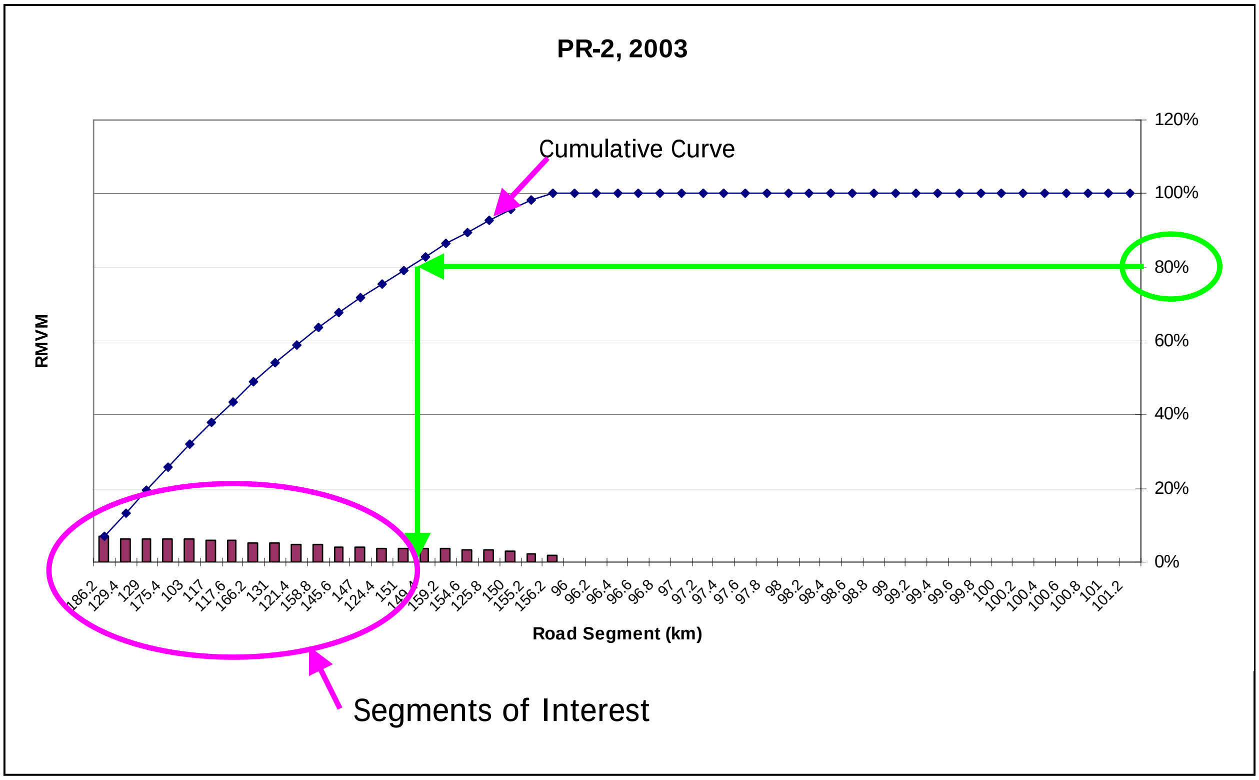


Figure 5.3: Pareto Diagram for PR-2, 2003, from km. 96 to 200.8.

When the cumulative curves of the 9-year study period are superimposed in a graphic for a specific highway section, the variation in total longitude of hazardous segments from one year to another can be identified. For example, Figure 5.4 shows that for PR-2, the higher difference is from 1995 to 1996. In 1995, 3.9% of the 105 km of road resulted as the most hazardous segments. In 1996, the longitude increased by 1.9%, reaching 5.8% of hazardous kilometers on the highway section.

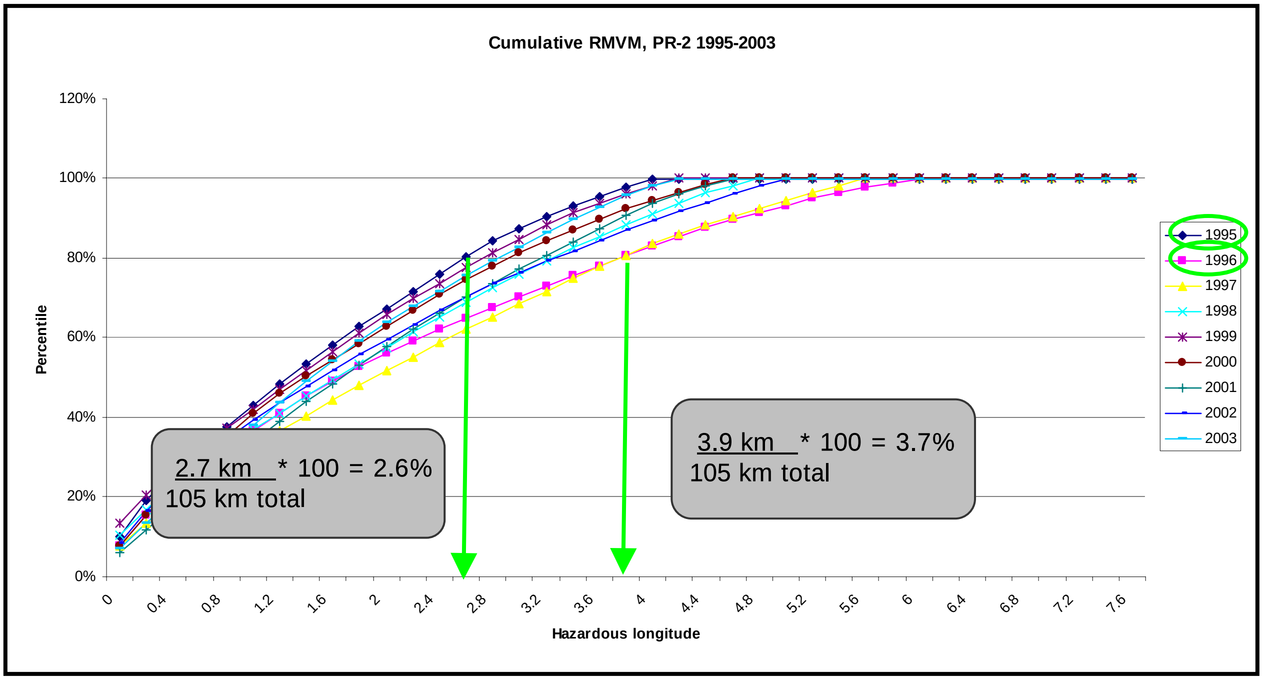


Figure 5.4: Longitude of hazardous segments in PR-2, km. 96 to 200.8, from 1995 to 2003.

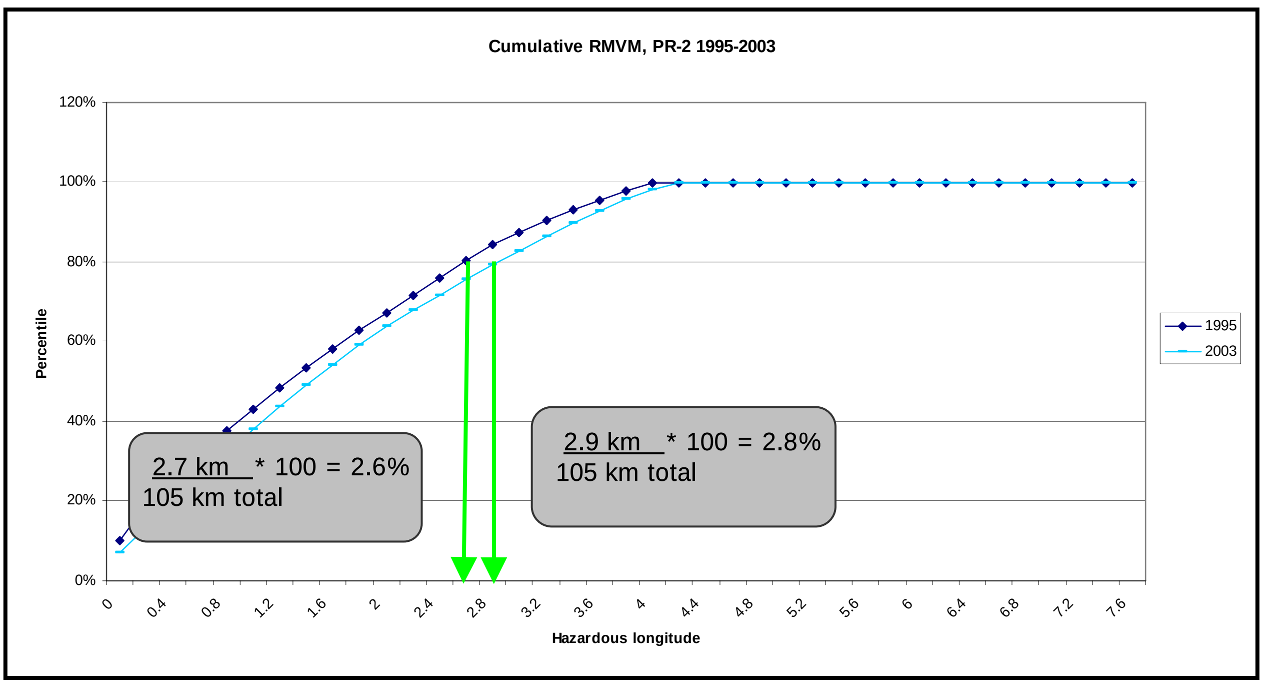


Figure 5.5: Longitude diffrerence of hazardous segments PR-2, km. 96 to 200.8, between 1995 and 2003.

If extreme years are compared, Figure 5.5 shows that between 1995 and 2003 the total hazardous longitude for PR-2 varied from 2.7 kn to 2.9 km, a total increase of 0.2 %. Pareto diagrams were constructed for each year to identify hazardous segments present in the 80th percentile. This data are summarized in Table 5.1

Table 5.1: Pareto Diagram results for PR-2.

Study Year	Segments in PR-2 80th Percentile	Other Segments with Fatality Occurrence
1995	137,142, 190, 123, 125, 107, 108, 177, 141, 155, 134, 133.4, 131	157.2, 138, 168, 152.6, 162.2, 162, 160
1996	177, 121, 131, 133.4, 134, 117, 108, 172, 184, 181, 150, 102, 100, 126, 155, 133, 106, 198, 141	175.4, 135, 200, 172.4, 138, 110, 170, 122, 127, 158, 156, 156.2
1997	113, 146, 186, 152, 99, 102, 118, 117, 120, 116, 199, 174, 10, 110.4, 109.8, 110, 172, 169, 148	165, 126, 152.4, 160, 161, 153, 155, 155.6, 149, 159
1998	155, 192, 122, 154.8, 96, 177, 142, 176, 118, 131, 108, 159 173.6, 168, 157.2, 171, 138	165, 146, 164, 125, 150, 160, 155.6, 156
1999	190, 154.8, 191, 113, 105, 100.4, 104, 98.6, 98, 96, 160.2, 199, 172.4, 166	141, 164, 129, 146, 154, 155, 156, 157.6
2000	172, 154, 133, 150, 142.8, 193, 126, 99, 109, 108, 107, 105, 117, 169.2, 199	123, 142, 154.8, 125, 152, 153, 159, 160.2, 156.2
2001	109.2, 102.8, 171.4, 172.4, 103.6, 169.2, 164.8, 111.4, 155.2, 137.2, 137.6, 123.4, 130, 156.8, 147, 144.2	148.6, 158.6, 152.8, 161.4, 126, 157.6, 157.2, 156.2
2002	96.8, 102.6, 137.6, 138.4, 109.8, 110.2, 98.4, 96.6, 168.4, 167.2, 104.4, 114.8, 121.4, 139.2, 142.4, 143.6	145.4, 152.2, 152.6, 163.2, 126.4,154.2, 161, 125.6, 160.2
2003	186.2, 129.4, 129, 175.4, 103, 117, 117.6, 166.2, 131, 121.4, 158.8, 145.6, 147, 124.4, 151	149.4, 159.2, 154.6, 125.8, 150, 155.2, 156.2

Elements appearing more than once are identified as shown in Table 5.2. Each of the elements that meets the criterion of appearing in 3 of 5 consecutive years is chosen for further analysis. For PR-2, 7 elements were identified. These are: km 108-108.1, km117.0-117.1, km 131.0-131.1, km 154.8-155.3, km 172.0-172.1, km 177.0-177.1, and km 199.0-199.1.

PR-2 is the road with more fatalities in the study area. In the case of km 154.8-155.3, three contiguous segments were merged. Km 154.8-154.9 appeared twice, 155.0-155.1 appeared three times and km 155.2-155.3 appeared once. In this particular case, PR-2 is an arterial and there is an evident difference in the amount of data obtained from the Pareto Diagram. Fifteen segments appeared more than once in the 80th percentile. There are also a few segments

Table 5.2: Identification of Repeated Elements in 80th Percentile of PR-2

PR-2, Start km of Segments in 80th Percentile									
ID	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
1	107	100	99	96	96	99	102.8	96.6	103
2	108	102	102	108	98	105	103.6	96.8	117
3	123	106	109	118	98.6	107	109.2	98.4	117.6
4	125	108	109.8	122	100.4	108	111.4	102.6	121.4
5	131	117	110	131	104	109	123.4	104.4	124.4
6	133.4	121	116	138	105	117	130	109.8	129
7	134	126	117	142	113	126	137.2	110.2	129.4
8	137	131	118	154.8	154.8	133	137.6	114.8	131
9	141	133	120	155	160.2	142.8	144.2	121.4	145.6
10	142	133.4	120.4	157.2	166	150	147	137.6	147
11	155	134	146	159	172.4	154	155.2	138.4	151
12	177	141	148	168	190	169.2	156.8	139.2	158.8
13	190	150	152	171	191	172	164.8	142.4	166.2
14	-	155	169	173.6	199	193	169.2	143.6	175.4
15	-	172	172	176	-	199	171.4	167.2	186.2
16	-	177	174	177	-	-	172.4	168.4	-
17	-	181	186	192	-	-	-	-	-
18	-	184	199	-	-	-	-	-	-
19	-	198	-	-	-	-	-	-	-

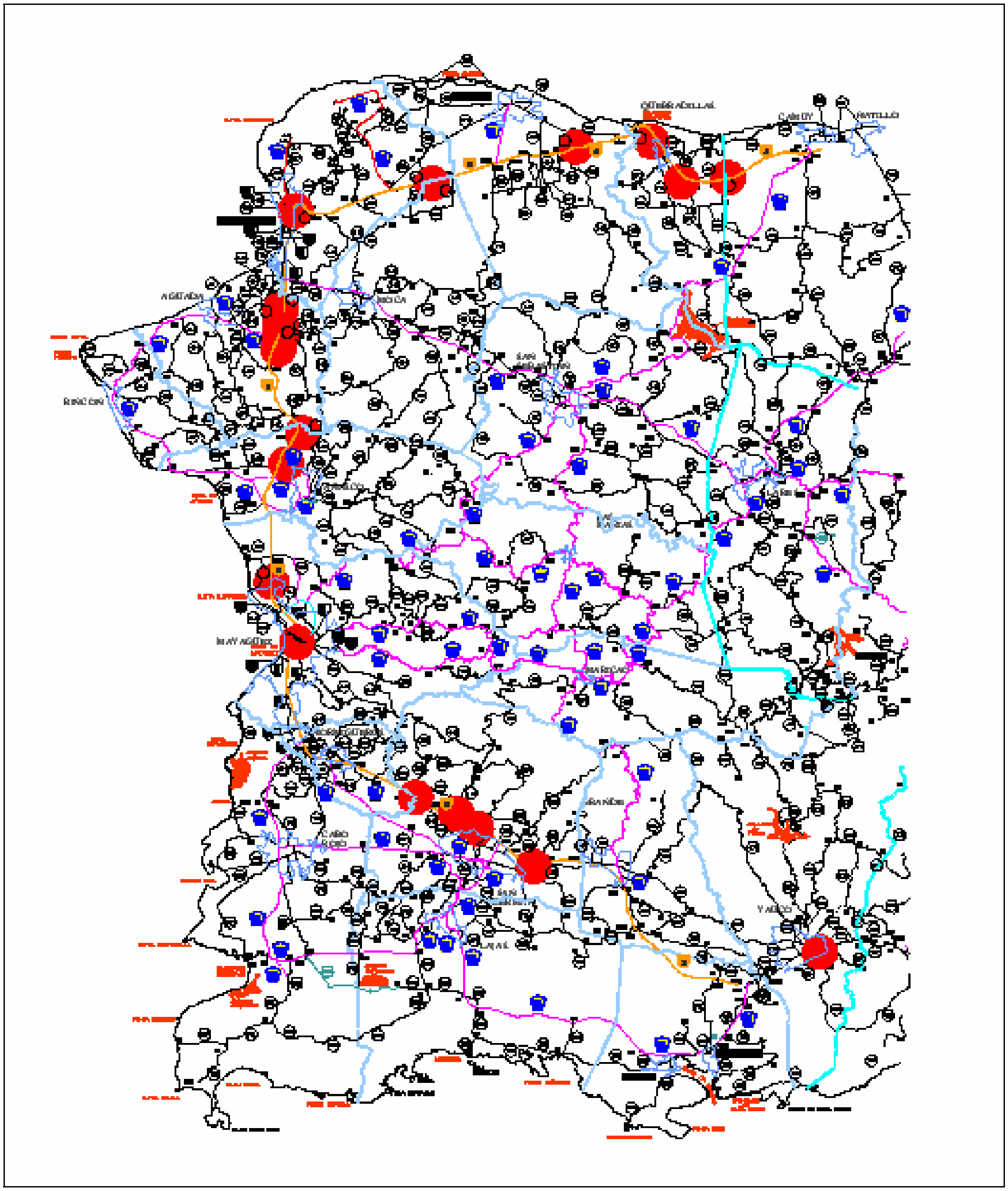
repeated outside the 80th percentile. For example, contiguous segments of km 156.0 and 156.2 appeared in 6 out of the 9 years but at the end of the list. Although these are not considered in our analysis, their behavior in future years should be observed.

Figure 5.6 presents a summary of the 0.2 km discreet elements that appeared more than once in the 80th percentile for the section of PR-2 from km 96 to km 200.8. These elements are identified graphically in a map of the studied area, and 13 out of the 15 segments are associated to intersections. These elements are located at intersections or contiguous to them.

For PR-100, segments of km 9.0 and km 9.2 are both repeated twice. Considering they are contiguous segments, they can be merged into one 0.4 km segment. This road was inspected in the initial network inspection. It is located in a touristy region. After the initial inspection a police officer from the Mayaguez Traffic Division was interviewed and identified PR-100 as one of the most hazardous roads in the area, specifically from km 9 to 14. The officer indicated that there is no illumination in the area. Table 5.3 shows all segments in the 80th percentile based on the RMVM variable, and other segments that had fatalities occurrence, but stayed out of the 80th percentile.

Table 5.3: Pareto Diagram results for PR-100, Cabo Rojo.

Study Year	Segments in PR-100 80th-Percentile	Other Segments with Fatality Occurrence
1995	13	13.4, 7.4
1996	11	14
1997	14.6, 9.2, 4	3.2, 8
1998	7.4	4.6
1999	9, 6, 4.6	7.4
2000	9, 13, 9.2	7.4, 2.8
2001	11.2	3.6
2002	10.6	-
2003	11.8, 8.4	7.4



Segment km	Municipality	Segment km	Municipality	Segment km	Municipality
96.0-96.1	Quebradillas	133.0-133.1	Aguada	169.2-169.3	San Germán
99.0-99.1	Quebradillas	133.4-133.5	Aguada	172.0-172.1	San Germán
102.0-102.1	Quebradillas	134.0-134.1	Aguada	172.4-172.5	San Germán
108.0-108.1	Isabela	141.0-141.1	Añasco	177.0-177.1	San Germán
117.0-117.1	Isabela	142.0-142.1	Añasco	199.0-199.1	Yauco
126.0-126.1	Aguadilla	150.0-150.1	Mayagüez		
131.0-131.1	Aguada	154.8-155.3	Mayagüez		

Figure 5.6: Repeated segments in the 80th percentile at PR-2

For PR-107, two segments were identified, namely km 1.4 and km 2.0, with 3 and 2 appearances, as shown in Table 5.4. Km 1.4 appeared during three consecutive years from 1995 to 1997 which could lead to the conclusion that there was a geometric problem that was corrected. Km 2.0 appeared on 1995 and then on 1998 what seems to be aleatory occurrences.

Table 5.4: Pareto Diagram results for PR-107, Aguadilla.

Study Year	Segments in PR-107 80th-Percentile	Other Segments with Fatality Occurrence
1995	1.4, 2	1
1996	1.8, 1.4, 0.8	0.6, 0
1997	1.4	-
1998	2	0
1999	4	4.2
2000	0.4	-
2001	3.6	4.2
2002	2.6	1.6
2003	4.2	4.4

Table 5.5 summarizes the results of the Pareto diagram for PR-109. This road had no repeated segments, and three of the nine years of the study period had no fatalities registered, therefore it was eliminated from the analysis. This fact confirms that frequency alone is not a reliable indicator for identifying a hazardous location. The relation between crash occurrence, in this case fatality frequency, and traffic volume is determinant in the degree of hazardousness of a site. For example, if two different segments have the same number of fatalities, the one with lower traffic volume is more hazardous than the other one.

Table 5.5: Pareto Diagram results for PR-109, Añasco.

Study Year	Segments in PR-109 80th-Percentile	Other Segments with Fatality Occurrence
1995	26	-
1996	-	-
1997	1.4	-
1998	-	-
1999	-	-
2000	0.4	-
2001	3.6	4.2
2002	4.4	0.2
2003	4.2	4.4

In PR-111, segments of km 18.0-18.1, and km 30.0-30.1 appeared in the 80th percentile 3, and 2 times, respectively in 2 of 3 consecutive years. Km 18.0-18.1 appeared on 1999, 2000, 2002 and also appeared on 1998 outside the 80th percentile. This could reflect a geometric change in the area or an increase in the quantity of accesses to road. Table 5.6 shows the results for PR-111.

Table 5.6: Pareto Diagram results for PR-111, Aguadilla, Moca, and San Sebastián.

Study Year	Segments in PR-109 80th-Percentile	Other Segments with Fatality Occurrence
1995	26	-
1996	-	-
1997	1.4	-
1998	-	-
1999	-	-
2000	0.4	-
2001	3.6	4.2
2002	4.4	0.2
2003	4.2	4.4

Table 5.7 presents that for PR-115, segment of km 7.0-7.1 appeared three times and segment km 19.0-19.1 appeared twice. Km 19 appears two consecutive years: 1997 and 1998. Whereas km 7.0 appeared in 1996, 1999, 2000, and 2003. Fatal crashes recurrence at km 7

shows that there is a safety problem in the area. Probably, there is a combination of road deficiencies in geometry and illumination complemented by user negligence.

Table 5.7: Pareto Diagram results for PR-115, Añasco-Rincón.

Study Year	Segments in PR-115 80th-Percentile	Other Segments with Fatality Occurrence
1995	3	18.6
1996	7	27.8
1997	19	26
1998	19, 5.2	26
1999	7	-
2000	7, 25, 27	7.6
2001	20	3.2
2002	27.6, 18.8, 27.4	11, 8.8
2003	7	10.8

As seen in Table 5.8, PR-116 showed km 10.0-10.1 and km 12.6-12.7 twice. In both cases, they were not consecutive occurrences what could be interpreted as aleatory events related to driver negligence or mechanical defects and not to the configuration of the road, but the second one meets the criterion of appearing in 2 out of 3 consecutive years.

Table 5.8: Pareto Diagram results for PR-116, Lajas, Guánica and Yauco.

Study Year	Segments in PR-116 80th-Percentile	Other Segments with Fatality Occurrence
1995	10, 14, 16.6	19, 2
1996	12.6, 7, 21	4, 3.4
1997	22.8	-
1998	12.6, 2	22
1999	10.6	4
2000	15, 4.2	4, 23
2001	20.2	19.2
2002	10	0.6
2003	-	-

Table 5.9 presents that for PR-459 in Aguadilla, only one segment was repeated in the 80^{th} percentile and it was km 4.0-4.1. It also appeared an additional year outside the 80^{th} percentile. In this specific case, all fatalities in this segment were registered exactly at km 4.0 which could be representative of an intersection.

Table 5.9: Pareto Diagram results for PR-459, Aguadilla.

Study Year	Segments in PR-459 80th-Percentile	Other Segments with Fatality Occurrence
1995	-	-
1996	15	4, 3
1997	10.8	-
1998	4	-
1999	3	-
2000	4, 5	0.8
2001	13.2	-
2002	0.6	-
2003	13.8	-

Due to the fact that there are many highway segments in the 80^{th} percentile, the segments that met the criteria of appearing in 3 of 5 consecutive years for primary roads, and in 2 of 3 consecutive years for secondary roads, will stay in the analysis for the computation of the hazardous index (HI). The 15 elements that were selected for the hazardous index analysis are shown in Table 5.10.

Table 5.10: Hazardous Segments selected for further analysis

Road ID	Road	Start Km	End Km	Segment ID	Segments Seleted for Hazardous Index (HI) Analysis	Year with Fatalities					RMVM Corresponding to Year with Fatalities					Ranking by Descending Average RMVM	Ranked by Repetitions and Maximum RMVM
1	PR 100	0.0	14.6	1	km 9.0-9.3	1997	1999	2000*	-	-	94	112	281, 141	-	-	5	6
2	PR 107	0.0	4.6	2	km 1.4-1.5	1995	1996	1997	-	-	98	95	278	-	-	8	7
3	PR 111	0.0	33.0	3	km 18.0-18.1	1999	2000	2002	-	-	203	99	98	-	-	7	9
				4	km 30.0-30.1	1998	2000	-	-	-	323	309	-	-	-	4	15
4	PR 115	0.0	28.0	5	km 7.0-7.1	1996	1999	2000	2003	-	255	193	175	398	-	1	2
				6	Km 19.0-19.1	1997	1998	-	-	-	290	325	-	-	-	6	14
5	PR 116	0.0	26.6	7	km 12.6-12.7	1996	1998	-	-	-	557	371	-	-	-	4	12
6	PR 459	0.0	16.0	8	km 4.0-4.1	1998	2000	-	-	-	338	253	-	-	-	2	13
7	PR 2	96.0	200.8	9	km 108-108.1	1995	1996	1998	2000	-	93	124	68	74	-	10	5
				10	km 117-117.1	1996	1997	2000	2003	-	137	68	69	69	-	14	4
				11	km 131.0-131.1	1995	1996	1998	2003	-	77	156	69	60	-	12	3
				13	km 154.8-155.3	1995	1996	1998*	1999	2001	78	76	177, 86	109	59	3	1
				14	km 172-172.1	1996	1997	2000	-	-	114	57	137	-	-	11	10
				15	km 177-177.1	1995	1996	1998	-	-	88	217	73	-	-	9	8
				16	km 199-199.1	1997	1999	2000	-	-	67	65	64	-	-	13	11

5.3.2. Hazardous Index

A hazardous index (HI) was developed for the selection of the final hazardous segments. The hazardous index is composed by three other indexes that consider frequency, fatal crash rate, and severity.

The calculation of the Severity Index (SI_f) was varied due to the fact that this research only considers fatal crashes. Usually, it is calculated assigning a value to each crash according to its magnitude: fatal, injury or property damage only. We only have fatality data, so calculations consider the magnitude of the fatal crash by assigning values to variables of number of deaths and number of injured people. Values assigned are: each fatality = 9 and each injured = 3.

$$SI_f = \frac{9 * F_{TSC} + 3\ I_{TSC}}{S_{Avg}} \tag{5.1}$$

Where:

SI_f = Severity Index of fatalities at the element
F_{TSC} = number of deaths involved in the fatal crash as identified in the TSC database.
I_{TSC} = number of injured people involved in the fatal crash as identified in the TSC database.
S_{Avg} = Average Severity of analyzed elements.

After calculating the SI_f, the segments were ranked. The SI_f values show that the segment at PR-2 from km. 154.8 to km 155.3 is the highest, and it is almost 3 times the second highest, which is at the same road from km. 172.0 to km 172.1. The highest value is 13 times the value of the lowest. The lowest value was the same for 2 segments. Three segments from PR-2 ranked in the highest five values of SI_f.

Table 5.11 shows that SI_f values mostly stayed near the average, except for the highest value that is 3.6 times the average. All segments were identified as hazardous, but clearly PR-2 from km 154.8 to 155.5, is the most critical.

Table 5.11: Severity Index (SI_f) for hazardous segments

Road	Segment	Fatal Crash Severity	Severity Index	Rank
PR 100	km 9.0-9.3	66	0.99	5
PR 107	km 1.4-1.5	45	0.67	9
PR 111	km 18.0-18.1	63	0.94	6
PR 111	km 30.0-30.1	18	0.27	11
PR 115	km 7.0-7.1	66	0.99	5
PR-115	Km 19.0-19.1	18	0.27	11
PR 116	km 12.6-12.7	36	0.54	10
PR 459	km 4.0-4.1	81	1.21	3
PR 2	km 108-108.1	54	0.81	7
PR 2	km 117-117.1	63	0.94	6
PR 2	km 131.0-131.1	75	1.12	4
PR 2	km 154.8-155.3	237	3.55	1
PR 2	km 172-172.1	84	1.26	2
PR 2	km 177-177.1	51	0.76	8
PR 2	km 199-199.1	45	0.67	9
	Average	66.80	1.00	

The Fatal Crash Rate Index is calculated with the rate per hundred million vehicle miles (RMVM), the number of accidents refers to each type of crash (lateral, form behind, against a fixed object, etc.) In our case, the type of crash was considered simply as fatal crashes at the road segment, because the database does not provide that kind of information. This computation considers the Annual Average Daily Traffic (AADT). For none of the segments the AADT for each of the 9 years were available, so the available years of data were used to calculate the missing values following the procedure explained previously in Chapter 3.

$$RI_f = \frac{RMVM_f}{RMVM_{Avg}} \quad (5.2)$$

Where:

RI_f = Fatal Crash Rate Index for the element
$RMVM_f$ = Fatal Crash Rate Rate per Hundred Vehicle Miles for element
$RMVM_{Avg}$ = Average RMVM of analysed elements.

$$RMVM_f = \frac{A \times 100{,}000{,}000}{VMT} \tag{5.3}$$

Where:

$RMVM_f$ = rate per 100 million vehicle miles
A = frequency of fatal crashes for the elemnt
VMT = total vehicle miles of travel during the given period
= ADT x (365 days) x (0.2km *1mi / 1.609 km)

The highest RI_f value is 2.45 for PR-115 from km 7.0 to 7.1. In this case, the highest value is almost 4 times the lowest. PR-2 had only one element in the first 8 positions. The highest RI values occurred for secondary roads. Table 5.12 shows the RI_f values and the ranking of elements.

Table 5.12: Fatal Crash Rate Index (RI_f) for hazardous segments

Road	Segment	RMVM	Fatal Crash Rate Index	Rank
PR 100	km 9.0-9.3	69.79	1.19	5
PR 107	km 1.4-1.5	52.43	0.89	8
PR 111	km 18.0-18.1	55.98	0.95	7
PR 111	km 30.0-30.1	70.25	1.20	4
PR 115	km 7.0-7.1	113.43	1.93	1
PR-115	Km 19.0-19.1	68.36	1.16	6
PR 116	km 12.6-12.7	70.25	1.20	4
PR 459	km 4.0-4.1	90.64	1.54	2
PR 2	km 108-108.1	39.76	0.68	10
PR 2	km 117-117.1	30.43	0.52	14
PR 2	km 131.0-131.1	33.55	0.57	12
PR 2	km 154.8-155.3	78.50	1.34	3
PR 2	km 172-172.1	34.26	0.58	11
PR 2	km 177-177.1	41.91	0.71	9
PR 2	km 199-199.1	31.12	0.53	13
	Average	58.71	1.00	

Finally, the frequency index is simply the total frequency for a segment divided by the average of the selected segments. The FI at PR-2 from km. 154.8 to km. 155.3 is 4.50, almost 3.5 times the value for the next position that is shared by 4 segments. The 2nd position is shared by 4 segments, one in PR-2 and the other three in secondary roads PR-100, PR-115 and PR-459. The highest FI_f is 10 times the value of the lowest. Table 5.13 shows the corresponding FI values.

$$FI_f = \frac{F_f}{F_{Avg}} \qquad (5.4)$$

Where:

FI_f = Frequency Index for the element
F_f = Fatality frequency for element
F_{Avg} = Average Frequency for analysed elements

Table 5.13: Frequency Index (FI_f) for hazardous segments

Road	Segment	Fatality Frequency	Frequency Index	Rank
PR 100	km 9.0-9.3	6	1.07	2
PR 107	km 1.4-1.5	5	0.89	3
PR 111	km 18.0-18.1	5	0.89	3
PR 111	km 30.0-30.1	2	0.36	5
PR 115	km 7.0-7.1	6	1.07	2
PR-115	Km 19.0-19.1	2	0.36	5
PR 116	km 12.6-12.7	3	0.54	4
PR 459	km 4.0-4.1	6	1.07	2
PR 2	km 108-108.1	5	0.89	3
PR 2	km 117-117.1	5	0.89	3
PR 2	km 131.0-131.1	5	0.89	3
PR 2	km 154.8-155.3	20	3.57	1
PR 2	km 172-172.1	6	1.07	2
PR 2	km 177-177.1	5	0.89	3
PR 2	km 199-199.1	3	0.54	4
	Average	5.60	1.00	

The hazardous index (HI_f) is the sum of the SI_f, the RI_f and the FI_f.

$$HI_f = \alpha\ SI_f + \beta\ RI_f + \gamma\ FI_f \tag{5.5}$$

Where:

α , β, and γ = coefficients of weight assigned to each index

For this research, it was assumed that all three indexes have the same same weight. These results are shown in Table 5.14. If the study is varied and different weights were assigned to the SI_f, RI_f and FI_f, for example, $\alpha = 0.40$, $\beta = 0.30$, and $\gamma = 0.30$, the HI_f results may vary. Tables 5.14 and Table 5.15 show the variations in the results. The 5 highest HI_f values stayed the same in both cases. When the coefficients were varied, two elements from PR-2 moved up to positions each. These were at km 117.0-117.1 and at km 199.0-199.1.

For this research, same weights were considered. The resulting top 5 segments mostly resulted in the 1st five positions for the individual indexes computations. The highest HI_f value is for PR-2 km 154.8 to k 155.3, and it doubles the 2nd position that is PR-115 from km 7.0 to 7.1. The highest HI_f value is near 5 times the lowest and 3 times the average for all segments. The lowest value is almost 2 times lower than the average.

After ranking the ten pre-selected segments, the five final segments are selected to inspect in detail and make recommendations.

Table 5.14: Hazardous Index and final ranking for hazardous segments: $\alpha = 1$, $\beta = 1$, $\gamma = 1$.

Road	Segment	FI	RI	SI	HI	Rank
PR 2	km 154.8-155.3	3.57	1.34	3.55	8.46	1
PR 115	km 7.0-7.1	1.07	1.93	0.99	3.99	2
PR 459	km 4.0-4.1	1.07	1.54	1.21	3.83	3
PR 100	km 9.0-9.3	1.07	1.19	0.99	3.25	4
PR 2	km 172-172.1	1.07	0.58	1.26	2.91	5
PR 111	km 18.0-18.1	0.89	0.95	0.94	2.79	6
PR 2	km 131.0-131.1	0.89	0.57	1.12	2.59	7
PR 107	km 1.4-1.5	0.89	0.89	0.67	2.46	8
PR 2	km 108-108.1	0.89	0.68	0.81	2.38	9
PR 2	km 177-177.1	0.89	0.71	0.76	2.37	10
PR 2	km 117-117.1	0.89	0.52	0.94	2.35	11
PR 116	km 12.6-12.7	0.54	1.20	0.54	2.27	12
PR 111	km 30.0-30.1	0.36	1.20	0.27	1.82	13
PR-115	Km 19.0-19.1	0.36	1.16	0.27	1.79	14
PR 2	km 199-199.1	0.54	0.53	0.67	1.74	15
	Average	1.00	1.00	1.00	3.00	

Table 5.15: Hazardous Index and final ranking for hazardous segments: $\alpha = 0.40$, $\beta = 0.30$, $\gamma = 0.30$

Road	Segment	FI	RI	SI	HI	Rank
PR 2	km 154.8-155.3	1.07	0.40	1.42	2.89	1
PR 115	km 7.0-7.1	0.32	0.58	0.40	1.30	2
PR 459	km 4.0-4.1	0.32	0.46	0.49	1.27	3
PR 100	km 9.0-9.3	0.32	0.36	0.40	1.07	4
PR 2	km 172-172.1	0.32	0.18	0.50	1.00	5
PR 111	km 18.0-18.1	0.27	0.29	0.38	0.93	6
PR 2	km 131.0-131.1	0.27	0.17	0.45	0.89	7
PR 107	km 1.4-1.5	0.27	0.27	0.27	0.81	8
PR 2	km 117-117.1	0.27	0.16	0.38	0.80	9*
PR 2	km 108-108.1	0.27	0.20	0.32	0.79	10
PR 2	km 177-177.1	0.27	0.21	0.31	0.79	11
PR 116	km 12.6-12.7	0.16	0.36	0.22	0.74	12
PR 2	km 199-199.1	0.16	0.16	0.27	0.59	13*
PR 111	km 30.0-30.1	0.11	0.36	0.11	0.57	14
PR-115	Km 19.0-19.1	0.11	0.35	0.11	0.56	15
	Average	0.30	0.30	0.40	1.00	

* Element moved two posiions up in the ranking, when having a higher weight for the SI.

In this study, the determination of the HI_f is based in the segments already identified as the 20% critical elements of each road. In other words, only the critical elements are considered, so having a hazardous index over the average will identify the most hazardous locations in the network. A priority level for hazardous elements was established according to the HI_f results. Table 5.16 shows the HI_f ranges with their respective priority levels.

Table 5.16: Priority levels for Hazardous Index

Hazardous Index	**Priority Level of Hazardous Element**
0 < HI < 3	Low
3 < HI < 6	Moderate
6 < HI < 10	High

5.4. Calibration and Validation

After computing the HI for the segments selected from the Pareto Analysis and ranking them, the five segments with the highest HI were inspected. Also more detailed information for those segments was gathered from the database. The inspection consisted of windshield inspections: the segments were traveled in both directions and video-recorded. Pictures were taken and measurements of fixed objects lateral distances, heights, slope, lane widths, etc. In some cases night inspections were executed to observe the effect of luminary system absence, to see signs reflectivity and pavement delineators' condition.

5.4.1. PR-100 km 9.0-9.3, Cabo Rojo

The segment is located in a suburban area (See Figure 5.7). It connects the commercial area of Cabo Rojo with the Boquerón beach. It has one lane per direction with right shoulders in both directions on a flexible pavement surface, plus clear zones with recoverable slopes. The shoulder in the North-South direction is 9ft wide, and 11ft in the South-North direction. Posted speed limit is 45mph. There is neither aerial electrical system nor illumination system. There are many trees on both sides of the road adjacent to ample clear zones.

There are no accesses to the road in this segment. The only pavement defect present along the entire segment is low weathering. In the N-S direction, there are many patches on the road. Thermoplastic pavement is single line un-continous. Thermoplastic markings are worn out, and raised pavement markings are in bad condition where still present.

The segment has a combination of vertical and horizontal curves. In the S-N direction, the segment starts with a vertical curve, once reached the crest, while going down starts a curve to the left. At this point, there are various brake marks on the shoulder pavement.

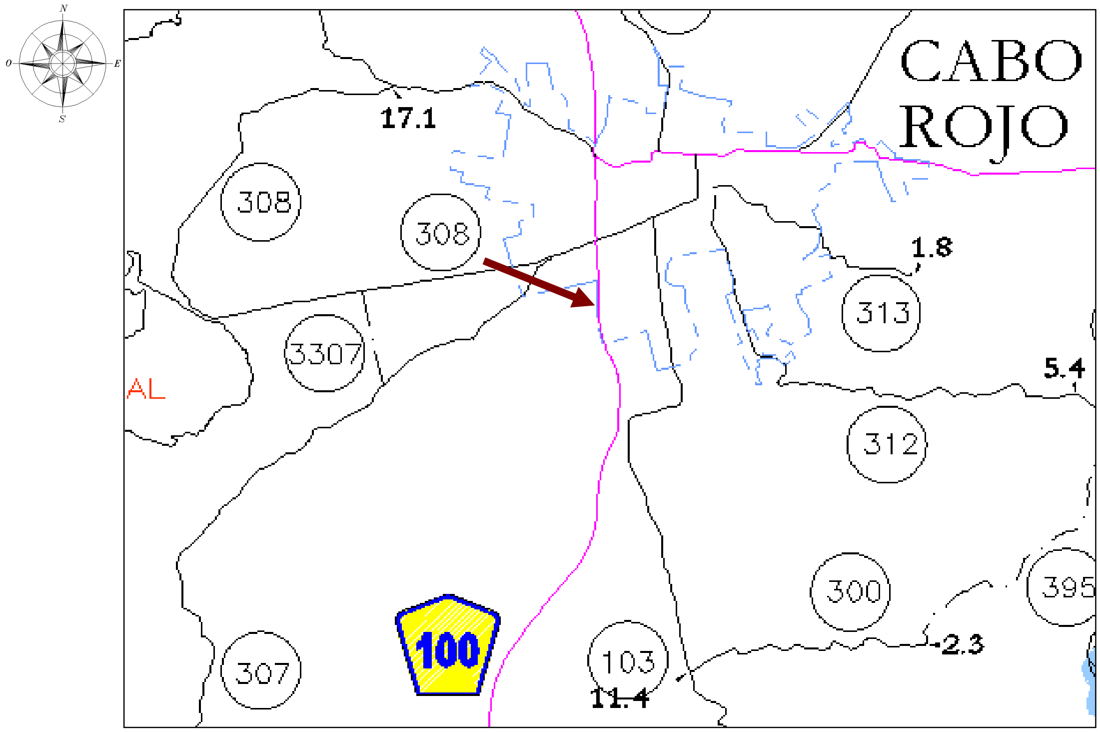


Figure 5.7: PR-100 segment location, km. 9.0 to 9.3, Municipality of Cabo Rojo

Some of the deficiencies identified during the field inspection were that the W-beam strong post guardrail is installed too low. Height varied from 7 in to 14 in. A vehicle could overturn after hitting the guardrail and fall down the slope which is approximately 20 ft high. The guardrail also has steel block-outs which do not meet with the NCHRP Report 350 requirements. The material should be timber or rubber. In the other direction, that is South to North, the roadside has a recoverable slope that is practically flat (15:1). The height of the signs is between 7 ft 6 in to 8 ft, a little higher than required by the MUTCD, but still visible and readable. Figures 5.8 and 5.9 show some of the field inspection findings.

Figure 5.8: Recoverable slope, PR-100 km 9.0-9.3, Municipality of Cabo Rojo.

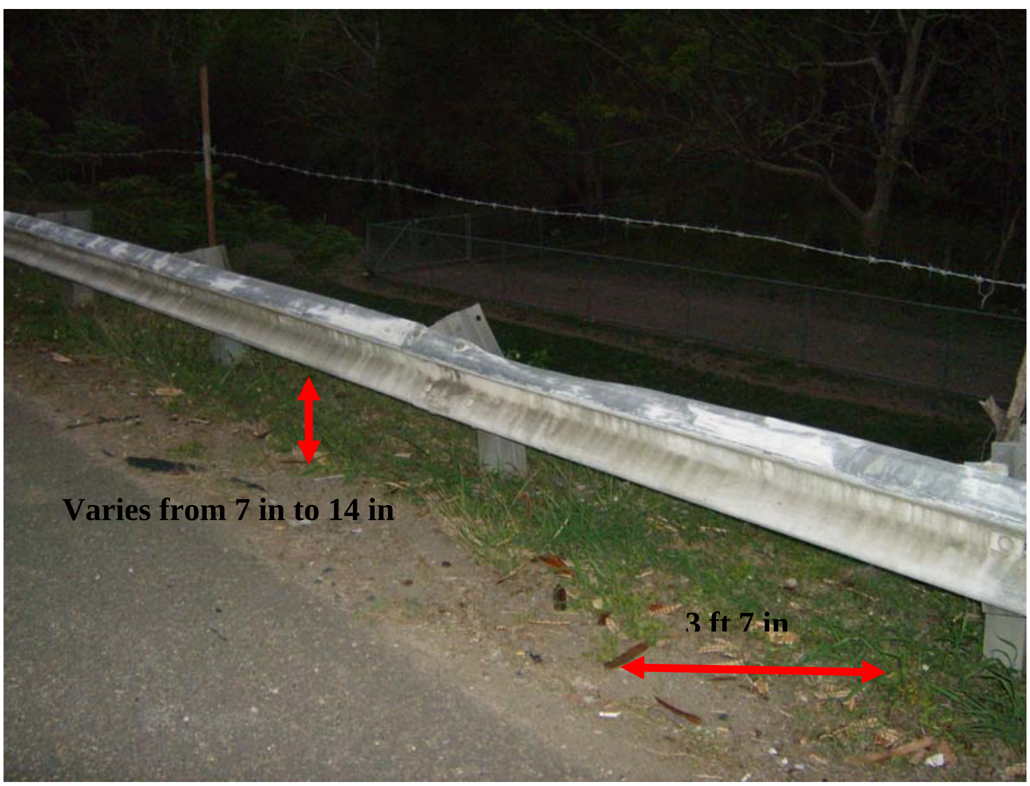


Figure 5.9: W beam strong post with steel block-out and deficient height

For this segment, all the fatalities occurred during the day, mostly in the morning, and the afternoon peak hour: 3:00pm-6:00pm. In 33% of the cases there were violations of forbidden maneuvers. Other violations were over the speed limit and out of control. None of the crashes were related to drugs, and only one had to do with alcohol, representing 17% of the total. Table 5.17 shows these characteristics.

Table 5.17: Characteristics of Fatal Crashes at PR-100 km 9.0-9.3

(a) Time fatality occurred

Period of Time	Total Frequency	Percent
12:01am - 3:00am	0	0.0
3:01am - 6:00am	0	0.0
6:01am -9:00am	2	33.3
9:01am - 12:00pm	2	33.3
12:01pm - 3:00pm	0	0.0
3:01pm - 6:00pm	2	33.3
6:01pm - 9:00pm	0	0.0
9:01pm - 12:00am	0	0.0
Total	6	100

(b) Day of Occurrence

Day of Week	Code	Frequency	Percent
Monday	1	2	33.3
Tuesday	2	1	16.7
Wednesday	3	1	16.7
Thursday	4	0	0.0
Friday	5	0	0.0
Saturday	6	2	33.3
Sunday	7	0	0.0
	Total	6	100

(c) Presence of Alcohol in the Blood

Over BAC	Frequency	Percent
Yes	1	16.7
No	4	66.7
Unknown	1	16.7
Total	6	100

(d) Under the effect of drugs

Drugs	Frequency	Percent
Yes	0	0.0
No	5	83.3
Unknown	1	16.7
Total	6	100

(e) Type of Infraction

Infraction	Code	Frequency	Percent
Other	0		0
Over speed limit	1	1	17
drunk	2		0
traffic control	3		0
Distracted	4		0
Wrong way	5		0
pavement deffect	6		0
mechanical deffect	7		0
forbidden maneuver	8	2	33
pedestrian violation	9		0
hit and run	10		0
obstructed visibility	11		0
none	12		0
not yielding	13		0
out of control	14	1	17
not leaving distance	15		0
not seeing object or person	16		0
overload	17		0
weather	18		0
n/a	19	1	17
go cart	20		0
speeding	21		0
forbidden reverse	22		0
forbidden turn	23		0
forbidden lane pass	24		0
has been drinking	25		0
driver condition	26		0
passw/out care	27		0
under alcohol effects	28		0
other	99		0
	Total	5	83.3

5.4.2. PR-115 km 7.0-7.1, Añasco

This segment is in a suburban area. There are many restaurants and pubs located exactly in the segment. This road leads to beaches and other pubs. A map showing the exact location of the segment is shown in Figure 5.10.

The segment is part of a series of curves: vertical and horizontal. In the Añasco-Rincón direction the roadway is a down slope -right curve combination. There is one lane per direction. Lanes are 12ft wide. There is right shoulder in both directions. The shoulder on the Añasco –Rincón direction is 18.5 ft wide ending in a gutter and a positive slope terrain. The shoulder on the other direction is 11.5ft wide, but it is used as parking space by the people in the restaurants. At night, both shoulders are used for parking. Some of these characteristics are shown in Figures 5.11 and 5.12.

Electrical System and luminary system run through the left side of the road. There are no sidewalks on either side of the road. Thermoplastic pavement markings are weared out. There are no raised pavement markings. Just after the segment there is the intersection with PR-429.

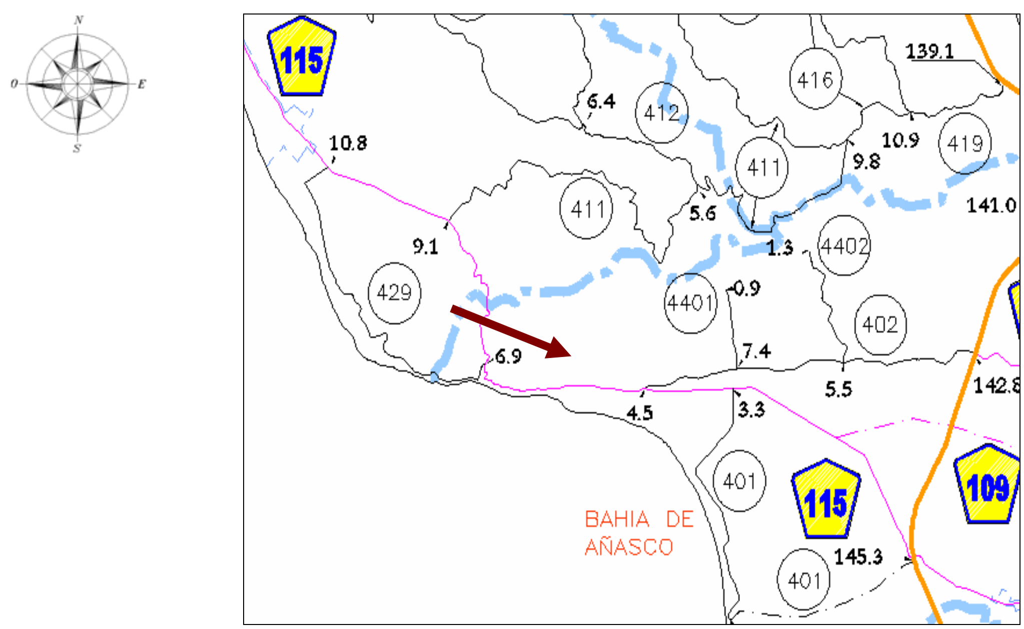


Figure 5.10: PR-115 segment location, km. 7.0-7.1, Municipality of Añasco.

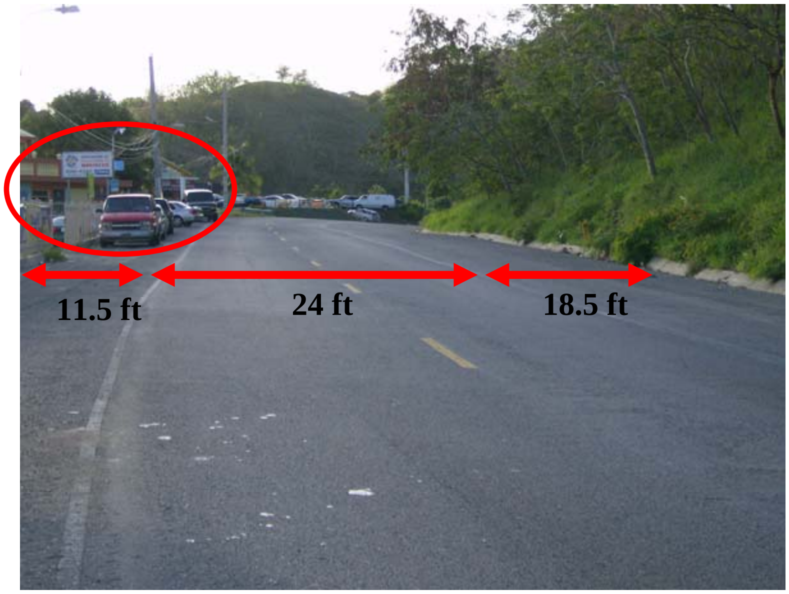


Figure 5.11: Motor vehicles parked on the shoulder along PR-115 km 7.0-7.1

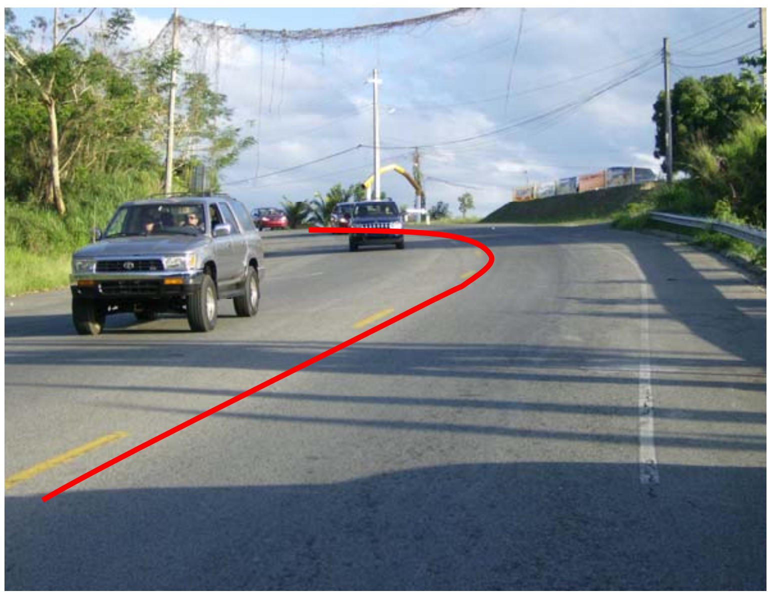


Figure 5.12: Vertical and horizontal curves, PR-115 km 7.0-7.1, Municipality of Añasco.

According to the statistics, most of the fatal crashes occurred during the weekend on Fridays and Saturdays by 83%. All of them were at night from 6 pm to 6am, with most of the crashes occurring from 9pm to 3am. In 33% of the cases alcohol was related to the crashes. Other causes involved were forbidden maneuvers, losing control of the vehicle, and not seeing object or person. Table 5.18 summarizes these characteristics.

Table 5.18: Characteristics of Fatal Crashes at PR-115 km 7.0-7.1

(a) Time fatality occurred

Period of Time	Total Frequency	Percent
12:01am - 3:00am	2	33.3
3:01am - 6:00am	1	16.7
6:01am -9:00am	0	0.0
9:01am - 12:00pm	0	0.0
12:01pm - 3:00pm	0	0.0
3:01pm - 6:00pm	0	0.0
6:01pm - 9:00pm	1	16.7
9:01pm - 12:00am	2	33.3
Total	6	100

(b) Day of Occurrence

Day of Week	Code	Frequency	Percent
Monday	1	1	16.7
Tuesday	2	0	0.0
Wednesday	3	0	0.0
Thursday	4	0	0.0
Friday	5	2	33.3
Saturday	6	3	50.0
Sunday	7	0	0.0
	Total	6	100

(c) Presence of Alcohol in the Blood

Over BAC	Frequency	Percent
Yes	2	33.3
No	4	66.7
Unknown	0	0.0
Total	6	100

(d) Under the effect of drugs

Drugs	Frequency	Percent
Yes	0	0.0
No	6	100.0
Unknown	0	0.0
Total	6	100

(e) Type of Infraction

Infraction	Code	Frequency	Percent
Other	0		0
Over speed limit	1		0
drunk	2	2	33.3
traffic control	3		0
Distracted	4		0
Wrong way	5		0
pavement deffect	6		0
mechanical deffect	7		0
forbidden maneuver	8	1	16.7
pedestrian violation	9		0
hit and run	10		0
obstructed visibility	11		0
none	12		0
not yielding	13		0
out of control	14	1	16.7
not leaving distance	15		0
not seeing object or person	16	1	16.7
overload	17		0
weather	18		0
n/a	19	1	17
go cart	20		0
speeding	21		0
forbidden reverse	22		0
forbidden turn	23		0
forbidden lane pass	24		0
has been drinking	25		0
driver condition	26		0
passw/out care	27		0
under alcohol effects	28		0
other	99		0
	Total	6	100

5.4.3. PR-459 km 4.0-4.1, Aguadilla

The road PR-459 is located in Aguadilla. It starts at PR-2 km 125.1 and runs north-east ending at Isabela. Figure 5.13 shows a map of the location of the segment. The segment is on a suburban area, about a kilometer after the Interamerican Univeristy of Aguadilla. Kilometer 4 is the intersection with PR-467. It is an asymmetrical intersection. It is a T intersection where the PR-467 connects in an angle to the PR-459. The segment starts in a straight section and ends in a right horizontal curve. Posted speed limit is 35 mph. See Figure 5.14.

There is one lane per direction, 16ft wide each. There are no shoulders, but the right side provides a sidewalk. Dashed thermoplastic pavement markings. No relevant pavement defects, only low severity weathering is appreciated. Electric and illumination systems are present on the left side of the road. There are many trees on the right side that project their shadow on the roadway. On the left side there are a few accesses to houses located along the road. Figure 5.15 shows some of the characteristics mentioned above.

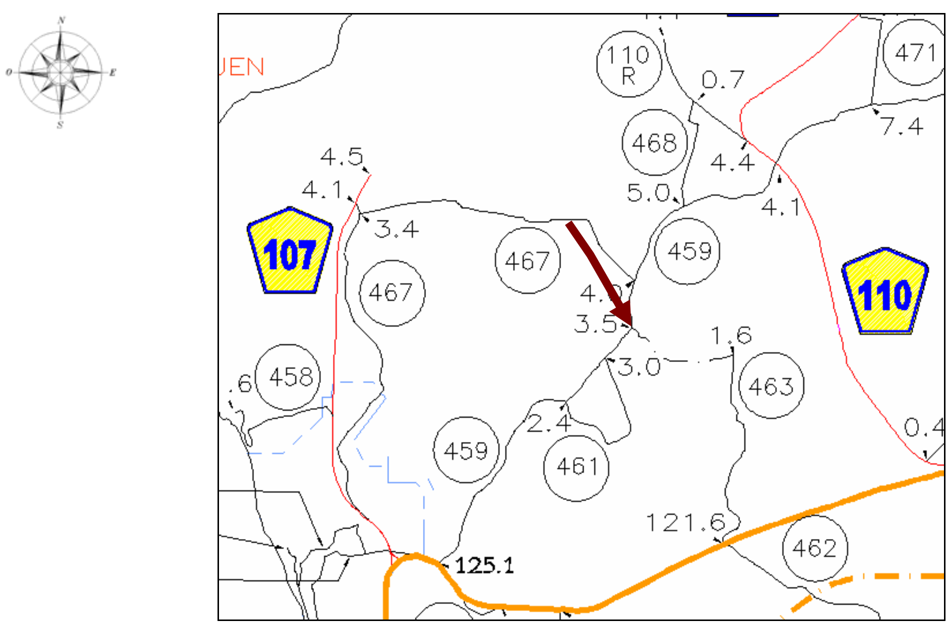


Figure 5.13: PR-459 segment location, km 4.0 to 4.1, Municipality of Aguadilla.

Double sign of PR-459 and Int. PR-467 are located 7.5ft high with a lateral distance of 6ft 8in from the border of the road. Lateral distance from border of road to house fence is 15ft 4 in.

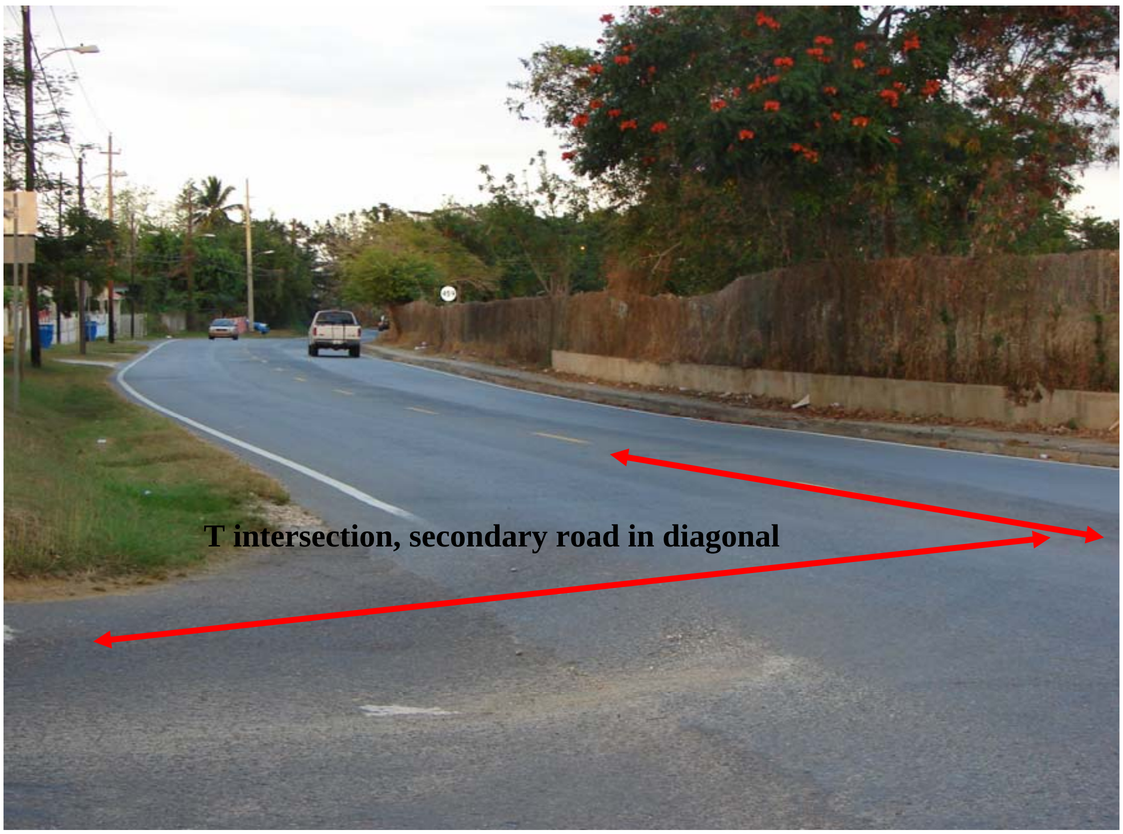


Figure 5.14: PR-459 Intersection with PR-467 Municipality of Aguadilla.

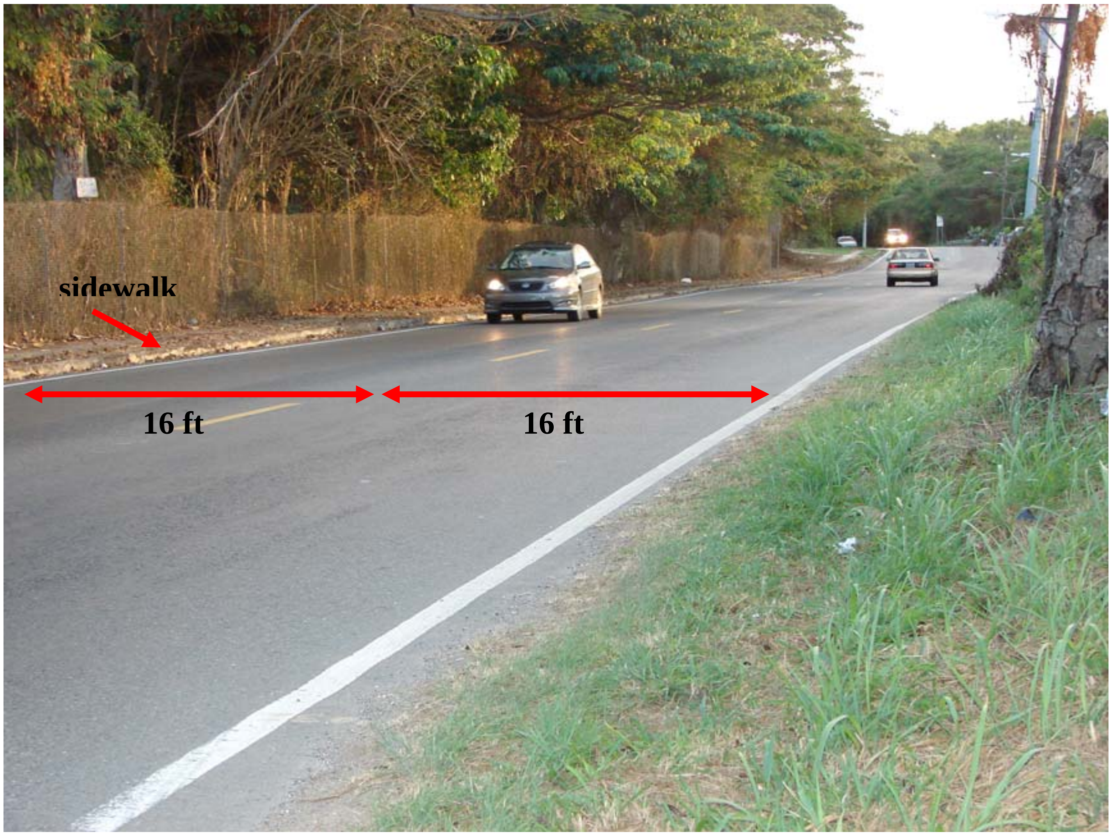


Figure 5.15: PR-459 km 4.0-4.1 Municipality of Aguadilla.

Most of the fatalities take place on Saturdays with a 60%. Crashes occur during day and night with no specific trend on the time period variable. Main reason for these accidents is driving in the wrong way. Secondary causes are: driving over speed limit, and hit and run. One crash was related to the use of drugs, and none to the use of alcohol. These data are in more detail in Table 5.19.

Table 5.19: Characteristics of Fatal Crashes at PR-459 km 4.0-4.1

(a) Time fatality occurred

Period of Time	Total Frequency	Percent
12:01am - 3:00am	1	20.0
3:01am - 6:00am	0	0.0
6:01am -9:00am	0	0.0
9:01am - 12:00pm	2	40.0
12:01pm - 3:00pm	0	0.0
3:01pm - 6:00pm	1	20.0
6:01pm - 9:00pm	0	0.0
9:01pm - 12:00am	1	20.0
Total	5	100

(b) Day of Occurrence

Day of Week	Code	Frequency	Percent
Monday	1	0	0.0
Tuesday	2	1	20.0
Wednesday	3	0	0.0
Thursday	4	1	20.0
Friday	5	0	0.0
Saturday	6	3	60.0
Sunday	7	0	0.0
	Total	5	100

(c) Presence of Alcohol in the Blood

Over BAC	Frequency	Percent
Yes	0	0.0
No	5	100.0
Unknown	0	0.0
Total	5	100

(d) Under the effect of drugs

Drugs	Frequency	Percent
Yes	1	20.0
No	4	80.0
Unknown	0	0.0
Total	5	100

(e) Type of Infraction

Infraction	Code	Frequency	Percent
Other	0		0
Over speed limit	1	1	20.0
drunk	2		0
traffic control	3		0
Distracted	4		0
Wrong way	5	3	60.0
pavement deffect	6		0
mechanical deffect	7		0
forbidden maneuver	8		0
pedestrian violation	9		0
hit and run	10	1	20.0
obstructed visibility	11		0
none	12		0
not yielding	13		0
out of control	14		0
not leaving distance	15		0
not seeing object or person	16		0
overload	17		0
weather	18		0
n/a	19		0
go cart	20		0
speeding	21		0
forbidden reverse	22		0
forbidden turn	23		0
forbidden lane pass	24		0
has been drinking	25		0
driver condition	26		0
passw/out care	27		0
under alcohol effects	28		0
other	99		0
	Total	5	100

5.4.4. PR-2 km 154.8-155.3, Mayagüez

This segment covers the distance from the Viaduct to midway between the Nenadich Street intersection and the Duscombe Avenue intersection. The segment location is shown by a map in Figure 5.16. The segment included two signalized intersections with Christy St, and Nenadich St. See Figure 5.17. Just a few months ago ended a PRHTA project in the area, constructing a connector with PR-102 which eliminated the intersection with Christy St. This intersection was approximately less than 330 ft apart from the next one (Nenadich St.). The intersection with Nenadich Street is unleveled as shown in Figure 5.18. This is an urban residential and commercial area. Some facilities nearby are the University of Puerto Rico, Mayagüez Campus, Government Center, schools, Baseball Park, and public residential buildings.

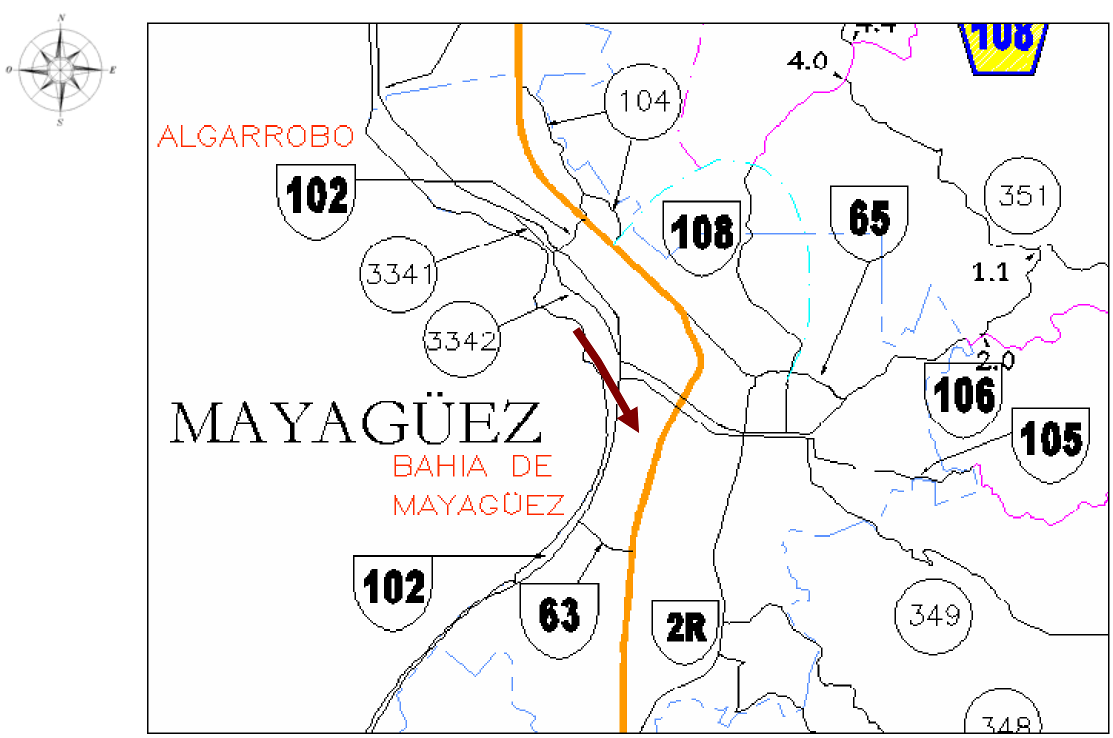


Figure 5.16: PR-2 segment location, km 154.8 to 155.3, Municipality of Mayagüez

In the Mayagüez-Hormigueros direction, the segment starts at the Viaduct with two lanes with right shoulder, concrete median and lateral barriers, and lighting system both at the median and at the roadside. Right after leaving the Viaduct the intersection with Christy St. was eliminated. From that point, there are three lanes plus right shoulder, aerial lighting and electrical systems on the roadside, islands on the median and right side. There are many patches on the pavement mostly on the left lane. There is a pedestrian bridge halfway to the next intersection that connects two public residential areas. Posted speed limit is 45 mph.

In the Mayagüez-Añasco direction there are sections of guardrail, sections of concrete barriers, sections of sidewalk, and the Viaduct in this direction which is the old section has steel rails.

Figure 5.17: Consecutive intersections at PR-2 km 154.8-155.3, Municipality of Mayagüez.

Figure 5.18: The intersection at PR-2 km 154.8-155.3, Municipality of Mayagüez

In this road segment, 40% of the fatalities occurred on Saturdays, and the other 60% is distributed evenly throughout the week, except for Sundays and Mondays. 65 % were from 6pm to midnight. 30% of the fatal crashes were related to alcohol, and 25% to drugs. The main causes of fatal crashes in descendent order are: disobeying a traffic control, over speed limit, and not seeing object or person with 30%, 25% and 20%, respectively. Table 5.20 contains the data just mentioned.

Table 5.20: Characteristics of Fatal Crashes at PR-2 km 154.8-155.3

(a) Time fatality occurred

Period of Time	Total Frequency	Percent
12:01am - 3:00am	1	5.0
3:01am - 6:00am	2	10.0
6:01am -9:00am	2	10.0
9:01am - 12:00pm	1	5.0
12:01pm - 3:00pm	1	5.0
3:01pm - 6:00pm	0	0.0
6:01pm - 9:00pm	9	45.0
9:01pm - 12:00am	4	20.0
Total	20	100

(b) Day of Occurrence

Day of Week	Code	Frequency	Percent
Monday	1	1	5.0
Tuesday	2	3	15.0
Wednesday	3	2	10.0
Thursday	4	3	15.0
Friday	5	3	15.0
Saturday	6	8	40.0
Sunday	7	0	0.0
	Total	20	100

(c) Presence of Alcohol in the Blood

Over BAC	Frequency	Percent
Yes	6	30.0
No	11	55.0
Unknown	3	15.0
Total	20	100

(d) Under the effect of drugs

Drugs	Frequency	Percent
Yes	5	25.0
No	11	55.0
Unknown	4	20.0
Total	20	100.0

(e) Type of Infraction

Infraction	Code	Frequency	Percent
Other	0		0
Over speed limit	1	5	16.7
drunk	2		0
traffic control	3	6	20.0
Distracted	4		0
Wrong way	5		0
pavement deffect	6		0
mechanical deffect	7		0
forbidden maneuver	8	1	3.3
pedestrian violation	9	1	3.3
hit and run	10	1	3.3
obstructed visibility	11		0
none	12		0
not yielding	13	1	3.3
out of control	14	1	3.3
not leaving distance	15		0
not seeing object or person	16	4	13.3
overload	17		0
weather	18		0
n/a	19		0
go cart	20		0
speeding	21		0
forbidden reverse	22		0
forbidden turn	23		0
forbidden lane pass	24		0
has been drinking	25		0
driver condition	26		0
passw/out care	27		0
under alcohol effects	28		0
other	99		0
	Total	20	66.7

5.4.5. PR-2 Km. 172.0-172.1, San Germán

This segment of PR-2 in right before km 172.4 at which is the signalized T-shape intersection with PR-119. About a kilometer after this, there is La Concepcion Hospital and Plaza del Oeste shopping center. Figure 5.19 shows a map of the location of the segment.

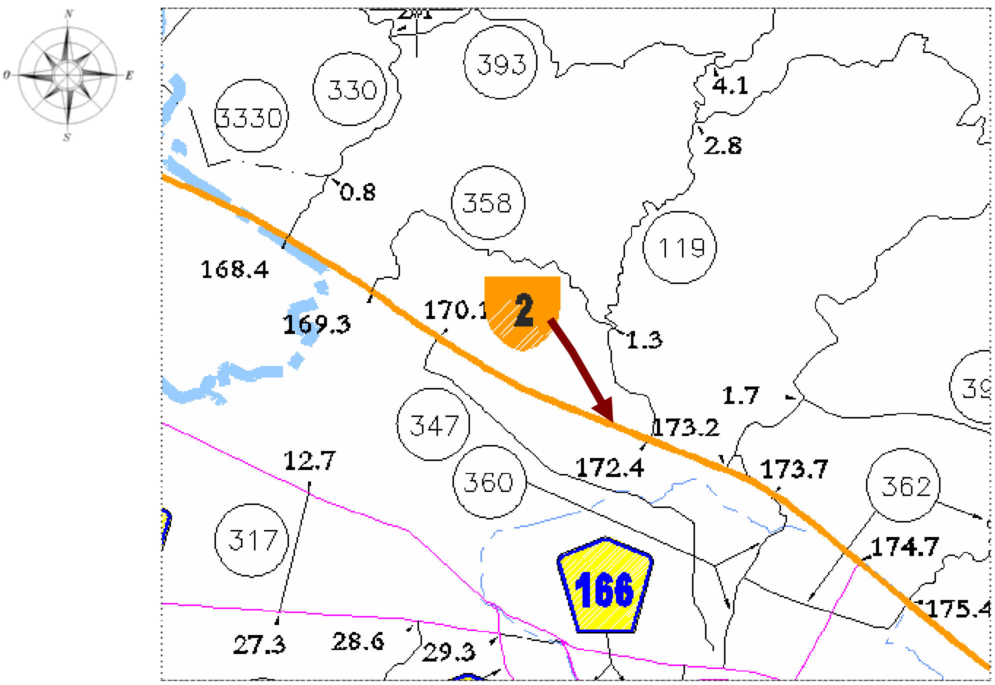


Figure: 5.19: PR-2 segment location, km 172.0 to 172.1, San Germán.

Road segment has two lanes per direction 12 ft wide each. There are right and left shoulders of 9.5ft and 10.5 ft, respectively. Both directions are separated by a median barrier. There is an aerial electrical system running through the left side. No illumination was in the area previous to the Conversion to Expressway project that recently built a bridge that will eliminate the actual intersection at km 172.4 and relocate the entrance to PR-119. Thermoplastic pavement markings are weared out. No presence of raised pavement markings. Posted speed limit is 55 mph, terrain is level. There are signs for intersection with PR-119, and for presence of traffic signal system. This is mainly an urban area. W-beam strong post guardrail installed on the right side of the roadway, was impacted and have not been replaced. It also has steel block-out which does not meet the requirements of NCHRP 350. See Figures 5.20 and 5.21. Obviously, the construction project did not change the guardrail. In fact, only new installations use the rubber block-out. If the same guardrail is reinstalled, the steel block-outs are not replaced.

Figure 5.20: PR-2 km 172.0-172.1, Municipality of San Germán

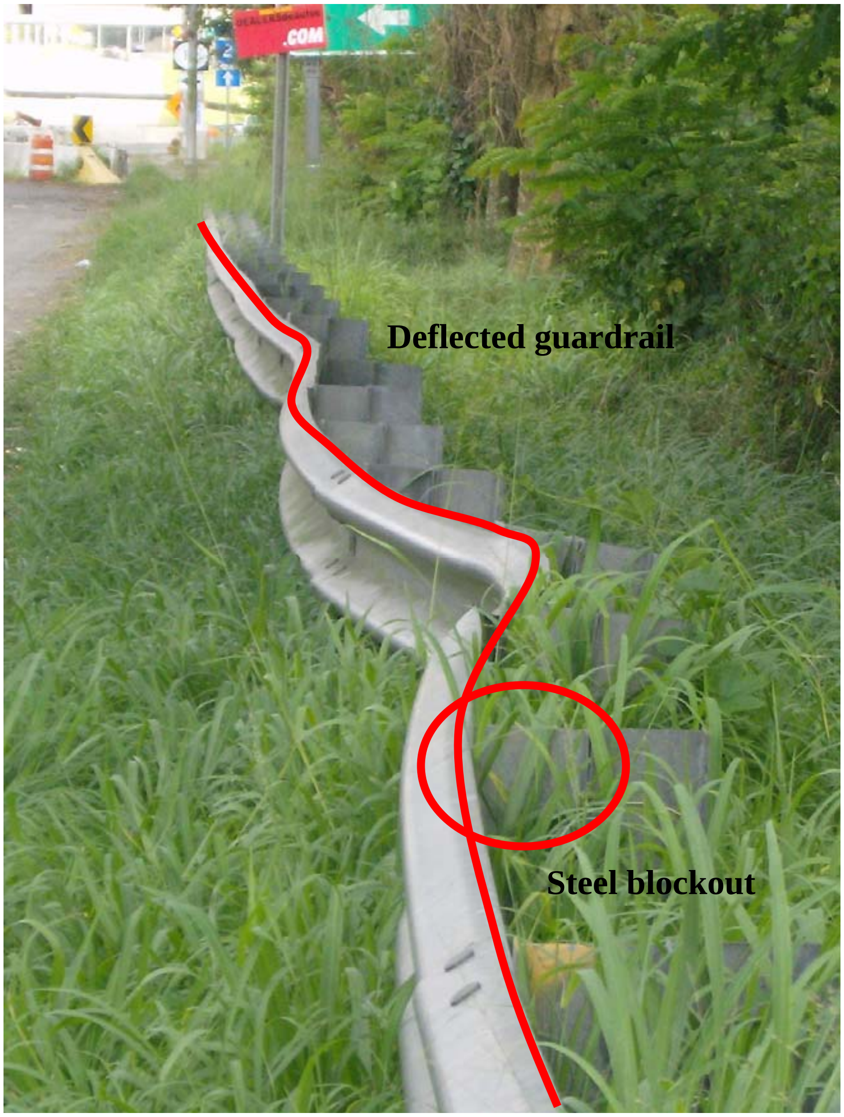


Figure 5.21: Section of W beam strong post guardrail on PR-2 km 172.0-172.1, Municipality of San Germán.

All fatal crashes occurred on Thursday, Friday and Sunday. No significant difference in the hour of occurrence is noted. None of the rashes were related to alcohol and only 20% was related to drugs usage. Driving over the speed limit was the main cause of crashes, with 60%. Not yielding and losing control of the vehicle were the other cause with 20% each. Table 5.21 presents these data.

Table 5.21: Characteristics of Fatal Crashes at PR-2 km 172.0-172.1

(a) Time fatality occurred

Period of Time	Total Frequency	Percent
12:01am - 3:00am	0	0.0
3:01am - 6:00am	0	0.0
6:01am -9:00am	1	20.0
9:01am - 12:00pm	0	0.0
12:01pm - 3:00pm	1	20.0
3:01pm - 6:00pm	1	20.0
6:01pm - 9:00pm	0	0.0
9:01pm - 12:00am	2	40.0
Total	5	100

(b) Day of Occurrence

Day of Week	Code	Frequency	Percent
Monday	1	0	0.0
Tuesday	2	0	0.0
Wednesday	3	0	0.0
Thursday	4	2	40.0
Friday	5	1	20.0
Saturday	6	0	0.0
Sunday	7	2	40.0
	Total	5	100

(c) Presence of Alcohol in the Blood

Over BAC	Frequency	Percent
Yes	0	0.0
No	4	80.0
Unknown	1	20.0
Total	5	100

(d) Under the effect of drugs

Drugs	Frequency	Percent
Yes	1	20.0
No	2	40.0
Unknown	2	40.0
Total	5	100.0

(e) Type of Infraction

Infraction	Code	Frequency	Percent
Other	0		0
Over speed limit	1	3	10.0
drunk	2		0
traffic control	3		0
Distracted	4		0
Wrong way	5		0
pavement deffect	6		0
mechanical deffect	7		0
forbidden maneuver	8		0
pedestrian violation	9		0
hit and run	10		0
obstructed visibility	11		0
none	12		0
not yielding	13	1	3.3
out of control	14	1	3.3
not leaving distance	15		0
not seeing object or person	16		0
overload	17		0
weather	18		0
n/a	19		0
go cart	20		0
speeding	21		0
forbidden reverse	22		0
forbidden turn	23		0
forbidden lane pass	24		0
has been drinking	25		0
driver condition	26		0
passw/out care	27		0
under alcohol effects	28		0
other	99		0
	Total	5	16.7

5.5. Discussion of Results

After comparing the fatal crashes data versus the site inspection data for each of the five hazardous locations, it can be concluded that indeed there are safety issues in the segments, but also the surroundings and use of the road play an important role in fatality trends.

There is an evident difference between arterials and secondary or tertiary roads. The arterial PR-2 is the road with more fatalities in the western region of the island; it is also the longest one with approximately 105 kilometers of roadway. The shortest in the analysis was PR-107 with 4.6 kilometers of longitude. From the 15 segments chosen for further analysis, 7 were located in PR-2, which is 47% of the total.

Results showed that although the major cause for fatal crashes is user behavior, highway safety conditions play a fundamental role in the magnitude of crashes. Prove of that is that all the segments studied in depth showed safety deficiencies that combined with alcohol, negligence, or tiredness turned them into hazardous locations. Designing forgiving roads definitively would reduce crash frequency and severity, which are the variables that could be modified given that volume commonly keeps growing.

After the HI_f analysis, several observations regarding the relation between variables emerged. The frequency and the HI_f are directly proportional, but not at the same rate (See Figure 5.22).

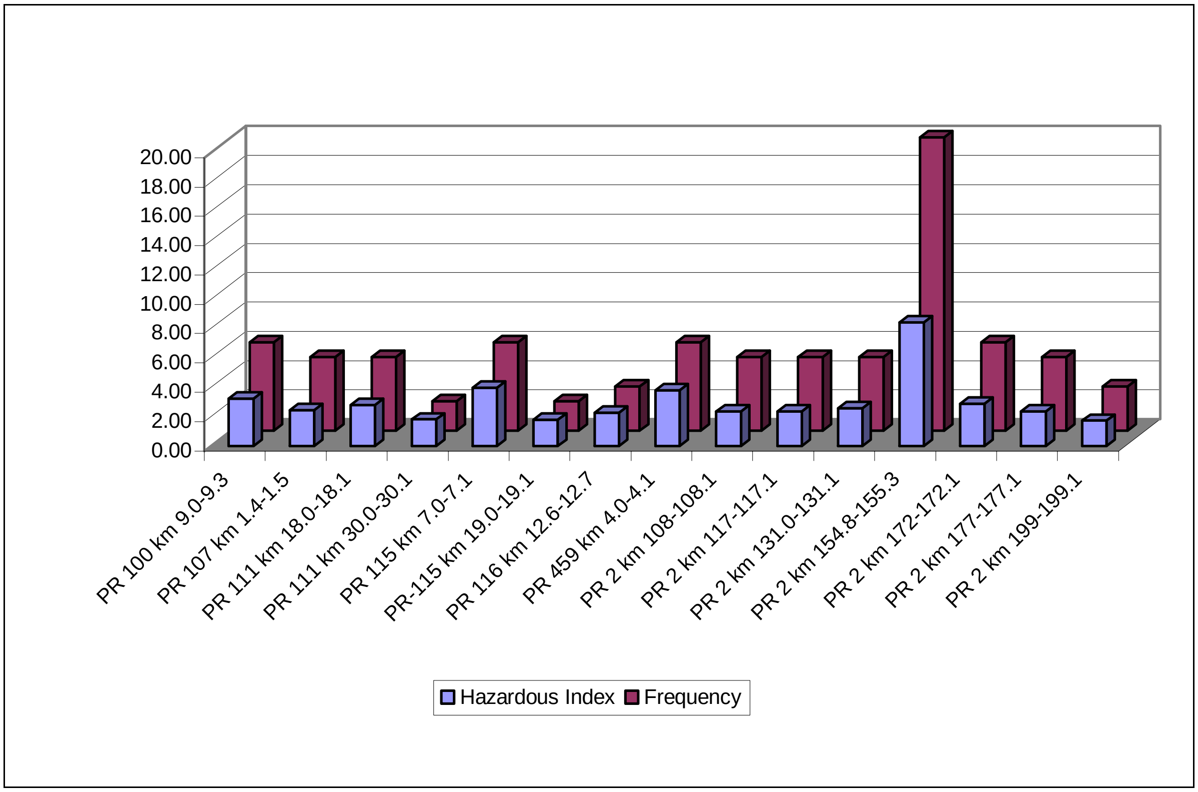


Figure 5.22: Comparison of Hazardous Index and Frequency for road segments initially analyzed with Pareto diagram.

RMVM variable which considers accident frequency, traffic volume and segment length, demonstrates that high frequency is more critical at segments with lower traffic volumes. For this research, the segment length is a constant of 0.2 km. This allowed observing the relation between fatality frequency and traffic volume, and its effect in hazardous locations. For example, Figure 5.23 shows that for PR-2 km 154.8-155.3, frequency is 25% the RMVM of the element. For PR-115 km 7.0-7.1, it is 5%.

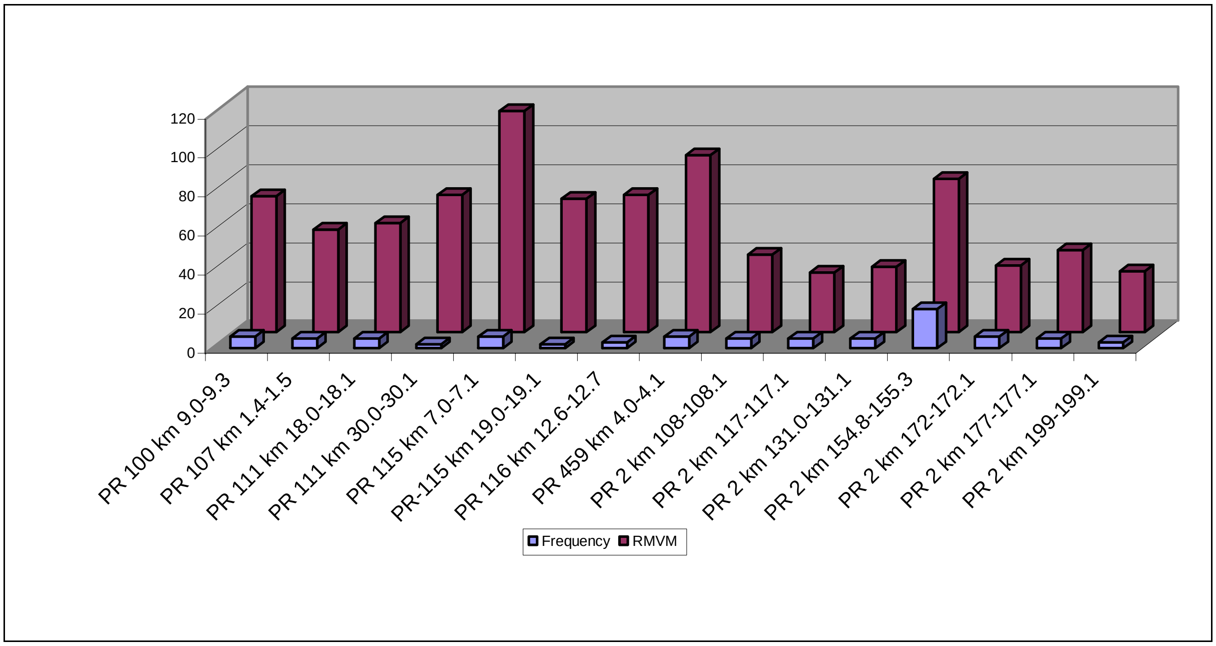


Figure 5.23: Comparison of Frequency and Rate per Hundred Million Vehicle Miles for road segments initially analyzed with Pareto diagram.

For PR-2 from 1995 to 2000, kilometers were identified by its integer with no detail of the hectometer. From 2001 to 2003 the hectometer detail was given. In this case the segment of km 172.0-172.1 initially seemed an intersection, but is a basic segment near the intersection with PR-119. This confirms that results are tied to the data collection process and entry into the database system.

In the case of PR-459 km 4.0-4.1 it is the intersection with PR-467. It is an asymmetrical intersection type T controlled by a STOP sign. PR-467 is the secondary road and it is difficult to get into PR-459 because drivers travel at fast speeds and there is a large traffic volume due to the university that is located near by. Probably drivers at the stop get impatient and student drivers that travel the PR-459 use to pass other vehicles that do not travel as fast as them.

For PR-115 km. 7.0-7.1, it is a short segment with critical safety issues. It has a combination of vertical and horizontal curves, with no illumination nor pavement raised delineators. There are many restaurants and night clubs in the area and it is also a tourist area. All these elements fit with the fatal crashes occurrence at the segment which are related to speed, alcohol, nighttime and weekends.

PR-100 km. 9.0-9.3 and PR-2 km. 154.8-155.3 are longer segments with particular characteristics. In the case of PR-100, the segment is located in a suburban area, the road is wide, and gives a sense of safety when driving by it, people tend to drive fast in the area. Probably, drivers feel so confident about the road that get distracted and this fact in combination with high speed and no illumination at night, make crashes occur. Also, this is a road that is driven by users at certain times of the year because Cabo Rojo is a tourist area and PR-100 leads to many beaches and festivals.

Initial inspection of road network and initial 2 km division allowed identifying the weaknesses of the process specially related to the longitude of the segment under study. In 2 km segments, intersections and basic segments were together and probably sections of the segment identified as hazardous did not belong there. The 0.2 km division made possible the identification of more specific deficiencies and causes of fatal crashes. It also made easier the aggregation of hazardous segments that had the same characteristics and may be identified as one longer segment.

6. Conclusions and Recommendations

6.1. Conclusions

The main purpose of this research was to develop a procedure for the identification and ranking of hazardous locations related to fatal crashes. Also the research intended to identify possible causes of crashes and provide recommendations for improvements of those hazardous locations.

The major contribution of this research is that with limited resources, given that the only available database was from the TSC, and that just a few locations and years had AADT data, the Pareto technique was applied in a powerful manner that by controlling the length of each road element made it possible for the effect of intersection and segment being irrelevant during the hazardous element identification process. Traditionally, three-year study periods are used to establish a representative trend in crash patterns. Study periods of five years or more are considered to be imprecise because traffic volume, road geometry, and other characteristics may change. The advantage of this methodology in establishing a longer study period (9 years) is that potential geometry deficiencies that have not been corrected by the PRHTA for lack of funds can be identified.

This research also led to the conclusion that in Puerto Rico most of the highway crashes are at intersections. Eighty percent of elements identified as the most hazardous in the western region of the island are related to intersections. Considering, a methodology for the analysis of intersections is available; it is recommended to apply it on the selected elements to study them in more depth [32].

Through the development of the methodology, it was concluded that frequency by itself is not a reliable variable for determining if a segment is more hazardous than others. However, RMVM takes the traffic volume into account, which is a very important factor to consider because for instance, many fatalities in a high volume road are not as severe as having many fatalities in a low volume road.

Other finding is that short segments (0.2 km in this case) allow discerning problems in an intersection from problems in contiguous segments. Longer segments could mix intersections with segments and consequently very important information would be lost.

Other general conclusions are:

- Roads near tourist centers does not show specific hour trends for fatalities, but finding a fair ample and uncongested road could create a comfort sense to the driver that could distract his attention from the road.
- The same comfort could lead a regular user to attempt forbidden maneuvers without complete precaution.
- Night commercial areas such as restaurants and pubs are directly related with crashes where blood alcohol content is over the limit and drivers lose control of their vehicles especially in curves.
- For arterial segments, in straight sections driving over the speed limit is the main cause of fatal crashes.
- For segments in secondary roads, forbidden maneuvers are the main cause for fatal crashes.
- In segments located near universities most of fatal crashes occur at night, on weekends and are related to alcohol and speed.

6.2. Recommendations

The following recommendations are based on the knowledge gained through the literature review, the database and field inspections of the hazardous locations. Countermeasures for the specific hazardous segments studied in this research are provided. Also, general recommendations are provided as a result of the research process.

- Create awareness among government agencies about the importance of highway safety.
- Importance of good and specific data collection.
- Importance of using data to identify and solve problems at all phases: planning, designing, construction and maintenance.
- Use and improve this methodology. Create a similar one for the DTPW database which considers all type of crashes.
- More aggressive highway safety campaigns in schools, television, radio and roads.
- Change police crash report and make all fields specific.
- Restrict field data entries when passing the data to the database system to reduce human error in the data management process.
- Perform accident studies for results based on before and after countermeasures applications.
- Give maintenance to post markers system. Some segments did not have them or they were in extremely bad conditions. This made harder to identify the segment.
- Train police officers on how to fill out the crash report form.
- The PRHTA should create an office whose sole purpose would be to continuously make road safety audits on existing roads. Each region office should have personnel for this task.
- To establish a percentage of funds for safety improvements projects by the PRHTA.
- Increase the number of traffic patrols on hazardous roads.
- Installation of Intelligent Transportation Systems (ITS) in arterials.

- Improve illumination and pavement markings on secondary roads, especially on asymmetrical intersections and curves.

- Develop a system to take AADT data periodically at strategic points along a road.

- For the long term, police officers could be provided with data collectors. They would input the information and it could be directly transferred to the database which would reduce human error. Also, with the help of a Global Positioning System (GPS) the location of the crash would be accurate regardless of the kilometer markers presence or condition.

For the specific hazardous locations studied in this research, recommendations are provided in Table 6.1 applying the AMF and Table 6.2 applying the CRF where costs are provided too. Law enforcement is also ecommended for these locations, specally where fatal crashes are related to alcohol consumption and driving over the speed limit.

In the case of the two segments at PR-2, construction projects have already modified the geometry of the road. At PR-2 km 154.8 to 155.3 the intersection with Cristie street was eliminated and right and left-turn lanes were provided at intersection with Nenadich Street. A connector with PR-102 was constructed. At PR-2 from km 172.0 to 172.1, currently, there is a project in the area to convert this arterial into an expressway. It will eliminate the intersection and provide a bridge with ramps to access PR-119.

Table 6.1: Recommendations for Hazardous Segments under study applying the AMF.

Rank	Road	Element	HI	Possible Countermeasures		AMF
1	PR 2	km 154.8-155.3	8.46	7-3	General guardrail upgrade	50%
				8-4	Realign intersection	40%
2	PR 115	km 7.0-7.1	3.99	1-2	Curve Warning	30%
				2-11	Flashing Beacon	30%
				3-4	Wide markings	25%
				3-7	Raised pavement markers	20%
				4-1	Lighting	50%
				6-4	Rumble strips	25%
				8-3	Modify horizontal and vertical alignment	40%
				9-1	Eliminate parking	35%
				9-3	Modify speed limits	20%
3	PR 459	km 4.0-4.1	3.83	1-3	Intersection related warning	30%
				2-12	Install flashing beacon at intersection	25%
				2-13	Intersection advance warning flasher	25%
				3-3	Centerline markings	30%
				3-5	No passing zone	25%
				8-4	Realign intersection	40%
4	PR 100	km 9.0-9.3	3.25	3-4	Wide markings	25%
				3-5	No passing zone	40%
				3-7	Raised pavement markers	10%
				7-3	General guardrail upgrade	50%
				8-11	Add passing lane	20%
5	PR 2	km 172-172.1	2.91	3-7	Raised pavement markers	20%
				7-3	General guardrail upgrade	50%

Figure 6.2: Recommendations for Hazardous Segments under study applying the CRF.

Rank	Road	Element	HI	Possible Countermeasures		CRF for Fatal Crashes	CRF for Total Crashes	Typical Cost per Unit	Unit
1	PR 2	km 154.8-155.3	8.46	-	-	-	-	-	-
2	PR 115	km 7.0-7.1	3.99	28	Install Warning Signs and Delineators on Curves	41%	22%	$ 6,450.00	Km
				29	Raised Centerline Pavement Markers	30%	30%	n/a	Km
				83	Prohibit Parking	5%	32%	$ 340.00	sign
				86	Durable Markings	40%	40%	n/a	Km
				74	Flashing Beacons w/Warning Signs Before Inters.	30%	30%	$345	Km
				78	Illuminate Roadway	25%	25%	n/a	Km
3	PR 459	km 4.0-4.1	3.83	29	Raised Centerline Pavement Markers	30%	30%	n/a	Km
				30	Warning Signs	14%	14%	$345	sign
4	PR 100	km 9.0-9.3	3.25	3	Install Guardrail At Embankment	47%	30%	$180,600	Km
				23	Delineators	47%	30%	$1,680	Km
				30	Warning Signs	36%	36%	345.00	sign
				86	Durable Markings	40%	40%	n/a	Km
				31	Non-Traversable (Curbed/Grass) 16 Foot Median	9%	n/a	$183,400	Km
				29	Raised Centerline Pavement Markers	30%	30%	n/a	Km
				78	Illuminate Roadway	25%	25%	n/a	Km
5	PR 2	km 172-172.1	2.91	3	Install Guardrail At Embankment	47%	30%	$180,600	Km

6.3. Recommendations for Further Research

Some recommendations for further research are listed below:

1. Conduct in-depth field inspections to obtain data such as: sight distance, curvature, slopes.

2. Conduct observational studies to detect traffic stream behavior.

3. Develop a computer program to make easier the procedure and analysis for the identification of hazardous locations.

4. Identify changes in segments that had consecutive fatalities occurrence and then stopped having them.

5. Apply methodology to other regions in the island

6. Apply the methodology including non-fatal crashes

7. Develop a Hazardous Index that considers other variables such as geometry, weather, time, pavement defects, and traffic control devices, among others.

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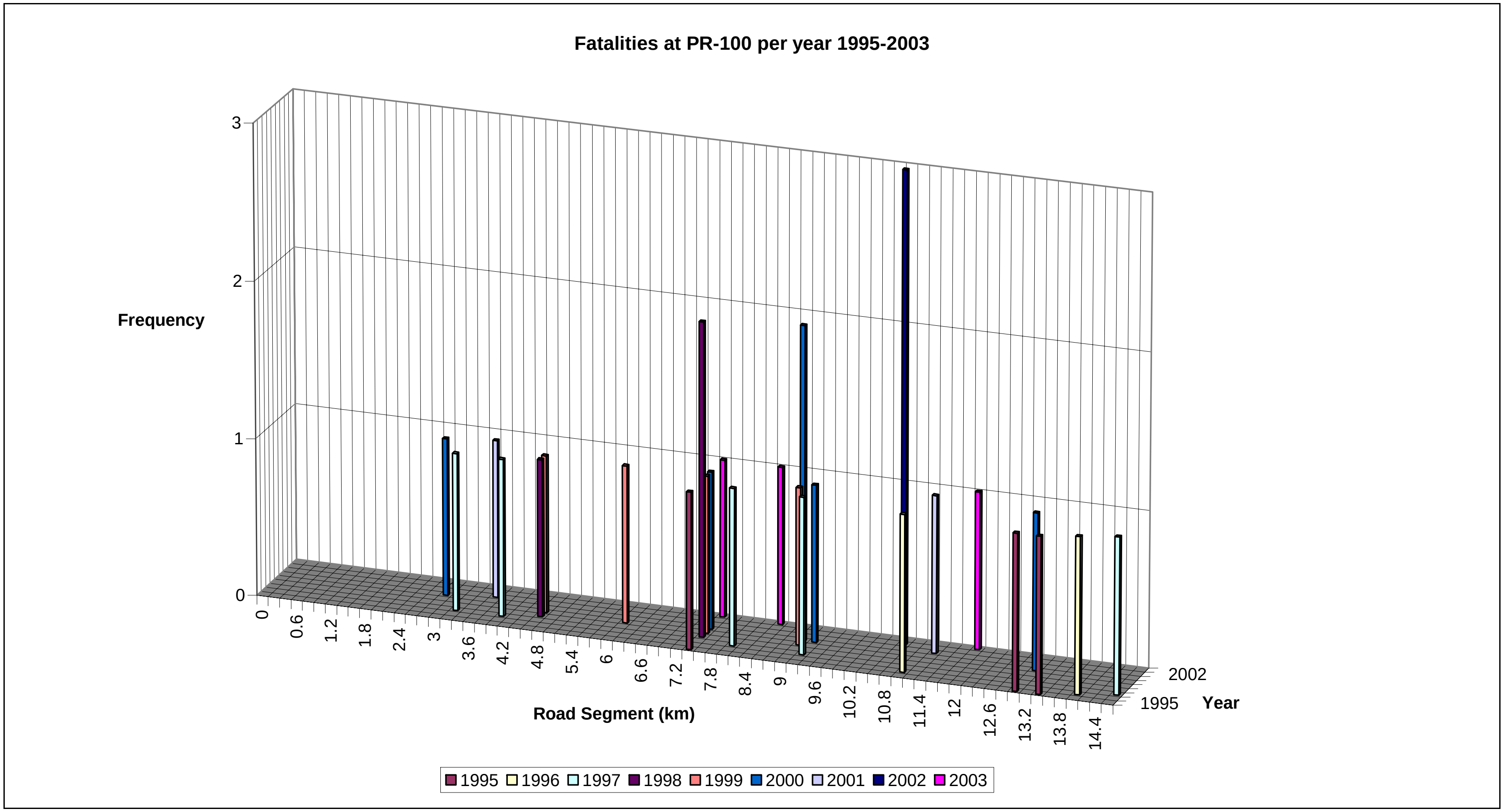
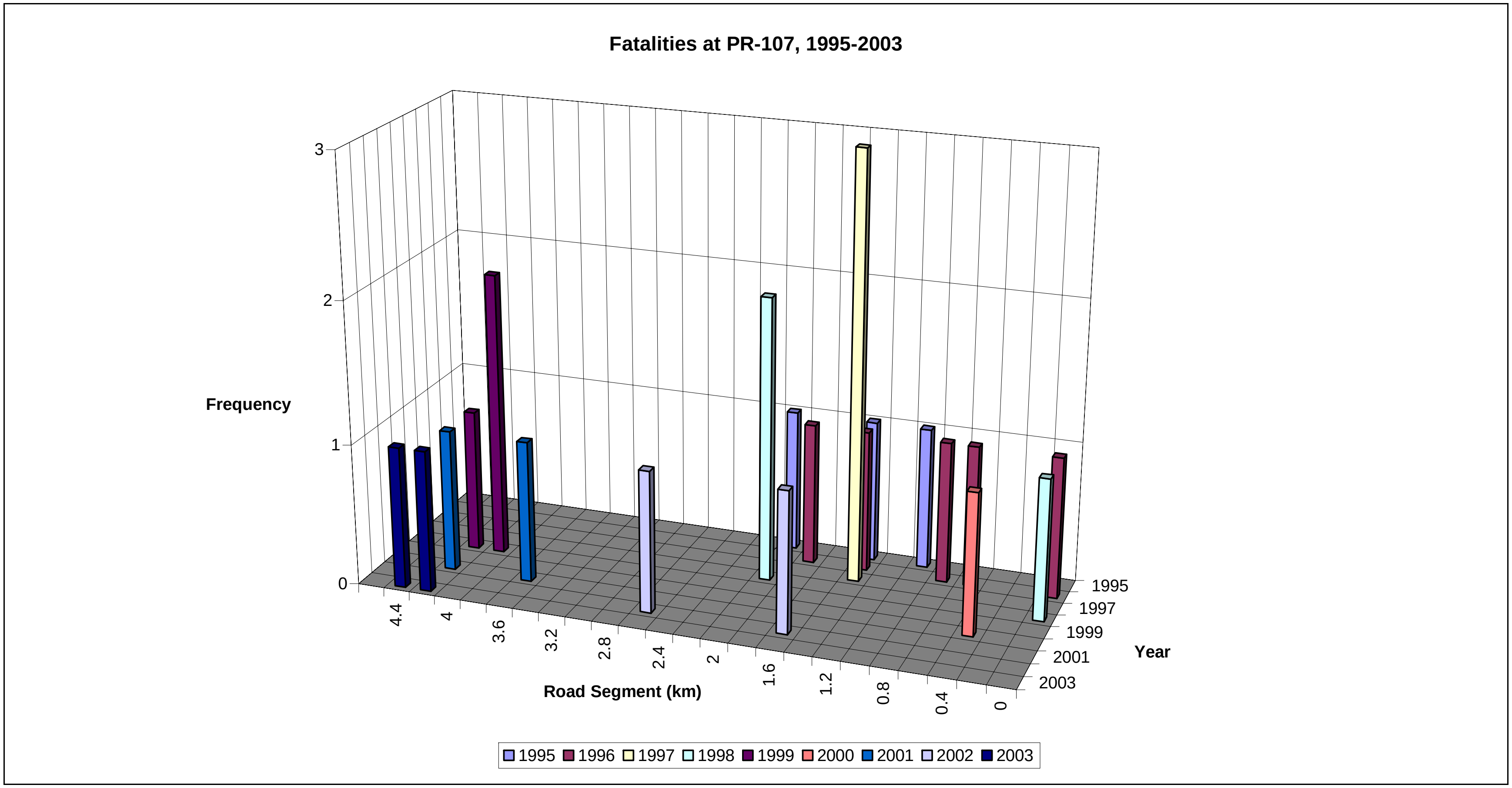
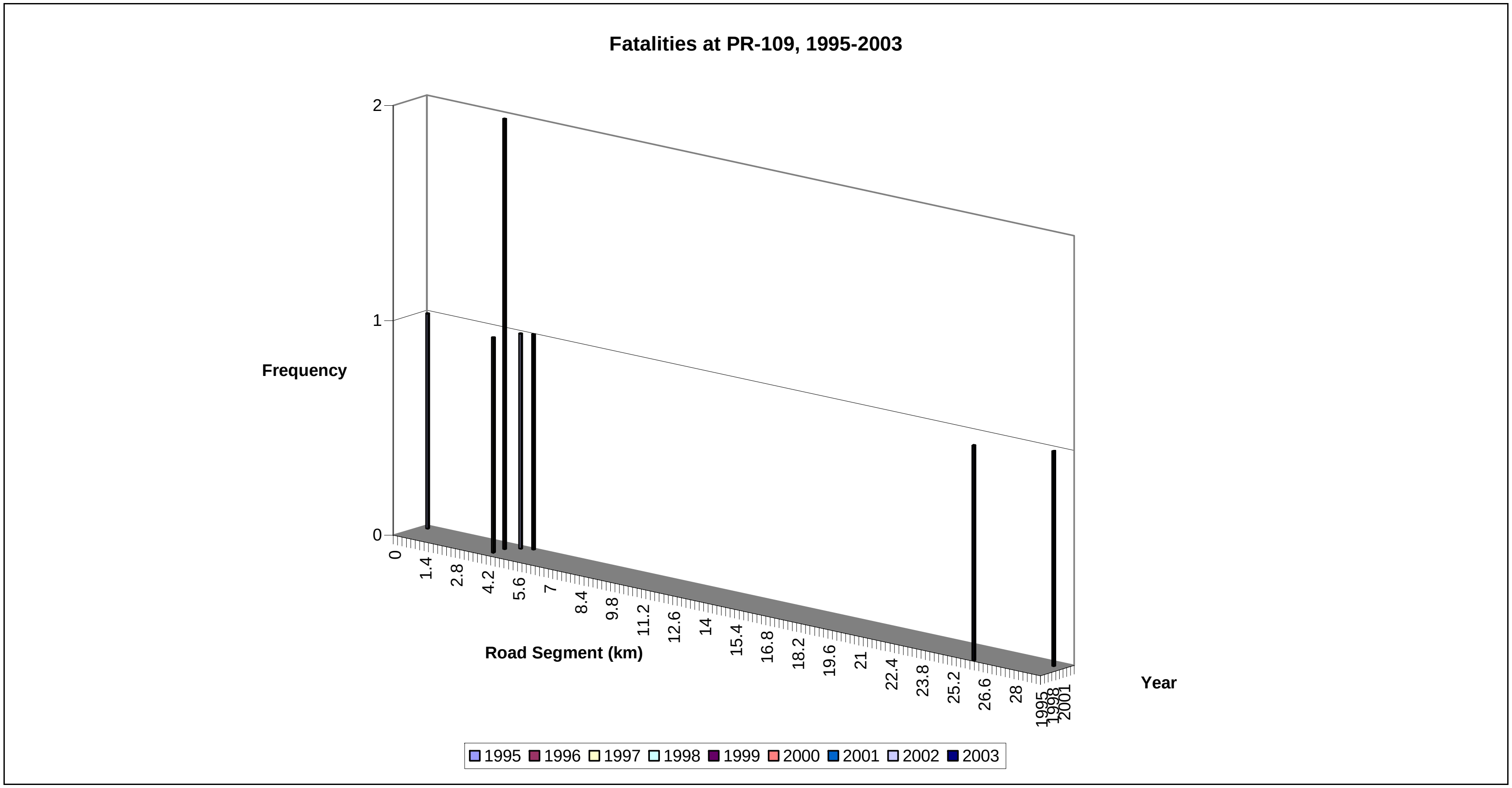
Appendix A: Fatality Frequency Graphs

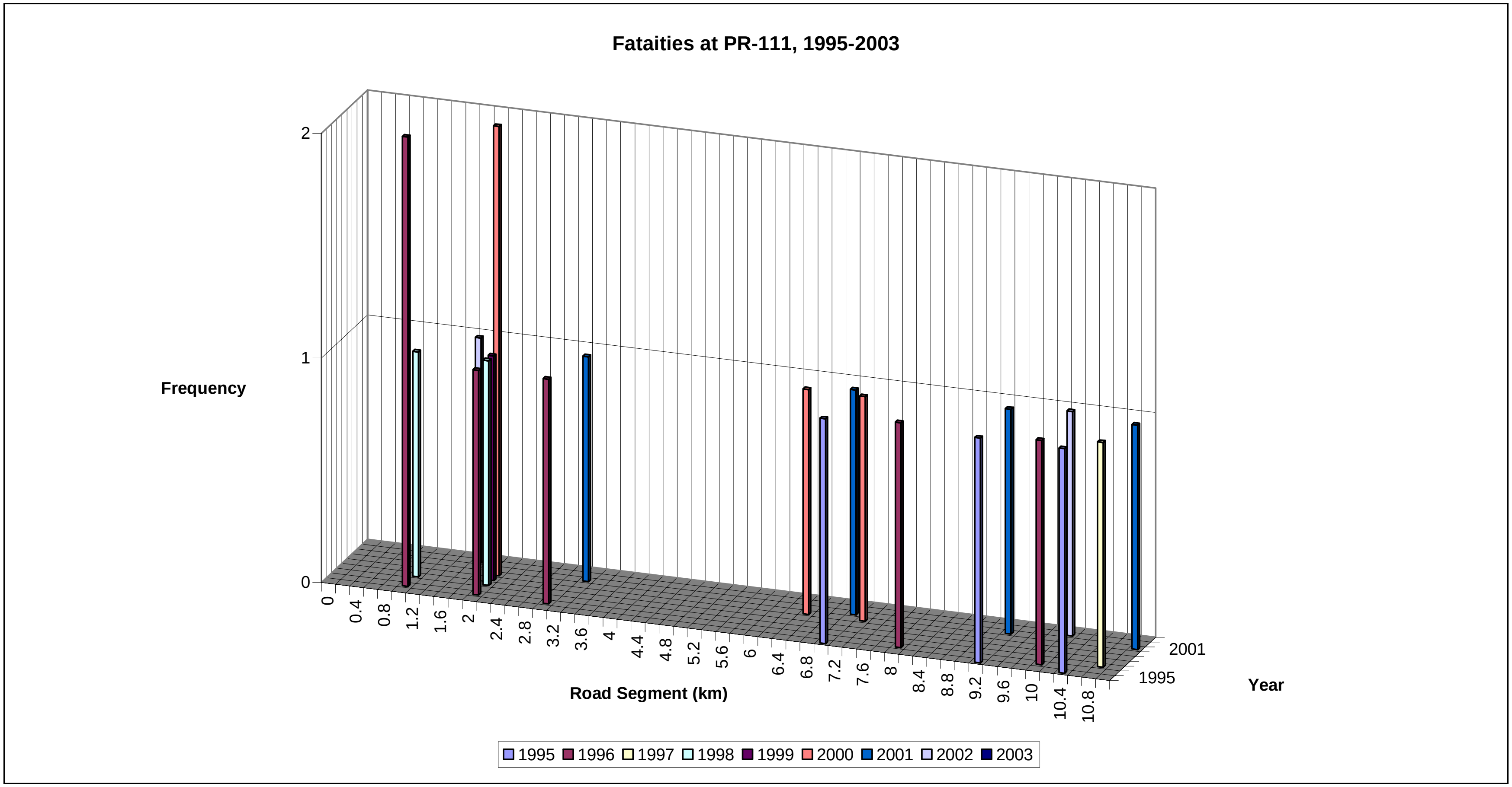


Fatalities at PR-100 per year 1995-2003
Frequency
0
1
2
3
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
5.4
6
6.6
7.2
7.8
8.4
9
9.6
10.2
10.8
11.4
12
12.6
13.2
13.8
14.4
Road Segment (km)
1995
2002
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003

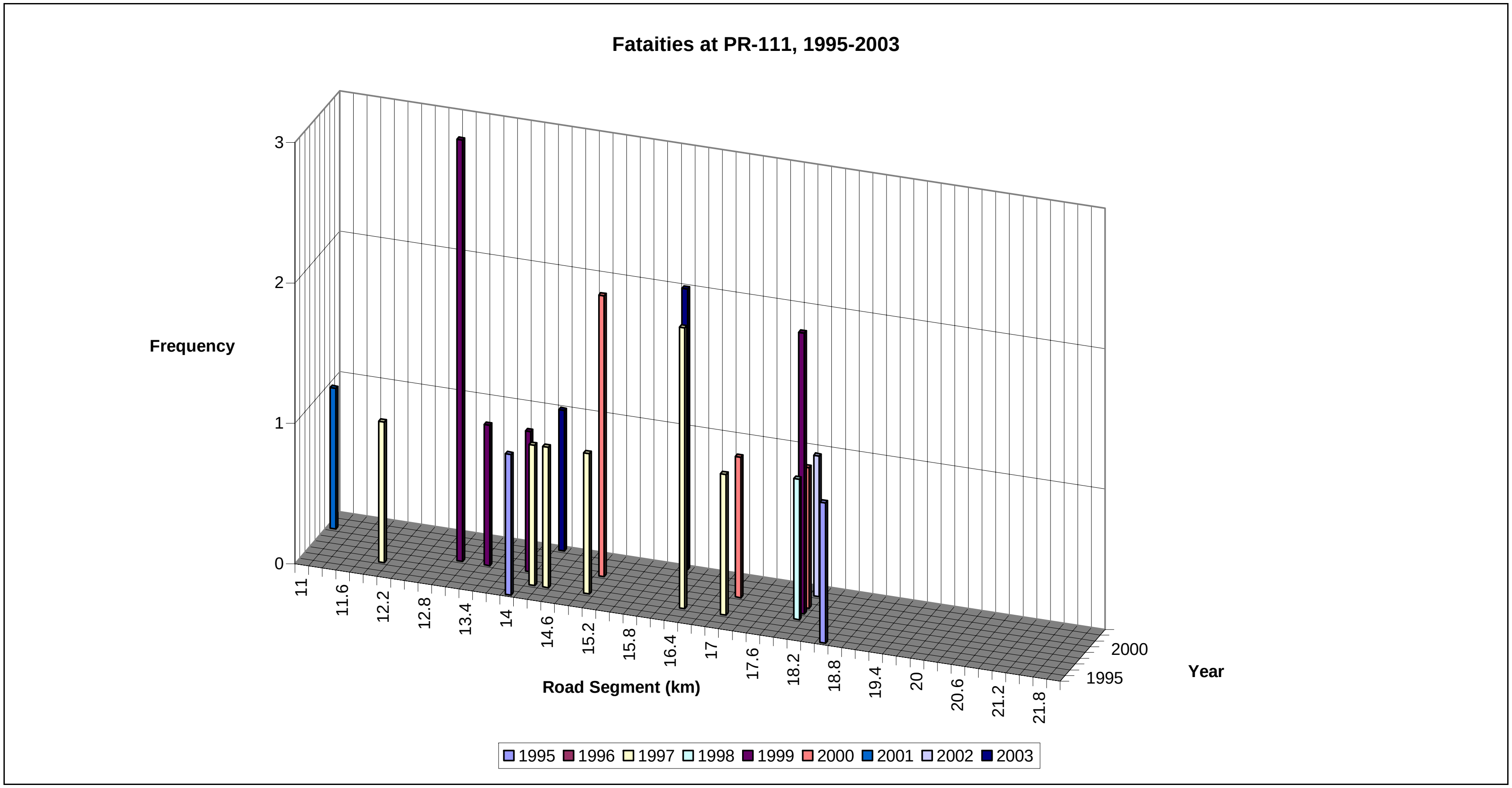

Fatalities at PR-107, 1995-2003
Frequency
3
2
1
0
4.4
4
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
Road Segment (km)
1995
1997
1999
2001
2003
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003



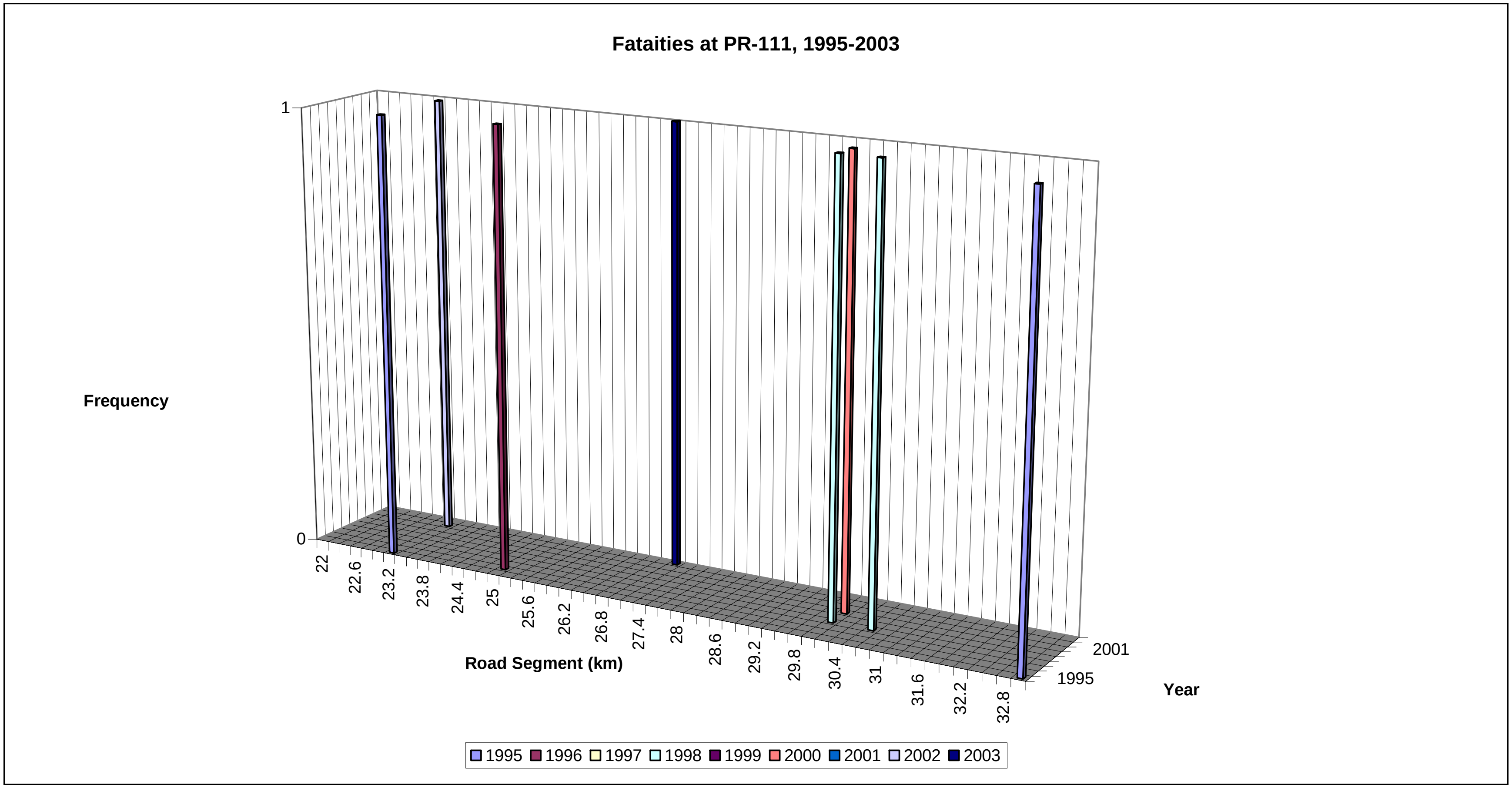
Fatalities at PR-109, 1995-2003
Frequency
0
1
2
Road Segment (km)
0
1.4
2.8
4.2
5.6
7
8.4
9.8
11.2
12.6
14
15.4
16.8
18.2
19.6
21
22.4
23.8
25.2
26.6
28
1995
1998
2001
Year
1995
1996
1997
1998
1999
2000
2001
2002
2003



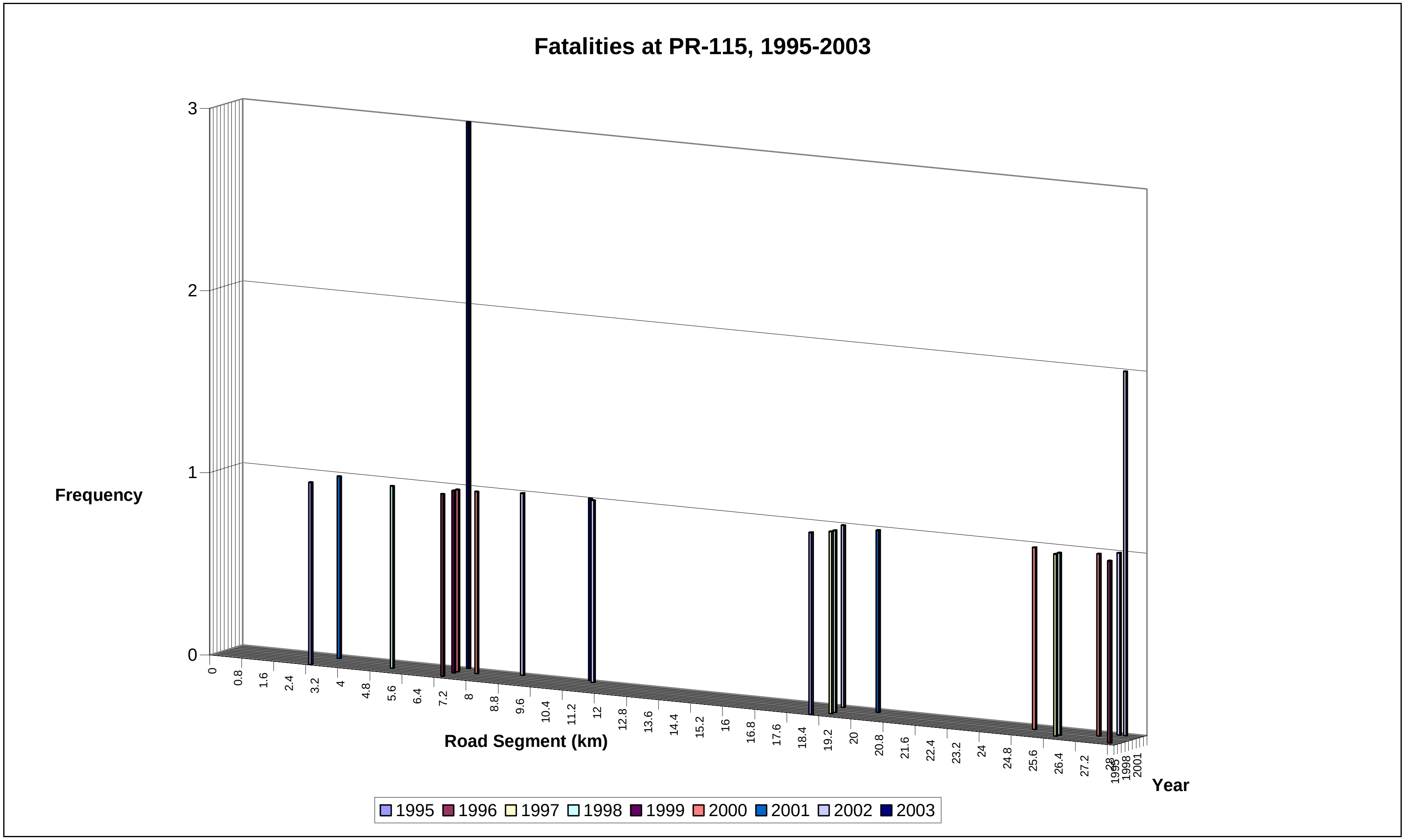
Fataities at PR-111, 1995-2003
Frequency
2
1
0
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
4.4
4.8
5.2
5.6
6
6.4
6.8
7.2
7.6
8
8.4
8.8
9.2
9.6
10
10.4
10.8
Road Segment (km)
2001
1995
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003



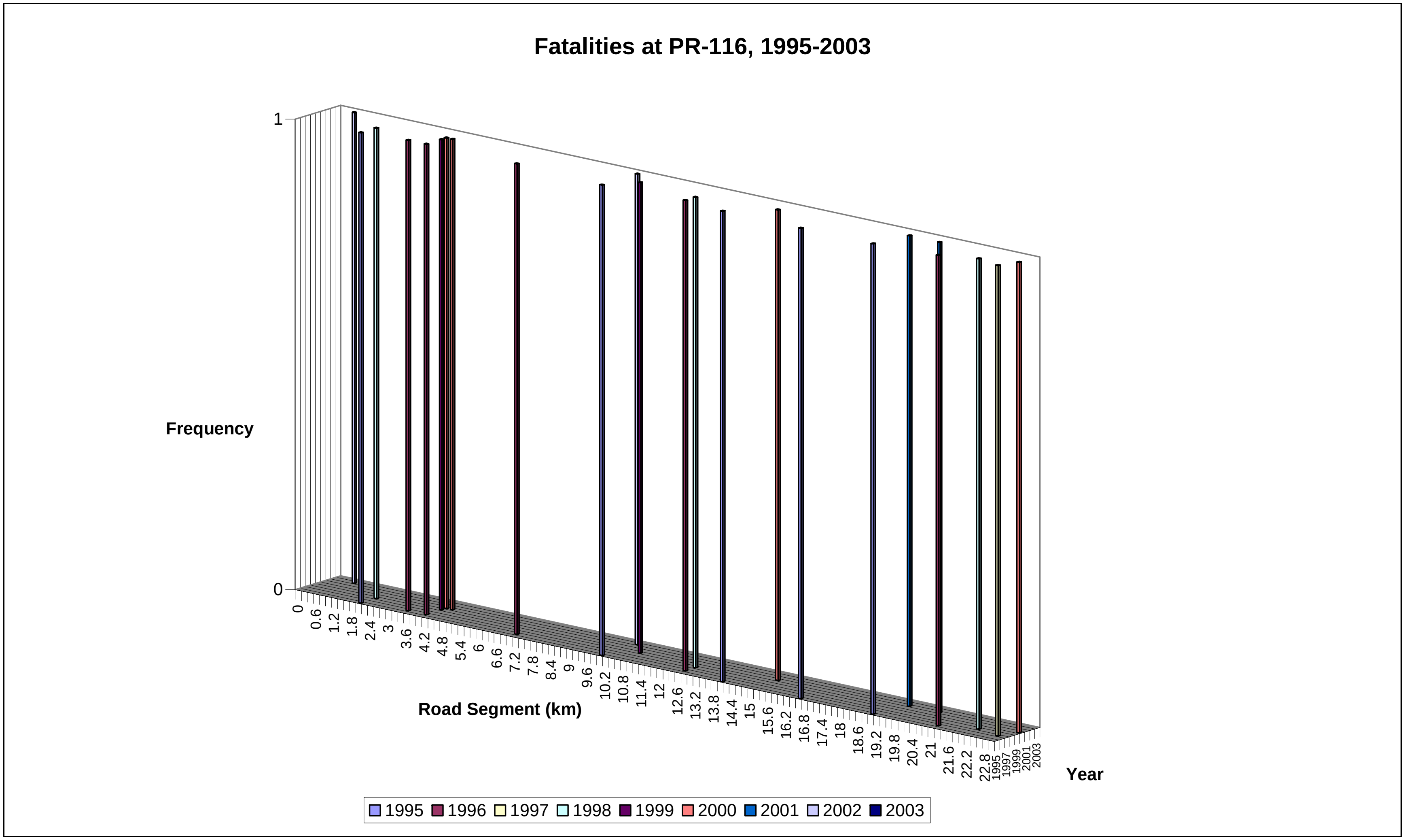
Fataities at PR-111, 1995-2003
Frequency
0
1
2
3
11
11.6
12.2
12.8
13.4
14
14.6
15.2
15.8
16.4
17
17.6
18.2
18.8
19.4
20
20.6
21.2
21.8
Road Segment (km)
1995
2000
Year
1995
1996
1997
1998
1999
2000
2001
2002
2003



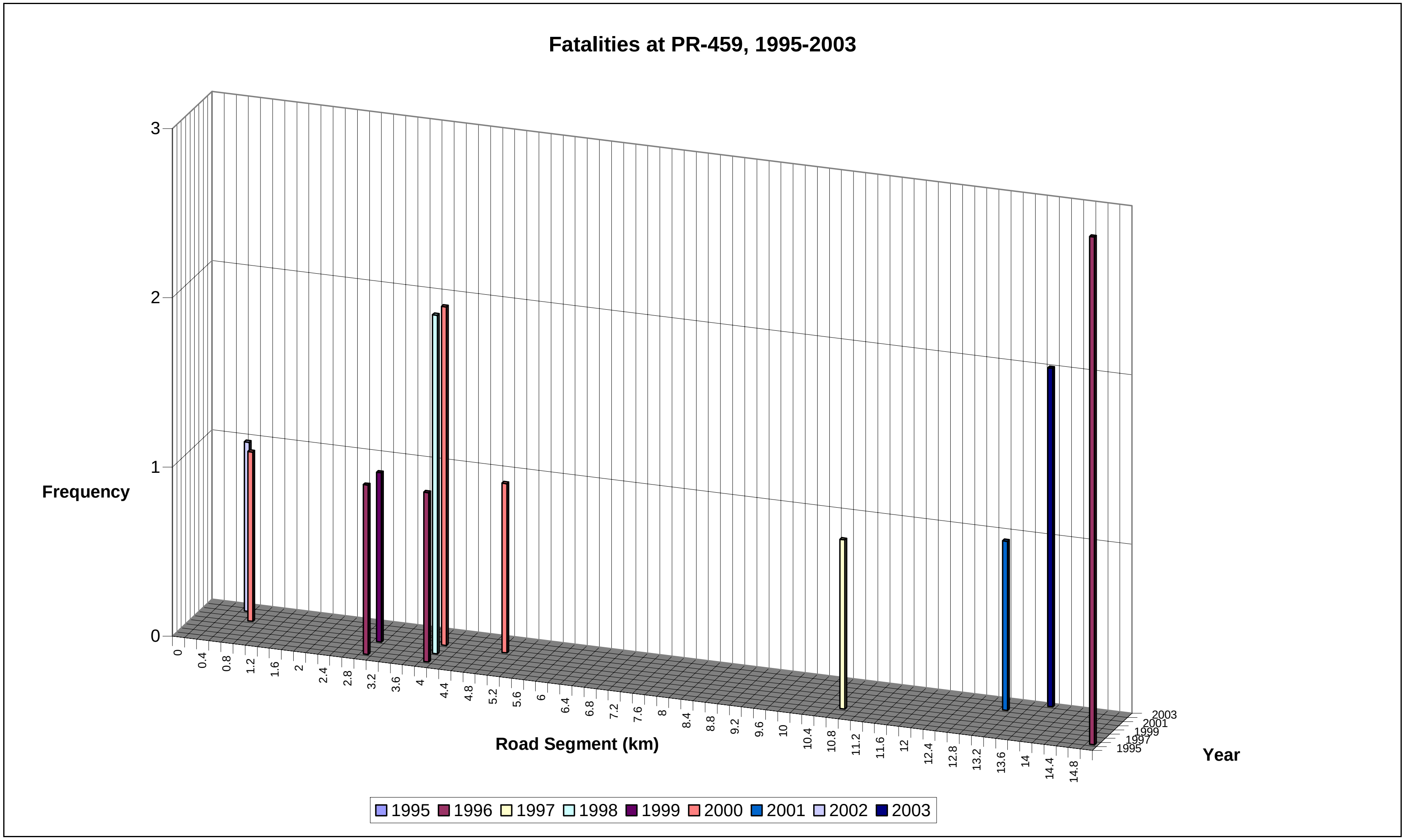
Fataities at PR-111, 1995-2003
Frequency
1
0
22
22.6
23.2
23.8
24.4
25
25.6
26.2
26.8
27.4
28
28.6
29.2
29.8
30.4
31
31.6
32.2
32.8
Road Segment (km)
2001
1995
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003



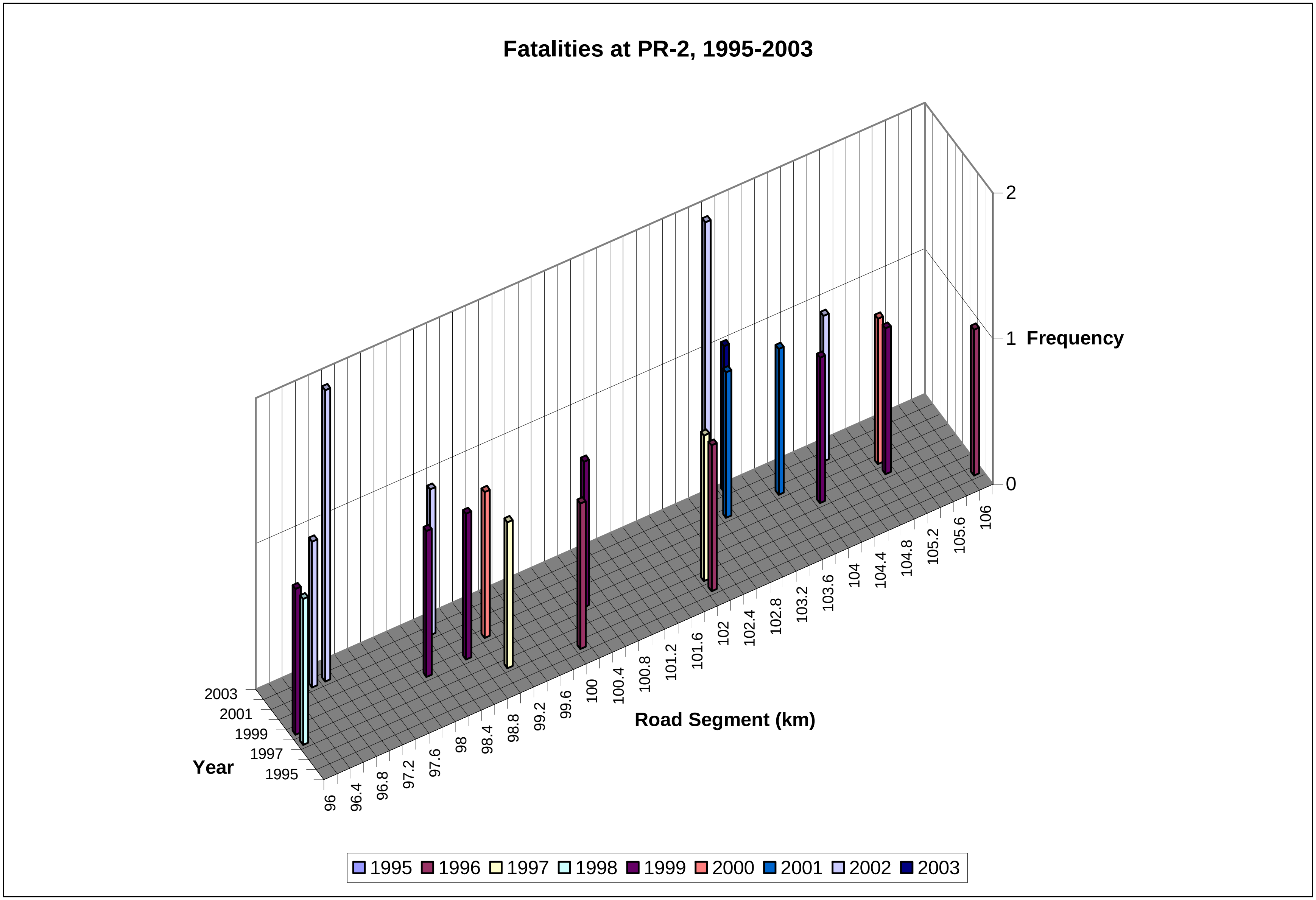
Fatalities at PR-115, 1995-2003
Frequency
3
2
1
0
Road Segment (km)
0
0.8
1.6
2.4
3.2
4
4.8
5.6
6.4
7.2
8
8.8
9.6
10.4
11.2
12
12.8
13.6
14.4
15.2
16
16.8
17.6
18.4
19.2
20
20.8
21.6
22.4
23.2
24
24.8
25.6
26.4
27.2
28
Year
1995
1998
2001
1995 1996 1997 1998 1999 2000 2001 2002 2003

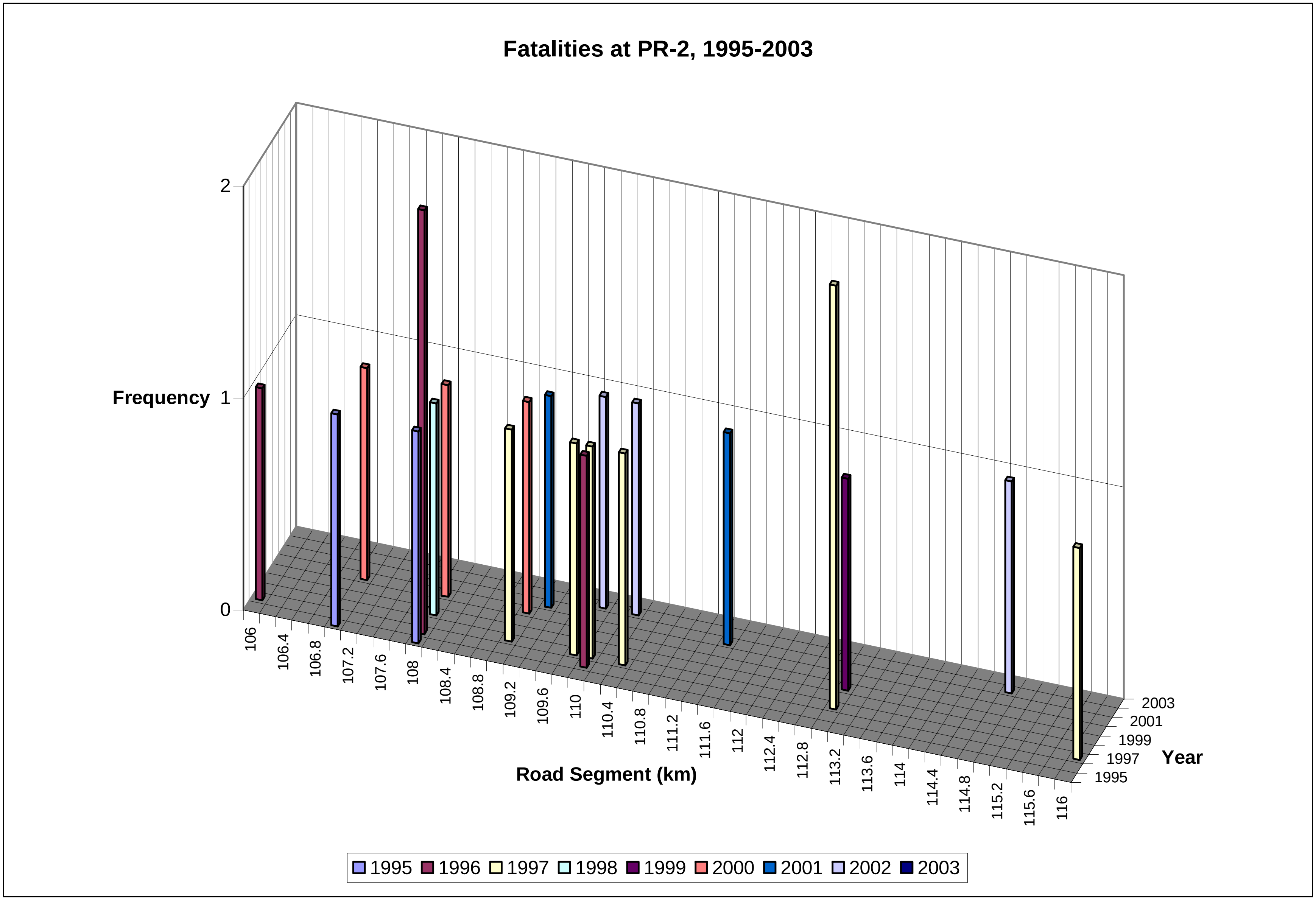


Fatalities at PR-116, 1995-2003
Frequency
1
0
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
5.4
6
6.6
7.2
7.8
8.4
9
9.6
10.2
10.8
11.4
12
12.6
13.2
13.8
14.4
15
15.6
16.2
16.8
17.4
18
18.6
19.2
19.8
20.4
21
21.6
22.2
22.8
Road Segment (km)
1995
1997
1999
2001
2003
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003

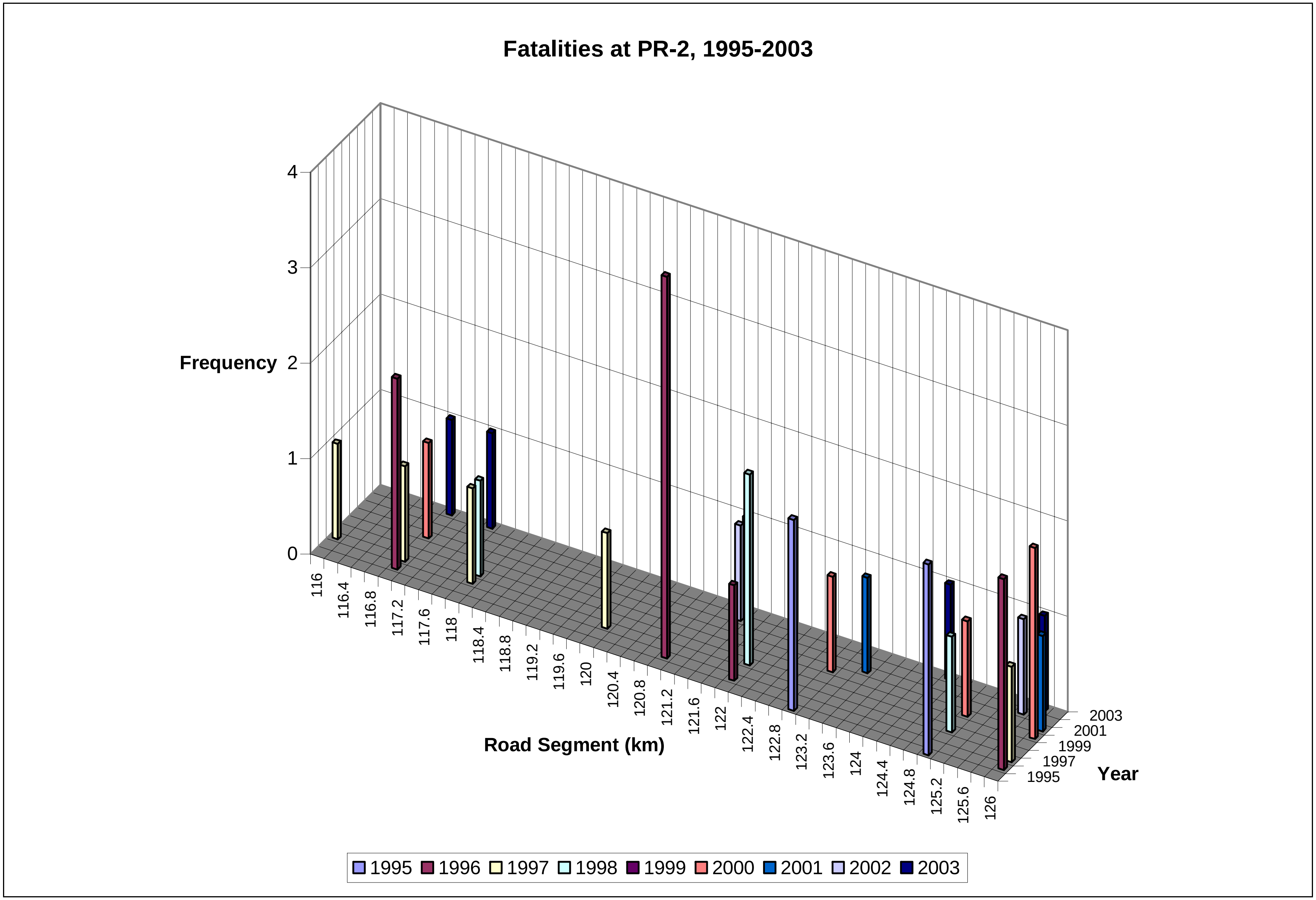


Fatalities at PR-459, 1995-2003
Frequency
0
1
2
3
Road Segment (km)
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
4.4
4.8
5.2
5.6
6
6.4
6.8
7.2
7.6
8
8.4
8.8
9.2
9.6
10
10.4
10.8
11.2
11.6
12
12.4
12.8
13.2
13.6
14
14.4
14.8
Year
1995
1997
1999
2001
2003
1995 1996 1997 1998 1999 2000 2001 2002 2003

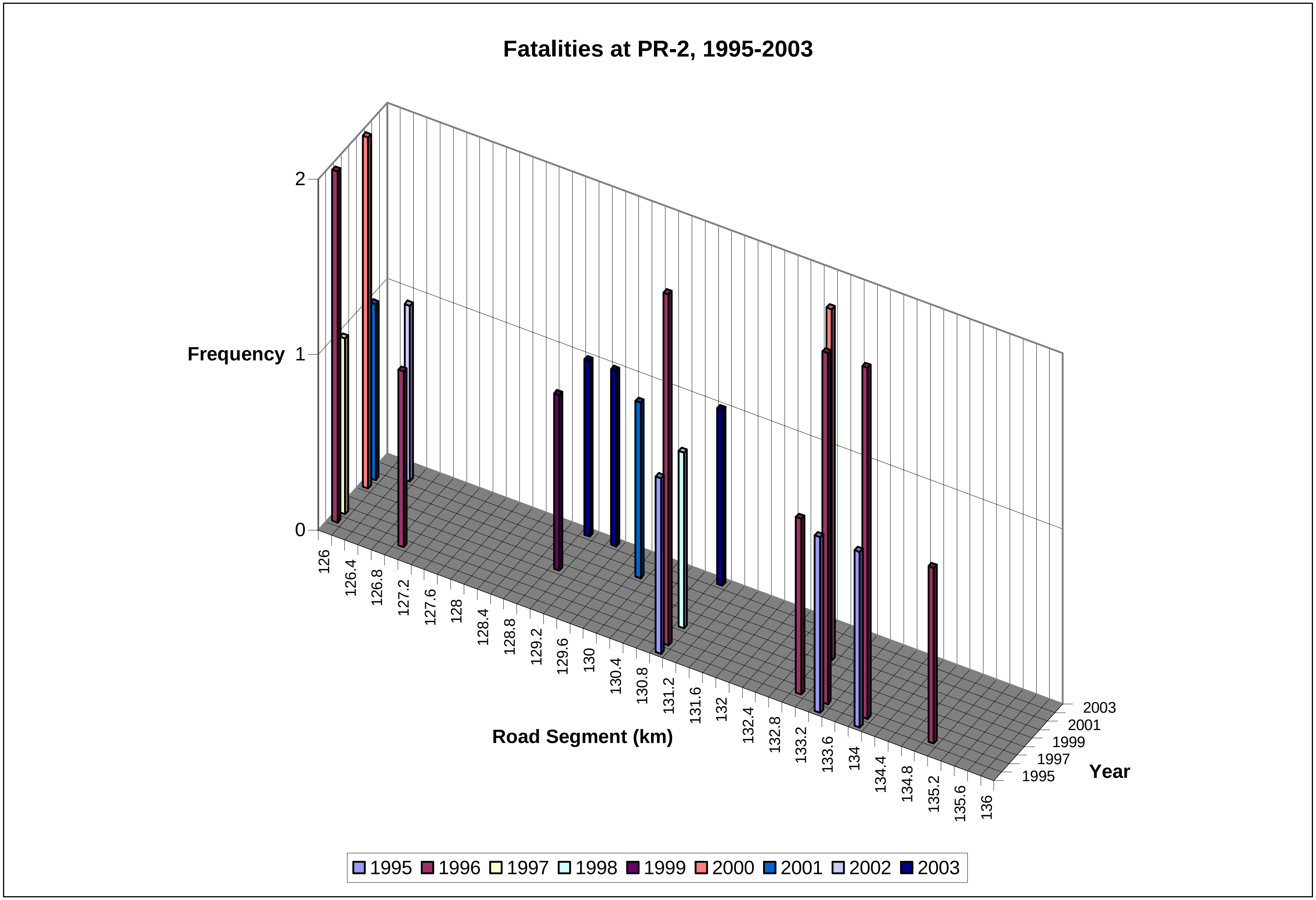

Fatalities at PR-2, 1995-2003
2
1
0
Frequency
Year
2003
2001
1999
1997
1995
96
96.4
96.8
97.2
97.6
98
98.4
98.8
99.2
99.6
100
100.4
100.8
101.2
101.6
102
102.4
102.8
103.2
103.6
104
104.4
104.8
105.2
105.6
106
Road Segment (km)
1995
1996
1997
1998
1999
2000
2001
2002
2003



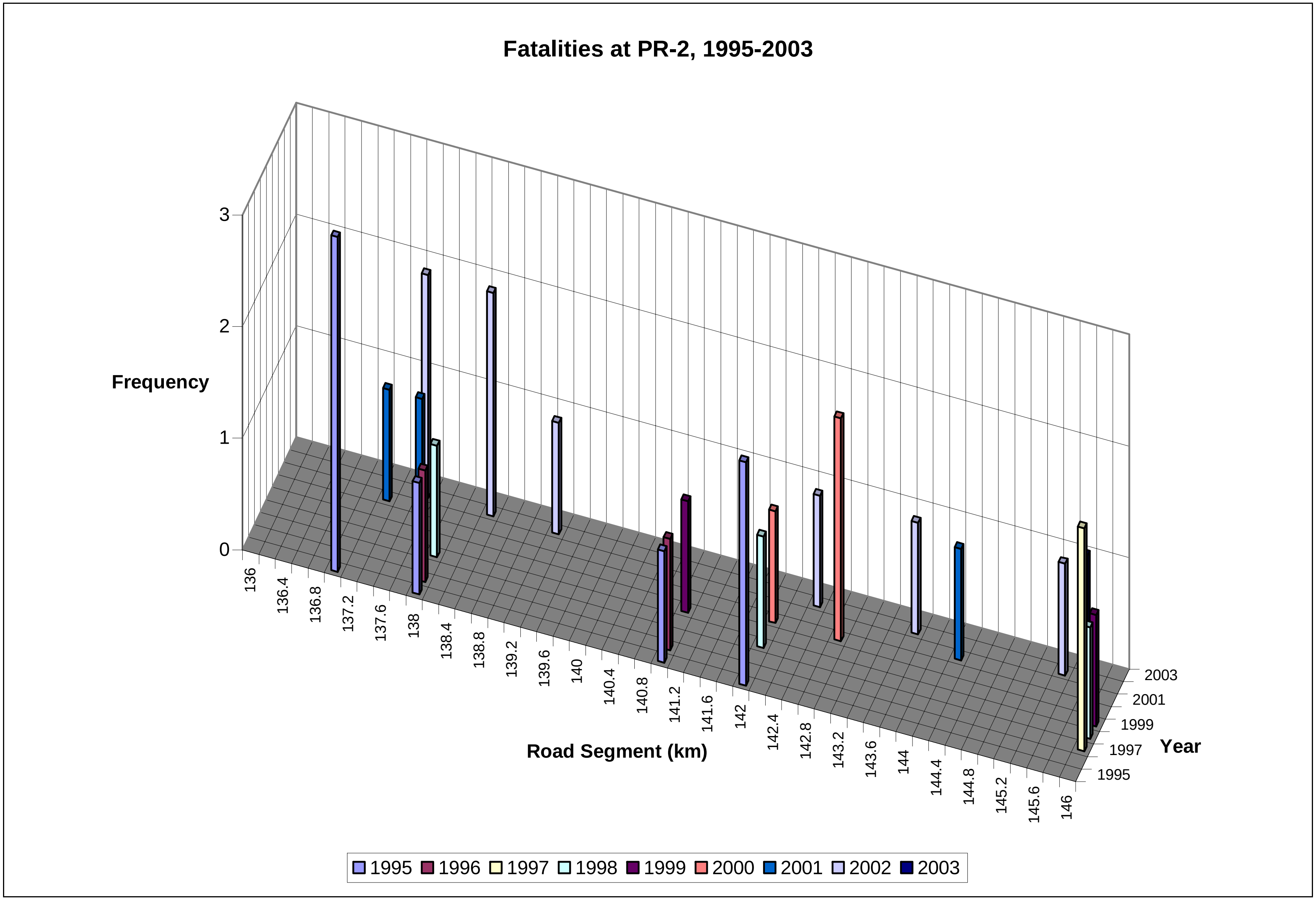
Fatalities at PR-2, 1995-2003
Frequency
0
1
2
Road Segment (km)
106
106.4
106.8
107.2
107.6
108
108.4
108.8
109.2
109.6
110
110.4
110.8
111.2
111.6
112
112.4
112.8
113.2
113.6
114
114.4
114.8
115.2
115.6
116
Year
1995
1997
1999
2001
2003
1995 1996 1997 1998 1999 2000 2001 2002 2003



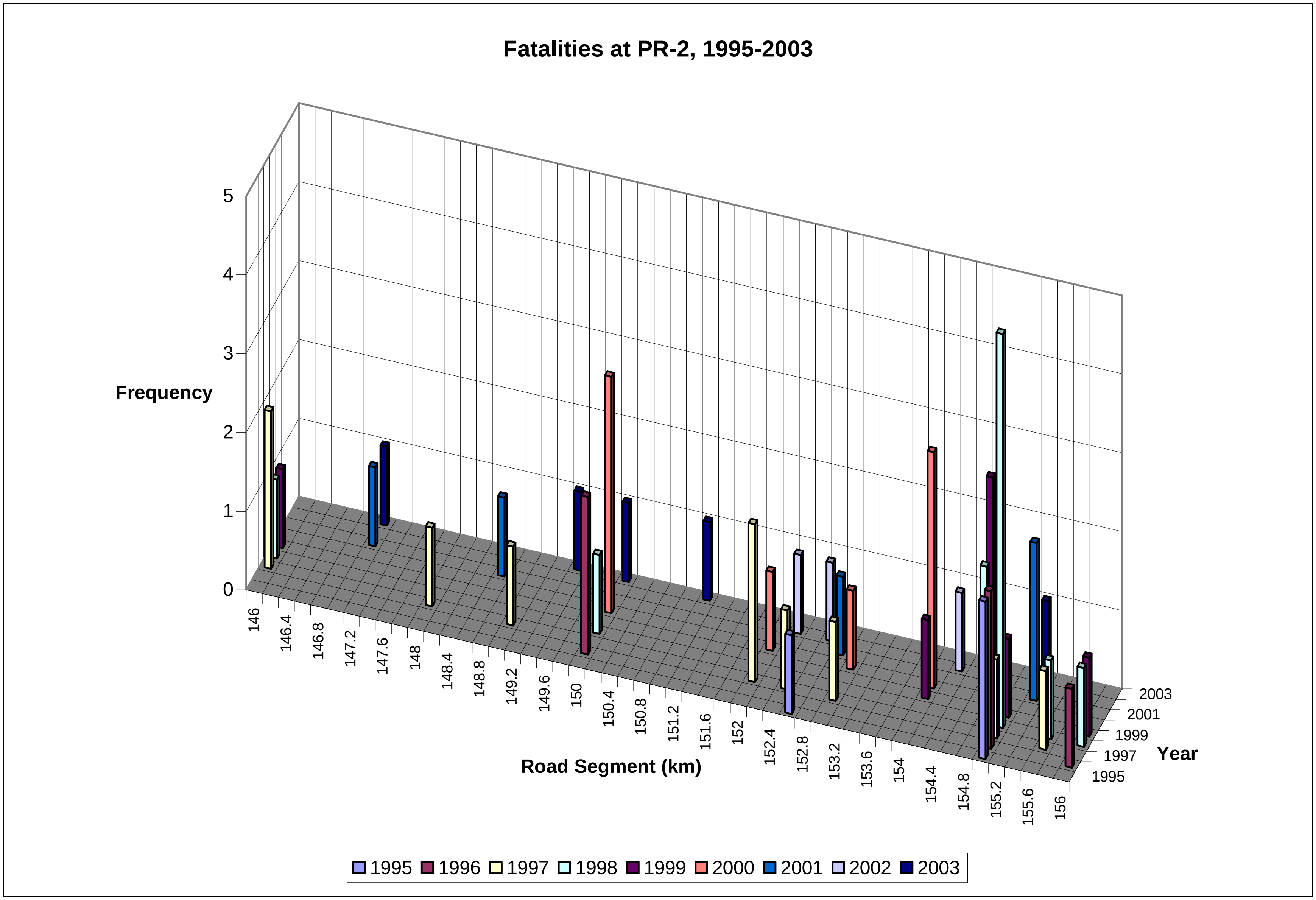
Fatalities at PR-2, 1995-2003
Frequency
0
1
2
3
4
Road Segment (km)
116
116.4
116.8
117.2
117.6
118
118.4
118.8
119.2
119.6
120
120.4
120.8
121.2
121.6
122
122.4
122.8
123.2
123.6
124
124.4
124.8
125.2
125.6
126
Year
1995
1997
1999
2001
2003
1995
1996
1997
1998
1999
2000
2001
2002
2003



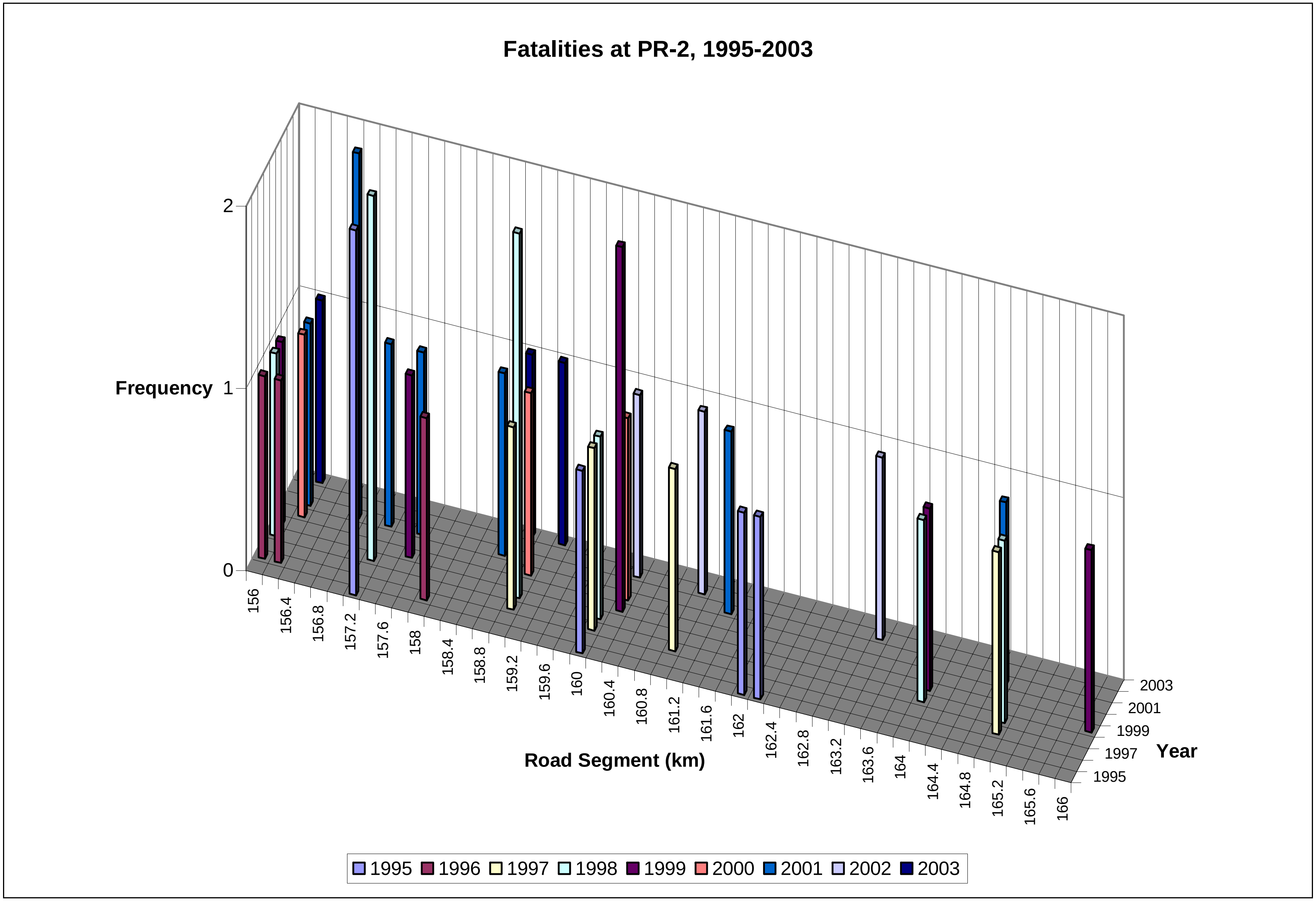
Fatalities at PR-2, 1995-2003
Frequency
2
1
0
126
126.4
126.8
127.2
127.6
128
128.4
128.8
129.2
129.6
130
130.4
130.8
131.2
131.6
132
132.4
132.8
133.2
133.6
134
134.4
134.8
135.2
135.6
136
Road Segment (km)
2003
2001
1999
1997
1995
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003

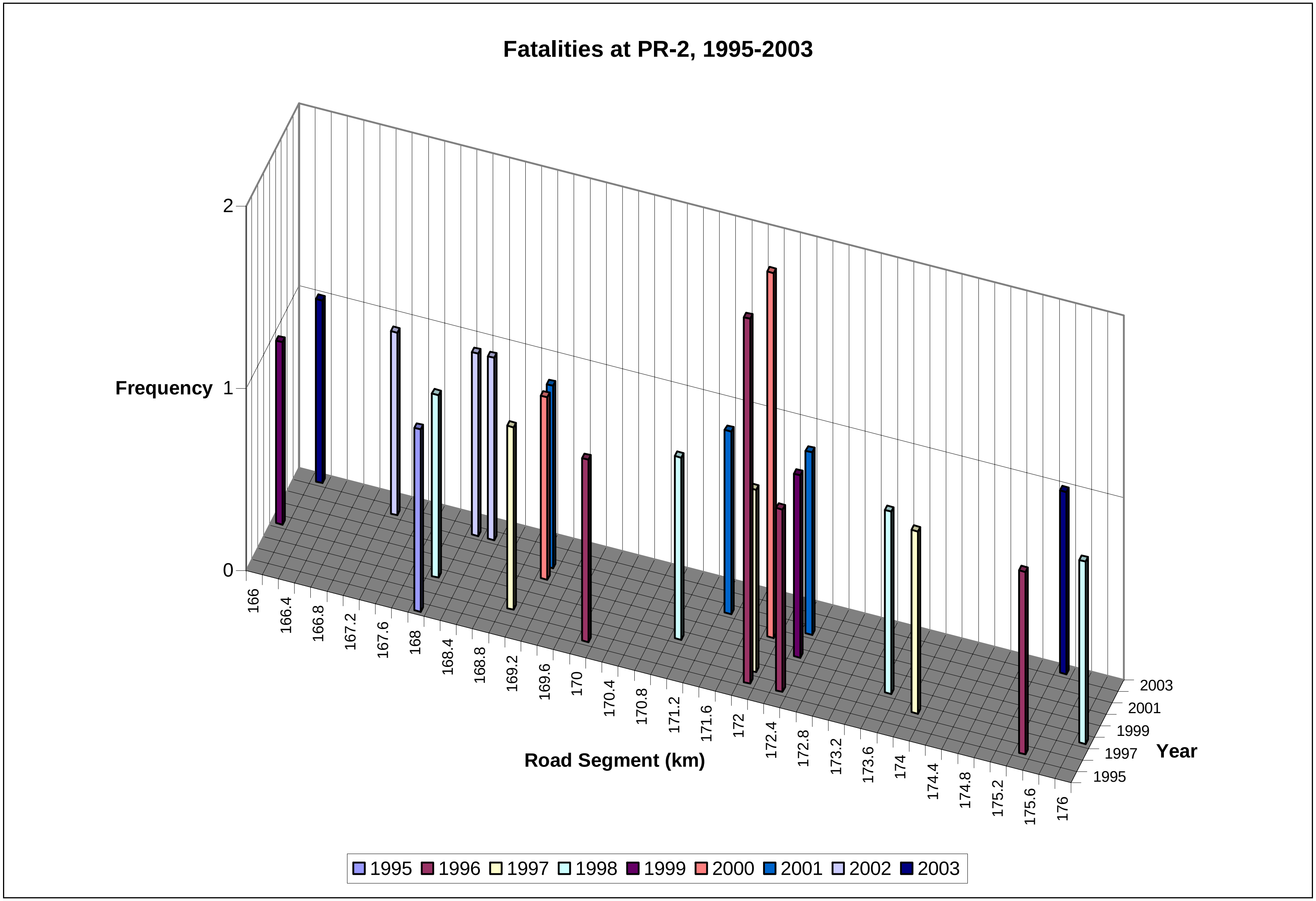


Fatalities at PR-2, 1995-2003
Frequency
0
1
2
3
136
136.4
136.8
137.2
137.6
138
138.4
138.8
139.2
139.6
140
140.4
140.8
141.2
141.6
142
142.4
142.8
143.2
143.6
144
144.4
144.8
145.2
145.6
146
Road Segment (km)
1995
1997
1999
2001
2003
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003

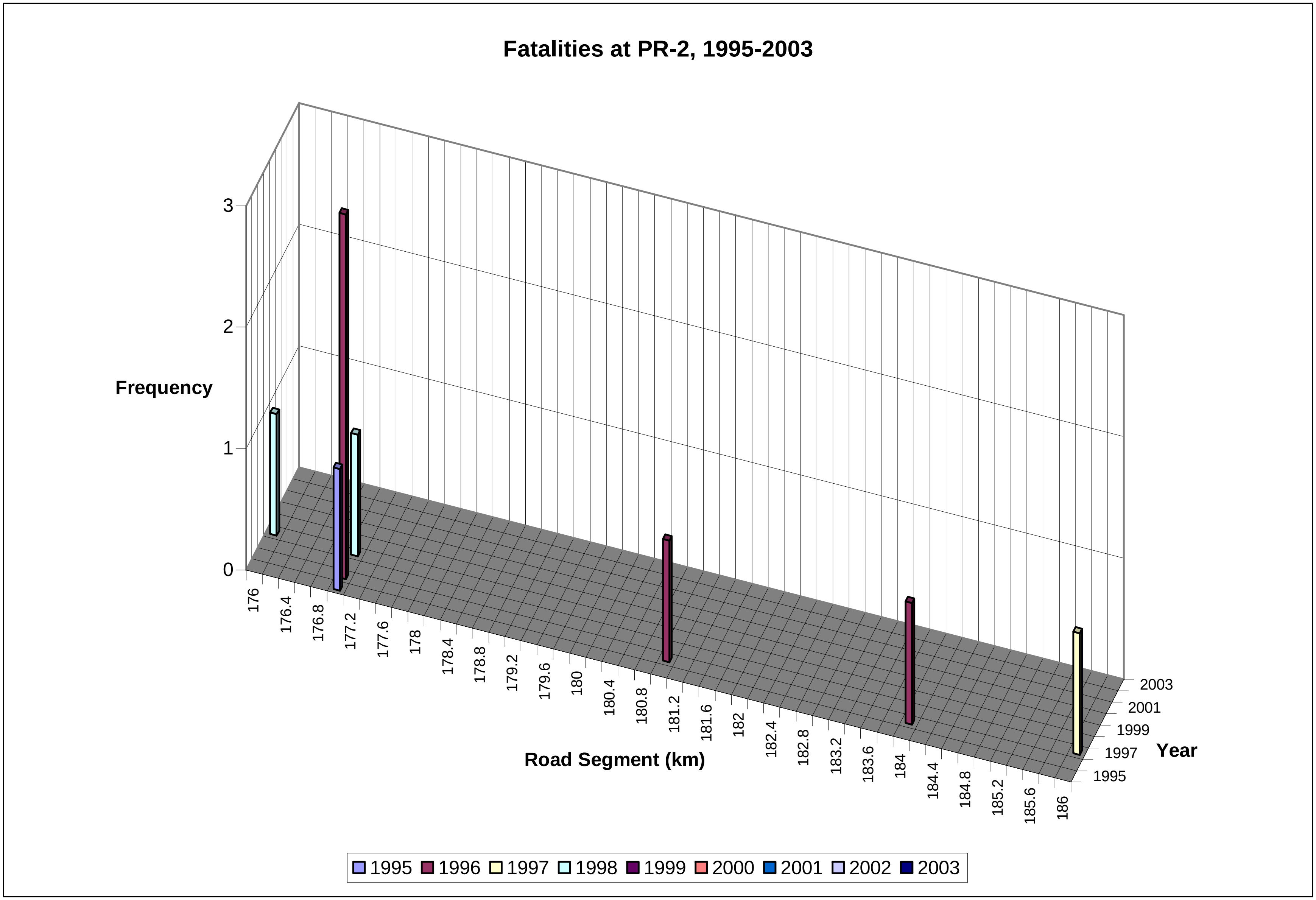


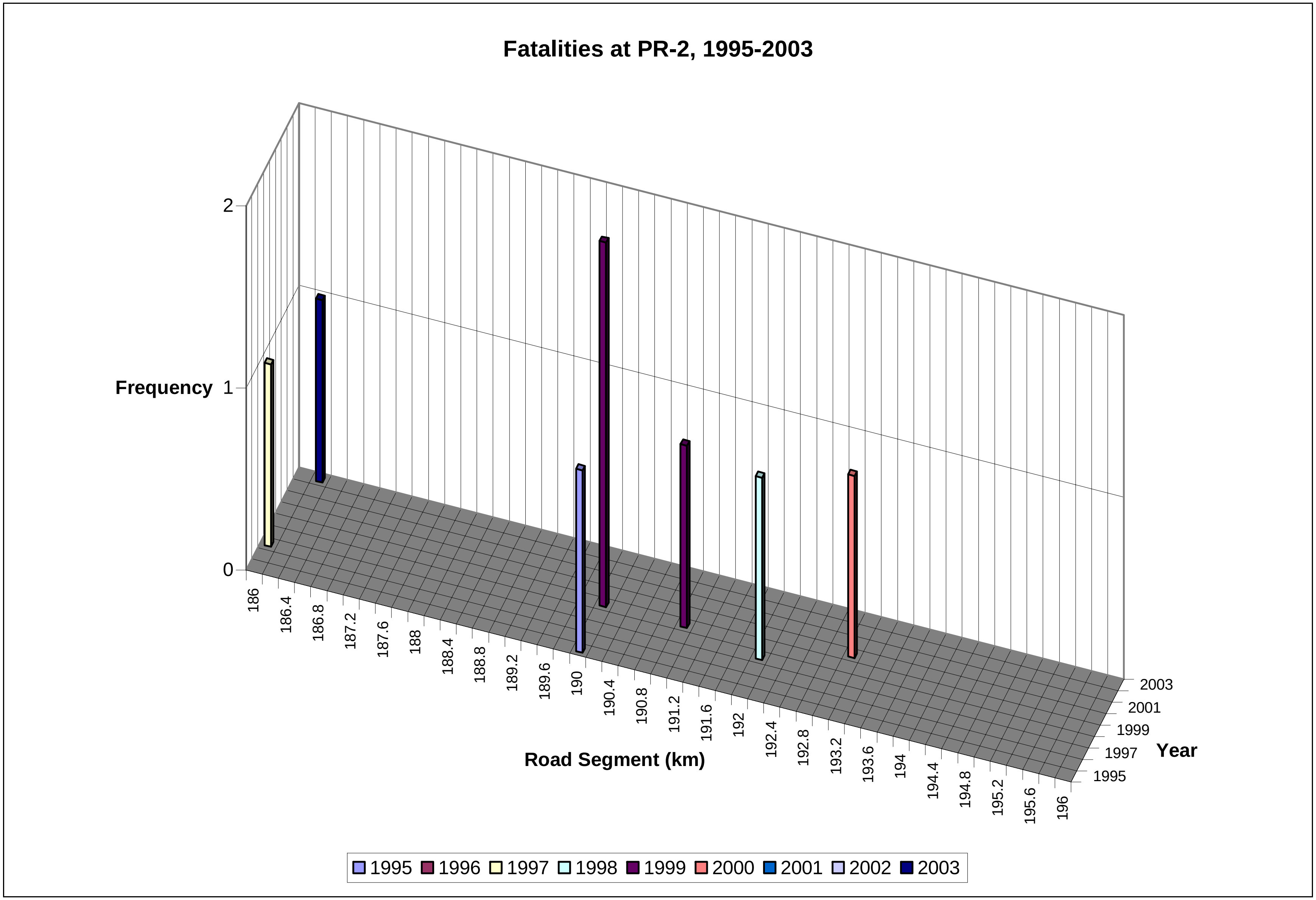
Fatalities at PR-2, 1995-2003
Frequency
0
1
2
3
4
5
146
146.4
146.8
147.2
147.6
148
148.4
148.8
149.2
149.6
150
150.4
150.8
151.2
151.6
152
152.4
152.8
153.2
153.6
154
154.4
154.8
155.2
155.6
156
Road Segment (km)
1995
1997
1999
2001
2003
Year
1995
1996
1997
1998
1999
2000
2001
2002
2003

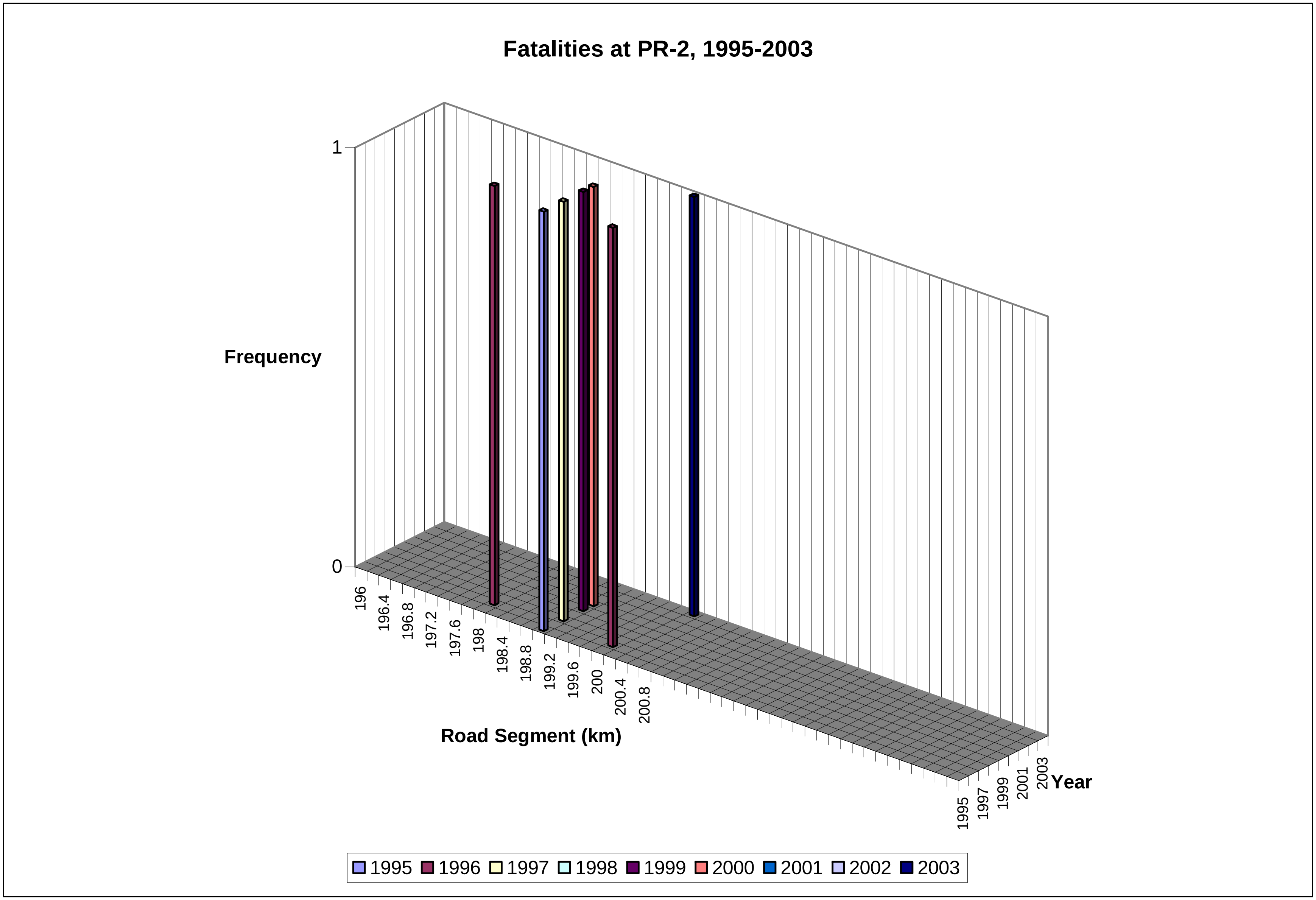

Fatalities at PR-2, 1995-2003
Frequency
0
1
2
156
156.4
156.8
157.2
157.6
158
158.4
158.8
159.2
159.6
160
160.4
160.8
161.2
161.6
162
162.4
162.8
163.2
163.6
164
164.4
164.8
165.2
165.6
166
Road Segment (km)
Year
1995
1997
1999
2001
2003
1995 1996 1997 1998 1999 2000 2001 2002 2003



Fatalities at PR-2, 1995-2003
Frequency
0
1
2
Road Segment (km)
166
166.4
166.8
167.2
167.6
168
168.4
168.8
169.2
169.6
170
170.4
170.8
171.2
171.6
172
172.4
172.8
173.2
173.6
174
174.4
174.8
175.2
175.6
176
Year
1995
1997
1999
2001
2003
1995 1996 1997 1998 1999 2000 2001 2002 2003


Fatalities at PR-2, 1995-2003
Frequency
3
2
1
0
176
176.4
176.8
177.2
177.6
178
178.4
178.8
179.2
179.6
180
180.4
180.8
181.2
181.6
182
182.4
182.8
183.2
183.6
184
184.4
184.8
185.2
185.6
186
Road Segment (km)
2003
2001
1999
1997
1995
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003


Fatalities at PR-2, 1995-2003
Frequency
0
1
2
Road Segment (km)
186
186.4
186.8
187.2
187.6
188
188.4
188.8
189.2
189.6
190
190.4
190.8
191.2
191.6
192
192.4
192.8
193.2
193.6
194
194.4
194.8
195.2
195.6
196
Year
1995
1997
1999
2001
2003
1995 1996 1997 1998 1999 2000 2001 2002 2003



Fatalities at PR-2, 1995-2003
Frequency
1
0
196
196.4
196.8
197.2
197.6
198
198.4
198.8
199.2
199.6
200
200.4
200.8
Road Segment (km)
1995
1997
1999
2001
2003
Year
1995 1996 1997 1998 1999 2000 2001 2002 2003

Appendix B: AADT calculation tables

PR-100	AADT								
Km	1995	1996	1997	1998	1999	2000	2001	2002	2003
0	24470	24956	25452	25958	26474	27000	27537	28084	28642
0.2	24470	24956	25452	25958	26474	27000	27537	28084	28642
0.4	24470	24956	25452	25958	26474	27000	27537	28084	28642
0.6	24470	24956	25452	25958	26474	27000	27537	28084	28642
0.8	24355	24887	25433	25993	26568	27167	27766	28386	29025
1	24240	24818	25414	26028	26662	27333	27994	28688	29408
1.2	24126	24749	25395	26064	26756	27500	28223	28990	29792
1.4	24011	24680	25376	26099	26850	27667	28452	29293	30175
1.6	23896	24611	25357	26134	26944	27833	28681	29595	30558
1.8	23781	24542	25338	26169	27038	28000	28910	29897	30942
2	23666	24473	25319	26204	27132	28167	29139	30199	31325
2.2	23552	24404	25300	26239	27226	28333	29368	30501	31708
2.4	23437	24335	25280	26274	27321	28500	29597	30804	32091
2.6	23322	24267	25261	26310	27415	28667	29826	31106	32475
2.8	23207	24198	25242	26345	27509	28833	30055	31408	32858
3	23092	24129	25223	26380	27603	29000	30284	31710	33241
3.2	22978	24060	25204	26415	27697	29167	30513	32012	33624
3.4	22863	23991	25185	26450	27791	29333	30742	32315	34008
3.6	22748	23922	25166	26485	27885	29500	30971	32617	34391
3.8	22633	23853	25147	26521	27979	29667	31200	32919	34774
4	22518	23784	25128	26556	28073	29833	31422	33221	35158
4.2	22404	23715	25109	26591	28167	30000	31643	33523	35541
4.4	22289	23646	25090	26626	28261	30106	31865	33825	35924
4.6	22174	23577	25071	26661	28355	30212	32087	34128	36307
4.8	22059	23508	25051	26696	28449	30318	32308	34430	36691
5	23007	24174	25026	26787	28244	29811	31493	33297	35232
5.2	23955	24839	25001	26877	28040	29304	30678	32165	33772
5.4	24903	25505	24976	26967	27835	28798	29862	31032	32313
5.6	25850	26171	24950	27058	27630	28291	29047	29900	30854
5.8	26798	26837	24925	27148	27425	27785	28231	28767	29395
6	27746	27503	24900	27239	27220	27278	27416	27634	27936
6.2	28694	28169	25889	27329	27015	26772	26600	26502	26477
6.4	29642	28834	26877	27419	26810	26265	25785	25369	25018
6.6	30589	29500	27866	27510	26605	25759	24970	24237	23559
6.8	31537	30166	28855	27600	26400	25252	24154	23104	22100
7	23579	24886	26266	27722	29259	30881	32593	34400	36307
7.2	23966	25192	26481	27835	29259	22890	29800	31324	34069
7.4	27997	28307	28621	28938	29259	21709	25475	25757	31831
7.6	32834	31901	30995	30114	29259	20528	21150	20549	29593
7.8	38231	35758	33445	31282	29259	19347	16825	15737	27355
8	35104	32691	30443	28349	26400	18166	12500	11640	25117
8.2	39450	35293	31575	28248	25271	17677	19264	20994	22878
8.4	38928	34545	30657	27205	24143	17189	18270	19419	20640
8.6	38506	33857	29769	26175	23014	16700	17249	17816	18402
8.8	37357	32683	28594	25016	21886	16604	16456	16309	16164

PR-100	AADT								
Km	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
9	36219	31513	27419	23857	20757	16507	15598	14738	13926
9.2	31087	27711	24702	22020	19629	16411	15537	14709	13926
9.4	26365	24131	22085	20213	18500	16315	15476	14681	13926
9.6	21787	20566	19414	18327	17300	16219	15415	14652	13926
9.8	17680	17271	16871	16481	16100	16122	15354	14623	13926
10	14043	14253	14465	14681	14900	16026	15293	14593	13926
10.2	10874	11520	12205	12931	13700	15930	15232	14564	13926
10.4	8164	9081	10102	11237	12500	15833	15170	14535	13926
10.6	8249	9152	10154	11266	12500	15737	15109	14505	13926
10.8	8334	9223	10207	11295	12500	15641	15047	14476	13926
11	8421	9295	10260	11325	12500	15544	14985	14446	13926
11.2	8509	9368	10313	11354	12500	15448	14923	14416	13926
11.4	8597	9441	10367	11383	12500	15352	14861	14386	13926
11.6	8687	9514	10420	11413	12500	15256	14799	14356	13926
11.8	8777	9588	10474	11442	12500	15159	14736	14326	13926
12	8868	9663	10529	11472	12500	15063	14674	14295	13926
12.2	8960	9738	10583	11502	12500	14967	14611	14265	13926
12.4	9053	9814	10638	11531	12500	14870	14549	14234	13926
12.6	9147	9890	10693	11561	12500	14774	14486	14203	13926
12.8	9242	9966	10748	11591	12500	14678	14423	14172	13926
13	9337	10044	10804	11621	12500	14581	14360	14141	13926
13.2	9434	10122	10859	11651	12500	14485	14296	14110	13926
13.4	9531	10200	10915	11681	12500	14389	14233	14079	13926
13.6	9630	10279	10971	11711	12500	14293	14169	14047	13926
13.8	9729	10358	11028	11741	12500	14196	14106	14016	13926
14	9829	10438	11084	11771	12500	14100	14042	13984	13926
14.2	9829	10438	11084	11771	12500	14100	14042	13984	13926
14.4	9829	10438	11084	11771	12500	14100	14042	13984	13926
14.6	9829	10438	11084	11771	12500	14100	14042	13984	13926

PR-115	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
0	7846	7994	8146	8300	8457	8617	8780	8947	9116
0.2	7846	7994	8146	8300	8457	8617	8780	8947	9116
0.4	7830	7962	8097	8233	8372	8514	8657	8804	8952
0.6	7814	7930	8047	8167	8288	8411	8535	8662	8790
0.8	7798	7897	7998	8100	8203	8308	8414	8521	8629
1	7782	7865	7949	8033	8119	8205	8293	8381	8470
1.2	7762	7830	7898	7967	8036	8106	8177	8248	8319
1.4	7742	7795	7847	7900	7953	8007	8061	8115	8170
1.6	7765	7846	7927	8010	8093	8177	8262	8347	8434
1.8	7788	7897	8007	8119	8233	8348	8465	8583	8703
2	7811	7948	8087	8229	8373	8520	8670	8822	8977
2.2	7833	7998	8167	8339	8515	8694	8877	9064	9255
2.4	7855	8048	8246	8449	8656	8869	9087	9310	9539
2.6	7877	8098	8325	8558	8798	9045	9299	9559	9827
2.8	7898	8147	8403	8668	8941	9222	9513	9812	10121
3	7919	8196	8482	8778	9084	9401	9729	10068	10420
3.2	7940	8244	8560	8887	9227	9581	9947	10328	10723
3.4	7961	8292	8637	8997	9371	9762	10168	10591	11032
3.6	7981	8340	8715	9107	9516	9944	10391	10858	11346
3.8	8002	8388	8792	9216	9661	10127	10616	11128	11665
4	8022	8435	8869	9326	9807	10312	10843	11401	11989
4.2	8041	8482	8946	9436	9952	10497	11072	11678	12318
4.4	8061	8528	9022	9546	10099	10684	11304	11959	12652
4.6	8080	8574	9099	9655	10246	10872	11537	12243	12992
4.8	8099	8620	9175	9765	10393	11062	11773	12531	13337
5	8118	8666	9250	9875	10541	11252	12011	12822	13687
5.2	8137	8711	9326	9984	10689	11444	12252	13117	14043
5.4	8155	8756	9401	10094	10838	11637	12494	13415	14403
5.6	8173	8801	9476	10204	10987	11830	12739	13717	14770
5.8	8191	8845	9551	10313	11137	12026	12985	14022	15141
6	8209	8889	9626	10423	11287	12222	13234	14331	15518
6.2	8227	8933	9700	10533	11437	12419	13485	14643	15900
6.4	8244	8977	9774	10643	11588	12618	13739	14959	16288
6.6	8261	9020	9848	10752	11739	12817	13994	15279	16682
6.8	8278	9063	9922	10862	11891	13018	14252	15602	17080
7	8295	9106	9995	10972	12043	13220	14511	15929	17485
7.2	8312	9148	10068	11081	12196	13423	14773	16259	17895
7.4	8329	9191	10142	11191	12349	13627	15037	16593	18310
7.6	8345	9233	10214	11301	12503	13832	15303	16931	18731
7.8	8361	9274	10287	11410	12656	14038	15571	17272	19158
8	8377	9316	10360	11520	12811	14246	15842	17617	19590
8.2	8393	9357	10432	11630	12965	14454	16115	17965	20028
8.4	8409	9398	10504	11740	13121	14664	16389	18317	20472
8.6	8425	9439	10576	11849	13276	14875	16666	18673	20922
8.8	8440	9480	10647	11959	13432	15087	16945	19032	21377

PR-115	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
9	8455	9520	10719	12069	13588	15300	17226	19396	21838
9.2	8470	9560	10790	12178	13745	15514	17510	19762	22305
9.4	8485	9600	10861	12288	13902	15729	17795	20133	22778
9.6	8797	9873	11086	12455	12768	15625	17718	19944	22458
9.8	9109	10145	11311	12623	11634	15522	17640	19755	22138
10	9422	10418	11536	12790	10500	15419	17563	19566	21819
10.2	9734	10691	11761	12958	10907	15316	17486	19377	21499
10.4	10046	10963	11986	13125	11315	15213	17409	19188	21180
10.6	10358	11236	12210	13293	11722	15110	17331	18999	20860
10.8	10670	11509	12435	13460	12129	15006	17254	18809	20541
11	10982	11781	12660	13628	12537	14903	17177	18620	20221
11.2	11294	12054	12885	13795	12944	14800	17100	18431	19902
11.4	11606	12327	13110	13963	13352	15000	17022	18242	19582
11.6	11918	12599	13335	14130	13759	15200	16945	18053	19263
11.8	12230	12872	13560	14298	14166	15400	16868	17864	18943
12	12542	13145	13784	14465	14574	15600	16791	17675	18624
12.2	12855	13417	14009	14633	14981	15800	16713	17486	18304
12.4	13167	13690	14234	14800	15388	16000	16636	17297	17985
12.6	13167	13690	14234	14800	15388	16000	16636	17297	17985
12.8	13068	13542	14039	14561	15107	16250	16323	16996	18534
13	12969	13393	13844	14321	14825	16500	16009	16695	18302
13.2	12870	13245	13649	14082	14544	14820	15696	16393	18069
13.4	12772	13097	13454	13842	14262	13140	15382	16092	17836
13.6	12673	12948	13259	13603	13981	11460	15069	15791	17604
13.8	12574	12800	13063	13364	13699	9780	14755	15490	17371
14	12476	12651	12868	13124	13418	8100	14442	15188	17139
14.2	12377	12503	12673	12885	13136	7923	14129	14887	16906
14.4	12278	12355	12478	12645	12854	7746	13815	14586	16673
14.6	12179	12206	12283	12406	12573	7569	13502	14284	16441
14.8	12081	12058	12088	12167	12291	7392	13188	13983	16208
15	11982	11910	11893	11927	12010	7215	12875	13682	15976
15.2	11883	11761	11697	11688	11728	7038	12561	13381	15743
15.4	11785	11613	11502	11448	11447	6862	12248	13079	15510
15.6	11686	11464	11307	11209	11165	6685	11934	12778	15278
15.8	11587	11316	11112	10970	10884	6508	11621	12477	15045
16	11488	11168	10917	10730	10602	6331	11308	12175	14813
16.2	11390	11019	10722	10491	10321	6154	10994	11874	14580
16.4	11291	10871	10527	10251	10039	5977	10681	11573	14347
16.6	11192	10723	10332	10012	9758	5800	10367	11272	14115
16.8	11093	10574	10136	9773	9476	5792	10054	10970	13882
17	10995	10426	9941	9533	9195	5783	9740	10669	13650
17.2	10896	10277	9746	9294	8913	5775	9427	10368	13417
17.4	10797	10129	9551	9054	8631	5767	9114	10066	12635
17.6	10699	9981	9356	8815	8350	5758	8800	9765	12165
17.8	10600	9832	9161	8576	8068	5750	8487	9464	11695
18	10501	9684	8966	8336	7787	5742	8173	9163	11224

PR-115	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
18.2	10402	9536	8771	8097	7505	5733	7860	8861	10754
18.4	10304	9387	8575	7857	7224	5725	7546	8560	10284
18.6	10205	9239	8380	7618	6942	5717	7233	8259	9813
18.8	10106	9090	8185	7379	6661	5708	6919	7957	9343
19	10008	8942	7990	7139	6379	5700	6606	7656	8873
19.2	10146	9191	8326	7542	6832	6189	7245	8018	8873
19.4	10275	9427	8648	7934	7279	6678	7885	8364	8873
19.6	10397	9651	8959	8317	7720	7167	8524	8697	8873
19.8	10512	9866	9260	8691	8157	7656	9164	9017	8873
20	10621	10072	9551	9057	8589	8144	9803	9326	8873
20.2	10725	10269	9833	9416	9016	8633	10442	9626	8873
20.4	10823	10460	10108	9768	9440	9122	11082	9916	8873
20.6	10918	10643	10375	10114	9859	9611	11721	10198	8873
20.8	11009	10821	10636	10454	10276	10100	12361	10473	8873
21	11080	10962	10844	10728	10614	10500	13000	10740	8873
21.2	11149	11099	11049	10999	10949	10900	13000	10740	8873
21.4	11217	11233	11250	11267	11283	11300	13000	10740	8873
21.6	11282	11364	11447	11531	11615	11700	13000	10740	8873
21.8	11345	11492	11641	11792	11945	12100	13000	10740	8873
22	11407	11618	11832	12051	12273	12500	13000	10740	8873
22.2	11467	11740	12020	12306	12600	12900	13000	10740	8873
22.4	11525	11860	12205	12560	12924	13300	13000	10740	8873
22.6	11525	11860	12205	12560	12924	13300	13000	10740	8873
22.8	11525	11860	12205	12560	12924	13300	13000	10740	8873
23	11525	11860	12205	12560	12924	13300	13000	10740	8873
23.2	11525	11860	12205	12560	12924	13300	13000	10740	8873
23.4	11525	11860	12205	12560	12924	13300	13000	10740	8873
23.6	11525	11860	12205	12560	12924	13300	13000	10740	8873
23.8	11525	11860	12205	12560	12924	13300	13000	10740	8873
24	11525	11860	12205	12560	12924	13300	13000	10740	8873
24.2	11525	11860	12205	12560	12924	13300	13000	10740	8873
24.4	11525	11860	12205	12560	12924	13300	13000	10740	8873
24.6	11525	11860	12205	12560	12924	13300	13000	10740	8873
24.8	11525	11860	12205	12560	12924	13300	13000	10740	8873
25	11525	11860	12205	12560	12924	13300	13000	10740	8873
25.2	11525	11860	12205	12560	12924	13300	13000	10740	8873
25.4	11525	11860	12205	12560	12924	13300	13000	10740	8873
25.6	11525	11860	12205	12560	12924	13300	13000	10740	8873
25.8	11525	11860	12205	12560	12924	13300	13000	10740	8873
26	11525	11860	12205	12560	12924	13300	13000	10740	8873
26.2	11525	11860	12205	12560	12924	13300	13000	10740	8873
26.4	11525	11860	12205	12560	12924	13300	13000	10740	8873
26.6	11525	11860	12205	12560	12924	13300	13000	10740	8873
26.8	11525	11860	12205	12560	12924	13300	13000	10740	8873
27	11525	11860	12205	12560	12924	13300	13000	10740	8873
27.2	11525	11860	12205	12560	12924	13300	13000	10740	8873

PR-115	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
27.4	11525	11860	12205	12560	12924	13300	13000	10740	8873
27.6	11525	11860	12205	12560	12924	13300	13000	10740	8873
27.8	11525	11860	12205	12560	12924	13300	13000	10740	8873
28	11525	11860	12205	12560	12924	13300	13000	10740	8873

PR-459	AADT								
km	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
0	15593	16628	17731	18908	19800	21500	22927	24448	26070
0.2	15593	16628	17731	18908	19800	21500	22927	24448	26070
0.4	15593	16628	17731	18908	19800	21500	22927	24448	26070
0.6	15593	16628	17731	18908	19800	21500	22927	24448	26070
0.8	15593	16628	17731	18908	19981	21500	22927	24448	26070
1	15593	16628	17731	18908	20162	21500	22927	24448	26070
1.2	16435	17342	18299	19309	20375	21500	22687	23939	25261
1.4	17331	18095	18892	19724	20593	21500	22447	23436	24468
1.6	16693	17499	18354	19261	20227	21256	21806	23533	24797
1.8	16054	16903	17816	18798	19860	21012	21165	23630	25126
2	15416	16308	17278	18336	19494	20768	20524	23727	25456
2.2	14777	15712	16740	17873	19128	20523	19882	23824	25785
2.4	14139	15116	16201	17410	18762	20279	19241	23921	26114
2.6	13500	14521	15663	16947	18396	20035	18600	24018	26443
2.8	12862	13925	15125	16485	18030	19791	18875	24115	26772
3	12223	13330	14587	16022	17663	19547	19149	24212	27101
3.2	11585	12734	14049	15559	17297	19303	19424	24310	27430
3.4	10947	12138	13511	15096	16931	19058	19698	24407	27759
3.6	10308	11543	12973	14634	16565	18814	19973	24504	28088
3.8	9670	10947	12435	14171	16199	18570	20248	24601	28418
4	9031	10351	11897	13708	15832	18326	20522	24698	28747
4.2	8393	9756	11359	13245	15466	18082	20797	24795	29076
4.4	7754	9160	10821	12783	15100	17838	21072	24892	29405
4.6	7874	9188	10729	12536	14658	17148	20073	23510	27550
4.8	7995	9217	10637	12290	14215	16458	19075	22128	25695
5	8115	9245	10546	12044	13773	15769	18076	20746	23839
5.2	8235	9274	10454	11798	13330	15079	17078	19365	21984
5.4	8356	9302	10362	11552	12888	14390	16079	17983	20129
5.6	8476	9330	10271	11306	12446	13700	15081	16601	18274
5.8	8476	9330	10271	11306	12446	13700	15081	16601	18274
6	10354	10723	11135	11596	12109	12680	13315	14020	14802
6.2	12232	12115	12000	11886	11772	11660	11549	11439	11330
6.4	13149	12570	12070	11637	11260	10930	10640	10383	10153
6.6	14066	13024	12140	11389	10748	10201	9731	9326	8976
6.8	14983	13478	12210	11140	10236	9471	8821	8270	7799
7	15899	13933	12281	10892	9724	8741	7912	7213	6622
7.2	16816	14387	12351	10644	9212	8011	7003	6157	5445
7.4	17733	14841	12421	10395	8700	7281	6094	5100	4268
7.6	17465	14640	12276	10298	8642	7257	6097	5127	4375
7.8	17197	14439	12131	10200	8584	7232	6101	5155	4481
8	16930	14238	11986	10102	8526	7207	6105	5182	4587
8.2	16662	14037	11842	10005	8468	7183	6108	5209	4693
8.4	16394	13836	11697	9907	8410	7158	6112	5237	4800
8.6	16126	13635	11552	9809	8352	7134	6115	5264	4906
8.8	15858	13434	11407	9712	8294	7109	6119	5291	5012

PR-459	AADT								
km	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
9	15591	13233	11262	9614	8236	7085	6122	5319	5119
9.2	15323	13032	11117	9516	8178	7060	6126	5346	5225
9.4	15055	12831	10973	9419	8120	7035	6130	5373	5331
9.6	14787	12630	10828	9321	8062	7011	6133	5401	5437
9.8	14519	12429	10683	9223	8004	6986	6137	5428	5544
10	14251	12229	10538	9126	7946	6962	6140	5456	5650
10.2	13984	12028	10393	9028	7888	6937	6144	5483	5756
10.4	13716	11827	10248	8930	7830	6913	6148	5510	5863
10.6	13448	11626	10104	8833	7772	6888	6151	5538	5969
10.8	13180	11425	9959	8735	7714	6863	6155	5565	6075
11	12912	11224	9814	8637	7656	6839	6158	5592	6181
11.2	12645	11023	9669	8540	7598	6814	6162	5620	6288
11.4	12377	10822	9524	8442	7540	6790	6165	5647	6394
11.6	12109	10621	9379	8344	7482	6765	6169	5674	6500
11.8	11841	10420	9235	8247	7424	6741	6173	5702	6606
12	11573	10219	9090	8149	7367	6716	6176	5729	6713
12.2	11305	10018	8945	8051	7309	6691	6180	5756	6819
12.4	11038	9817	8800	7954	7251	6667	6183	5784	6925
12.6	10770	9616	8655	7856	7193	6642	6187	5811	7032
12.8	10502	9415	8510	7759	7135	6618	6191	5838	7138
13	10234	9214	8365	7661	7077	6593	6194	5866	7244
13.2	9966	9013	8221	7563	7019	6569	6198	5893	7350
13.4	9698	8812	8076	7466	6961	6544	6201	5920	7457
13.6	9431	8611	7931	7368	6903	6519	6205	5948	7563
13.8	9163	8410	7786	7270	6845	6495	6208	5975	7669
14	8895	8209	7641	7173	6787	6470	6212	6003	7776
14.2	8627	8008	7496	7075	6729	6446	6216	6030	7882
14.4	8359	7807	7352	6977	6671	6421	6219	6057	7988
14.6	8092	7606	7207	6880	6613	6397	6223	6085	8094
14.8	7824	7405	7062	6782	6555	6372	6226	6112	8201
15	7556	7204	6917	6684	6497	6347	6230	6139	8307
15.2	7288	7003	6772	6587	6439	6323	6234	6167	8850
15.4	7020	6802	6627	6489	6381	6298	6237	6194	9393
15.6	6752	6601	6483	6391	6323	6274	6241	6221	9936
15.8	6485	6400	6338	6294	6265	6249	6244	6249	10479
16	6217	6199	6193	6196	6207	6225	6248	6276	8417
16.2	5949	5998	6048	6098	6149	6200	6251	6303	6356

PR-2	AADT								
km	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
96	29506	29750	29996	30244	30494	30746	31000	31256	31515
96.2	29446	29695	29926	30199	30455	30725	30972	31234	31498
96.4	29386	29640	29857	30154	30415	30705	30944	31212	31482
96.6	29325	29584	29787	30110	30376	30684	30916	31189	31466
96.8	29265	29529	29718	30065	30337	30664	30888	31167	31449
97	29205	29474	29648	30020	30298	30643	30860	31145	31433
97.2	29145	29419	29578	29976	30258	30623	30832	31123	31417
97.4	29084	29364	29509	29931	30219	30602	30804	31100	31400
97.6	29024	29309	29439	29886	30180	30582	30776	31078	31384
97.8	28964	29253	29370	29842	30140	30561	30748	31056	31368
98	28904	29198	29300	29797	30101	30541	30720	31034	31351
98.2	28843	29143	29263	29752	30062	30520	30692	31011	31335
98.4	28783	29088	29226	29708	30023	30500	30663	30989	31319
98.6	28723	29033	29189	29663	29983	30454	30635	30967	31302
98.8	28663	28978	29152	29618	29944	30408	30607	30945	31286
99	28602	28922	29115	29574	29905	30362	30579	30922	31270
99.2	28542	28867	29078	29529	29866	30316	30551	30900	31253
99.4	28482	28812	29042	29484	29826	30270	30523	30878	31237
99.6	28422	28757	29005	29440	29787	30224	30495	30856	31221
99.8	28361	28702	28968	29395	29748	30179	30467	30833	31204
100	28301	28647	28931	29350	29709	30133	30439	30811	31188
100.2	28241	28591	28894	29306	29669	30087	30411	30789	31172
100.4	28181	28536	28857	29261	29630	30041	30383	30767	31155
100.6	28120	28481	28820	29216	29591	29995	30355	30744	31139
100.8	28060	28426	28783	29171	29552	29949	30327	30722	31123
101	28000	28371	28746	29127	29512	29903	30299	30700	31106
101.2	27794	28433	29089	29763	30456	31168	31899	32651	33423
101.4	27587	28495	29432	30400	31400	32433	33500	34602	35740
101.6	27587	28495	29432	30400	31400	32433	33500	34602	35740
101.8	27641	28504	29394	30313	30950	32238	33247	34288	35362
102	27695	28513	29356	30225	30500	32043	32994	33974	34984
102.2	27749	28523	29319	30138	30050	31849	32742	33661	34607
102.4	27803	28532	29281	30051	29600	31654	32489	33347	34229
102.6	27857	28541	29243	29963	29874	31459	32236	33033	33851
102.8	27911	28551	29205	29876	30148	31264	31984	32720	33473
103	27965	28560	29168	29788	30422	31070	31731	32406	33096
103.2	26928	27716	28534	29386	30273	31485	32158	33161	34207
103.4	25892	26871	27901	28983	30123	31900	32585	33915	35317
103.6	24855	26027	27267	28581	29973	31833	33012	34670	36428
103.8	23818	25182	26634	28178	29823	31767	33438	35424	37539
104	22782	24338	26000	27776	29673	31700	33865	36178	38650
104.2	22894	24998	26486	28093	29487	31691	33698	35841	38167
104.4	23007	25658	26972	28410	29300	31683	33530	35503	37685
104.6	23120	26318	27458	28728	29113	31674	33362	35165	37203
104.8	23232	26978	27944	29045	28927	31665	33194	34827	36720

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
105	23345	27638	28430	29362	28740	31656	33026	34489	36238
105.2	23458	28298	28917	29680	28553	31648	32859	34151	35756
105.4	23571	28958	29403	29997	28367	31639	32691	33814	35273
105.6	23683	29618	29889	30314	28180	31630	32523	33476	34791
105.8	23796	30278	30375	30631	27993	31621	32355	33138	34309
106	23909	30938	30861	30949	27807	31613	32188	32800	33827
106.2	24022	31598	31347	31266	27620	31604	32020	32481	33344
106.4	24134	32259	31833	31583	27433	31595	31852	32162	32862
106.6	24247	32919	32319	31901	27247	31586	31684	31844	32380
106.8	24360	33579	32805	32218	27060	31578	31517	31525	31897
107	24473	34239	33291	32535	26873	31569	31349	31206	31415
107.2	24585	34899	33778	32852	26687	31560	31181	30887	30933
107.4	24698	35559	34264	33170	26500	31552	31013	30569	30450
107.6	24811	36219	34750	33487	26500	31543	30845	30250	29968
107.8	24924	36879	35236	33804	26500	31534	30678	29931	29486
108	25036	37539	35722	34122	26500	31525	30510	29612	29004
108.2	25149	38199	36208	34439	26500	31517	30342	29294	28521
108.4	25262	38859	36694	34756	27450	31508	30174	28975	28039
108.6	25375	39519	37180	35073	28400	31499	30007	28656	27557
108.8	25487	40180	37666	35391	29350	31490	29839	28337	27074
109	25600	40840	38152	35708	30300	31482	29671	28019	26592
109.2	30987	41500	38639	36025	31250	31473	29503	27700	26110
109.4	36374	42160	39125	36343	32200	31464	29336	27381	25627
109.6	41761	42820	39611	36660	33150	31456	29168	27062	25145
109.8	47148	43480	40097	36977	34100	31447	29000	26744	24663
110	47148	43480	40097	36977	34100	31447	29000	26744	24663
110.2	45149	40402	39167	36559	34183	32022	30062	28288	26690
110.4	43150	37324	38237	36142	34266	32597	31123	29833	28716
110.6	41151	34246	37308	35724	34349	33173	32185	31378	30743
110.8	39152	31168	36378	35306	34432	33748	33247	32922	32770
111	37152	28090	35448	34889	34515	34323	34308	34467	34797
111.2	35153	28256	34518	34471	34599	34899	35370	36011	36824
111.4	33154	28422	33589	34053	34682	35474	36432	37556	38850
111.6	31155	28588	32659	33636	34765	36049	37493	39101	40877
111.8	29156	28755	31729	33218	34848	36625	38555	40645	42904
112	27157	28921	30799	32800	34931	37200	39617	42190	44931
112.2	27157	28921	30799	32800	34931	37200	39617	42190	44931
112.4	30222	31195	32225	33316	34473	35700	37001	38381	39845
112.6	33288	33469	33650	33832	34016	34200	34385	34572	34759
112.8	36074	34639	33325	32121	31020	30013	29092	28251	27485
113	38859	35810	33000	30410	28024	25825	23799	21931	20210
113.2	38859	35810	33000	30410	28024	25825	23799	21931	20210
113.4	37060	35050	33229	31583	30101	28769	27578	26517	25579
113.6	35261	34290	33458	32756	32177	31713	31357	31103	30947
113.8	33462	33530	33687	33929	34253	34656	35136	35690	36316
114	31663	32770	33916	35102	36330	37600	38915	40276	41684

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
114.2	32127	33055	34015	35007	36032	37092	38188	39321	40492
114.4	32591	33340	34114	34911	35735	36584	37461	38366	39300
114.6	33055	33626	34212	34816	35437	36076	36734	37411	38107
114.8	33519	33911	34311	34721	35140	35568	36007	36456	36915
115	33983	34196	34410	34625	34842	35060	35280	35501	35723
115.2	32506	32891	33282	33677	34076	34481	34890	35304	35723
115.4	31100	31643	32196	32759	33331	33914	34507	35109	35723
115.6	33072	33134	33203	33280	33363	33455	33553	33660	33773
115.8	35044	34624	34210	33800	33395	32995	32600	32210	31824
116	35044	34624	34210	33800	33395	32995	32600	32210	31824
116.2	34836	34488	34144	33467	31663	33147	32825	32509	32198
116.4	34629	34351	34078	33133	29932	33298	33050	32808	32572
116.6	34421	34214	34013	32800	28200	33450	33275	33108	32947
116.8	34213	34077	33947	32891	28731	33601	33501	33407	33321
117	34006	33940	33881	32982	29262	33753	33726	33706	33695
117.2	33798	33803	33816	33073	29793	33904	33951	34006	34069
117.4	33590	33666	33750	33164	30325	34056	34176	34305	34443
117.6	33383	33529	33685	33255	30856	34208	34401	34604	34818
117.8	33175	33392	33619	33346	31387	34359	34626	34904	35192
118	32967	33255	33553	33437	31918	34511	34851	35203	35566
118.2	32760	33118	33488	33528	32449	34662	35077	35503	35940
118.4	32552	32981	33422	33619	32980	34814	35302	35802	36315
118.6	32344	32844	33356	33711	33511	34965	35527	36101	36689
118.8	32137	32707	33291	33802	34043	35117	35752	36401	37063
119	31929	32571	33225	33893	34574	35268	35977	36700	37437
119.2	31180	32003	32850	33722	34620	35546	36498	37480	38491
119.4	30431	31435	32475	33552	34667	35823	37020	38260	39545
119.6	29683	30868	32100	33381	34714	36100	37541	39040	40598
119.8	29683	30868	32100	33381	34714	36100	37541	39040	40598
120	32033	32945	33903	34908	35962	37067	37548	39059	40632
120.2	34383	35022	35706	36435	37210	38033	37554	39079	40665
120.4	36733	37100	37509	37962	38458	39000	37561	39098	40698
120.6	39083	39177	39312	39488	39706	39967	37567	39117	40732
120.8	41432	41255	41115	41015	40954	40933	37574	39137	40765
121	43782	43332	42918	42542	42202	41900	37580	39156	40798
121.2	46132	45409	44721	44068	43450	42867	37587	39176	40831
121.4	48482	47487	46525	45595	44698	43833	37593	39195	40865
121.6	50832	49564	48328	47122	45946	44800	37600	39214	40898
121.8	50049	48839	47658	46506	45382	44285	37809	39169	40592
122	49266	48113	46988	45890	44817	43771	38018	39124	40286
122.2	48483	47388	46318	45274	44253	43256	38227	39079	39980
122.4	47700	46662	45649	44658	43689	42741	38436	39033	39674
122.6	46916	45937	44979	44041	43124	42227	38645	38988	39368
122.8	46133	45212	44309	43425	42560	41712	38855	38943	39062
123	45350	44486	43639	42809	41995	41198	39064	38898	38756
123.2	44567	43761	42970	42193	41431	40683	39273	38852	38450

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
123.4	43784	43035	42300	41577	40867	40168	39482	38807	38144
123.6	43784	43035	42300	41577	40867	40168	39482	38807	38144
123.8	43852	43523	43200	42884	42574	42270	41972	41680	41394
124	43920	44010	44100	44190	44281	44371	44462	44553	44644
124.2	44610	44779	44950	45113	45277	45443	47585	48130	48695
124.4	45300	45549	45800	46036	46274	46514	50708	51706	52747
124.6	45990	46318	46650	46959	47271	47586	53831	55283	56798
124.8	46680	47088	47500	47882	48267	48657	56954	58860	60850
125	47370	47857	48350	48805	49264	49729	60077	62437	64901
125.2	48060	48627	49200	49728	50261	50800	63200	66014	68953
125.4	48246	51121	48614	49426	49813	50869	61884	64456	67393
125.6	48432	53616	48029	49125	49365	50938	60568	62898	65833
125.8	48618	56111	47443	48824	48916	51006	59252	61340	64274
126	48804	58605	46857	48522	48468	51075	57936	59782	62714
126.2	48990	61100	46271	48221	48020	51144	56621	58224	61154
126.4	49175	60289	45686	47919	47572	51213	55305	56666	59595
126.6	49361	59478	45100	47618	47124	51281	53989	55108	58035
126.8	49547	58666	44514	47317	46676	51350	52673	53550	56475
127	49733	57855	43929	47015	46228	51419	51357	51992	54916
127.2	49919	57044	43343	46714	45779	51488	50041	50434	53356
127.4	50105	56233	42757	46412	45331	51556	48725	48876	27650
127.6	50291	55421	42171	46111	44883	51625	47409	47318	28238
127.8	50477	54610	41586	45810	44435	51694	46094	45760	28825
128	50663	53799	41000	45508	43987	51763	44778	44203	29413
128.2	50848	52988	41874	45207	43539	51831	43462	42645	30001
128.4	51034	52177	42747	44906	43090	51900	42146	41087	30588
128.6	51220	51365	43621	44604	42642	48682	40830	39529	31176
128.8	51406	50554	44495	44303	42194	45464	39514	37971	31764
129	51592	49743	45368	44001	41746	42246	38198	36413	32351
129.2	51778	48932	46242	43700	41298	39028	36882	34855	32939
129.4	49900	47157	44565	42115	39800	37612	35545	33591	31744
129.6	46355	44805	43361	42018	40772	39616	38547	37561	36652
129.8	42810	42452	42157	41922	41743	41620	41550	41530	41560
130	39264	40100	40953	41825	42715	43624	44552	45500	46468
130.2	30000	31155	32354	33600	34413	35247	36100	36974	37869
130.4	30000	30670	32366	33616	34460	35327	36216	37128	38063
130.6	30000	30185	32377	33631	34507	35407	36332	37281	38257
130.8	30000	29700	32388	33647	34554	35487	36447	37435	38450
131	29999	29796	32399	33662	34601	35568	36563	37588	38644
131.2	29999	29893	32410	33678	34648	35648	36679	37742	38838
131.4	29999	29989	32422	33693	34695	35728	36795	37895	39032
131.6	29999	30086	32433	33709	34742	35808	36911	38049	39225
131.8	29999	30182	32444	33724	34788	35889	37026	38203	39419
132	29999	30279	32455	33740	34835	35969	37142	38356	39613
132.2	29998	30375	32466	33755	34882	36049	37258	38510	39806
132.4	29998	30472	32478	33771	34929	36129	37374	38663	40000

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
132.6	29998	30568	32489	33786	34976	36210	37489	38817	40194
132.8	29998	30665	32500	33802	35023	36290	37605	38971	40388
133	29998	30761	32507	33818	35070	36370	37721	39124	40581
133.2	29998	30858	32514	33833	35117	36451	37837	39278	40775
133.4	29998	30954	32521	33849	35164	36531	37953	39431	40969
133.6	29997	31051	32528	33864	35210	36611	38068	39585	41163
133.8	29997	31147	32536	33880	35257	36691	38184	39738	41356
134	29997	31244	32543	33895	35304	36772	38300	39892	41550
134.2	30618	31776	32539	34242	35554	36923	38350	39837	41388
134.4	31239	32307	32536	34588	35805	37074	38400	39783	41226
134.6	31860	32839	32533	34935	36055	37226	38450	39728	41064
134.8	32481	33371	32529	35281	36305	37377	38499	39674	40902
135	33101	33902	32526	35628	36556	37529	38549	39619	40740
135.2	33722	34434	32523	35974	36806	37680	38599	39564	40578
135.4	34343	34966	32520	36321	37056	37832	38649	39510	40416
135.6	34964	35498	32516	36667	37306	37983	38699	39455	40254
135.8	35585	36029	32513	37014	37557	38134	38749	39401	40092
136	36206	36561	32510	37361	37807	38286	38798	39346	39930
136.2	36827	37093	32507	37707	38057	38437	38848	39291	39768
136.4	37447	37624	32503	38054	38307	38589	38898	39237	39606
136.6	38068	38156	32500	38400	38558	38740	38948	39182	39444
136.8	38689	38688	33764	38747	38808	38891	38998	39128	39282
137	39310	39219	35028	39093	39058	39043	39048	39073	39120
137.2	39931	39751	36292	39440	39309	39194	39097	39018	38958
137.4	40552	40283	37556	39786	39559	39346	39147	38964	38796
137.6	41173	40815	38820	40133	39809	39497	39197	38909	38634
137.8	41793	41346	40084	40479	40059	39649	39247	38855	38471
138	42414	41878	41349	40826	40310	39800	39297	38800	38309
138.2	42414	41878	41349	40826	40310	39800	39297	38800	38309
138.4	40821	40535	40267	40017	39786	39674	39597	39156	38242
138.6	39227	39192	39185	39208	39263	39548	39898	39511	38174
138.8	37634	37849	38103	38400	38740	39423	40198	39867	38107
139	36040	36506	37022	37591	38216	39297	40498	40222	38039
139.2	34446	35162	35940	36782	37693	39171	40799	40578	37972
139.4	32853	33819	34858	35973	37170	39045	41099	40933	37904
139.6	31259	32476	33776	35165	36647	38919	41399	41289	40476
139.8	29666	31133	32695	34356	36123	38794	41700	41644	43048
140	28072	29790	31613	33547	35600	38668	42000	42000	45619
140.2	28214	30442	32213	33475	36085	38972	42385	42297	45801
140.4	28356	31095	32814	33403	36570	39277	42769	42594	45983
140.6	28498	31747	33414	33330	37055	39582	43154	42892	46165
140.8	28640	32400	34015	33258	37539	39886	43538	43189	46346
141	28782	33052	34615	33185	38024	40191	43923	43486	46528
141.2	28923	33704	35216	33113	38509	40495	44308	43783	46710
141.4	29065	34357	35816	33041	38994	40800	44692	44080	46892
141.6	29207	35009	36417	32968	39479	41217	45077	44378	47074

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
141.8	29349	35661	37017	32896	39964	41634	45462	44675	47255
142	29491	36314	37618	32824	40449	42051	45846	44972	47437
142.2	29633	36966	38218	32751	40933	42468	46231	45269	47619
142.4	29774	37619	38819	32679	41418	42885	46615	45566	47801
142.6	29916	38271	39419	32607	41903	43301	47000	45864	47983
142.8	30058	38923	40020	32534	42388	43718	47385	46161	48164
143	30200	39576	40620	32462	42873	44135	47769	46458	48346
143.2	31545	40228	41221	32389	43358	44552	48154	46755	48528
143.4	32891	40880	41821	32317	43843	44969	48538	47052	48710
143.6	34236	41533	42422	32245	44327	45386	48923	47350	48891
143.8	35581	42185	43022	32172	44812	45803	49308	47647	49073
144	36927	42838	43623	32100	45297	46220	49692	47944	49255
144.2	38272	43490	44223	34188	45782	46637	50077	48241	49437
144.4	39617	44142	44824	36275	46267	47054	50462	48538	49619
144.6	40963	44795	45424	38363	46752	47470	50846	48836	49800
144.8	42308	45447	46025	40450	47237	47887	51231	49133	49982
145	43653	46099	46625	42538	47721	48304	51615	49430	50164
145.2	44998	46752	47226	44625	48206	48721	52000	49727	50346
145.4	46344	47404	47826	46713	48691	49138	50968	50024	50527
145.6	47689	48057	48427	48800	49176	49555	49937	50322	50709
145.8	45382	46282	47200	48136	49091	50065	51058	52071	53104
146	45987	46365	46745	47129	47516	47907	48300	48697	49097
146.2	47600	47716	47832	47949	48066	48183	48300	48418	48536
146.4	47221	47834	41516	48507	48175	48426	48682	48943	49210
146.6	46842	47953	35200	49066	48284	48669	49063	49469	49885
146.8	46463	48071	36291	49624	48393	48912	49445	49994	50560
147	46084	48190	37381	50183	48503	49155	49827	50520	51235
147.2	45704	48308	38472	50741	48612	49398	50209	51046	51910
147.4	45325	48426	39562	51300	48721	49641	50590	51571	52584
147.6	44946	48545	40653	50702	48831	49884	50972	52097	53259
147.8	44567	48663	41743	50104	48940	50127	51354	52622	53934
148	44188	48782	42834	49507	49049	50370	51736	53148	54609
148.2	43809	48900	43924	48909	49158	50613	52117	53674	55283
148.4	43430	46726	45015	48311	49268	50856	52499	54199	55958
148.6	43051	44552	46105	47713	49377	51099	52881	54725	56633
148.8	64989	61850	59086	56665	54562	52749	51206	49912	53083
149	86927	79149	72066	65618	59746	54400	49532	45100	49532
149.2	78622	72843	67644	50500	58790	55051	51722	48768	52935
149.4	70316	66538	63222	50975	57834	55703	53911	52436	56338
149.6	62011	60233	58799	51450	56878	56354	56100	56104	59741
149.8	53705	53928	54377	51925	55922	57005	58290	59772	63143
150	45400	47623	49954	52400	54965	57656	60479	63440	66546
150.2	47606	49111	50678	52307	54003	55769	57606	59520	61513
150.4	49812	50600	51401	52215	53041	53881	54734	55600	56480
150.6	50730	51300	51880	52471	53073	53685	54309	54943	55589
150.8	51648	52000	52360	52728	53105	53490	53883	54286	54697

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
151	52567	52700	52839	52985	53136	53294	53458	53629	53806
151.2	53485	53400	53319	53242	53168	53099	53033	52972	52915
151.4	54403	54100	53798	53498	53200	52903	52608	52315	52023
151.6	54403	54100	53798	53498	53200	52903	52608	52315	52023
151.8	53691	53433	53176	52921	52667	52414	52162	51912	51662
152	52980	52767	52555	52344	52133	51924	51716	51508	51302
152.2	52268	52100	51933	51766	51600	51434	51269	51105	50941
152.4	53420	53150	52882	52615	52350	52086	51824	51564	51304
152.6	54572	54200	53831	53464	53100	52738	52379	52022	51668
152.8	54082	54200	54319	54437	54556	54676	54795	54915	55035
153	65353	63936	62550	61194	59868	58570	57300	56058	54843
153.2	72763	71070	69416	67800	66222	64681	63175	61705	60268
153.4	66200	65064	63947	62850	61771	60711	59669	58645	57639
153.6	48500	46448	44482	42600	40797	39071	37418	35834	34318
153.8	55682	58500	56939	55419	53940	52500	58100	58939	59791
154	57297	58970	54631	55082	55872	51340	58760	59556	60364
154.2	58912	59440	52323	54745	57804	50180	59420	60173	60936
154.4	60526	59910	50015	54408	59736	49020	60080	60790	61509
154.6	62141	60380	47708	54072	61668	47860	60740	61407	62082
154.8	63756	60850	45400	53735	63600	46700	61400	62024	62655
155	59105	61215	63400	65663	68007	70434	72948	75552	78248
155.2	59673	62411	65274	68268	71400	74675	78101	81684	85431
155.4	63307	65240	67232	69285	71400	73580	75827	78142	80527
155.6	64757	67152	69646	72242	70633	77762	80696	83754	86940
155.8	66206	69064	72059	75199	69867	81944	85566	89366	93353
156	67656	70976	74473	78156	69100	86126	90436	94978	99765
156.2	69106	72888	76886	81114	79114	90308	95305	100590	106178
156.4	70555	74800	79300	84071	89128	94490	100175	106202	112591
156.6	70555	74800	79300	84071	89128	94490	100175	106202	112591
156.8	70044	73480	77120	81591	86323	91103	96158	101502	107154
157	69533	72160	74940	79111	83517	87716	92141	96803	101718
157.2	69022	70840	72760	76631	80711	84329	88123	92104	96282
157.4	68511	69520	70580	74152	77906	80942	84106	87405	90845
157.6	67999	68199	68400	71672	75100	77554	80089	82706	85409
157.8	67662	67241	66851	69051	71409	75666	74648	76406	78258
158	67324	66282	65302	66430	67719	73777	69207	70107	71108
158.2	66986	65323	63754	63809	64028	71889	63767	63807	63958
158.4	66649	64364	62205	61189	60337	70000	58326	57507	56807
158.6	66311	63405	60656	58568	56646	60062	52885	51207	49657
158.8	65973	62446	59107	55947	52956	50124	47444	44908	42507
159	81975	77592	73444	69517	65800	62282	58952	55800	52817
159.2	77280	72456	70011	66653	65900	63562	61391	59380	57522
159.4	72585	67320	66578	63790	66000	64841	63829	62960	62228
159.6	67890	64006	63145	60927	66100	66121	66268	66539	66933
159.8	63195	60692	59712	58063	66200	67400	68707	70119	71639
160	58500	57379	56279	55200	66300	68680	71145	73699	76344

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
160.2	60800	60405	60022	59650	65368	66728	68130	69578	71073
160.4	63100	63432	63765	64100	64437	64775	65116	65458	65802
160.6	62200	61514	62885	63180	58458	63854	63393	64508	64838
160.8	61300	59596	62005	62260	52479	62932	61671	63558	63874
161	60400	57678	61124	61340	46500	62010	59948	62609	62910
161.2	59500	55761	60244	60420	46135	61088	58226	61659	61947
161.4	58600	53843	59364	59500	45771	60167	56503	60709	60983
161.6	57700	51925	58484	58580	45406	59245	54780	59759	60019
161.8	56800	50008	57604	57660	45042	58323	53058	58809	59055
162	55900	48090	56724	56740	44677	57401	51335	57860	58091
162.2	55000	47589	55844	55820	44313	56479	49613	56910	57127
162.4	54100	47089	54963	54900	43948	55558	47890	55960	56163
162.6	53200	46588	54083	53980	43584	54636	46168	55010	55199
162.8	52300	46087	53203	53060	43219	53714	44445	54061	54236
163	51400	45587	52323	52140	42855	52792	42723	53111	53272
163.2	50500	45086	51443	51220	42490	51870	41000	52161	52308
163.4	49600	44585	50563	50300	42126	50949	40411	51211	51344
163.6	48700	44084	49682	49380	41761	50027	39822	50261	50380
163.8	47800	43584	48802	48460	41397	49105	39233	49312	49416
164	46900	43083	47922	47540	41032	48183	38644	48362	48452
164.2	46000	42582	47042	46620	40668	47261	38056	47412	47488
164.4	45100	42082	46162	45700	40303	46340	37467	46462	46525
164.6	44200	41581	45282	44780	39938	45418	36878	45512	45561
164.8	43300	41080	44402	43860	39574	44496	36289	44563	44597
165	42400	40580	43521	42940	39209	43574	35700	43613	43633
165.2	41500	40079	42641	42020	38845	42653	35751	42663	42669
165.4	40600	39578	41761	41100	38480	41731	35802	41713	41705
165.6	39700	39077	40881	40314	38116	40809	35853	40763	40741
165.8	38800	38577	40001	39529	37751	39887	35904	39814	39777
166	37900	38076	39121	38743	37387	38965	35954	38864	38814
166.2	37489	37575	38240	37958	37022	38044	36005	37914	37850
166.4	37079	37075	37360	37172	36658	37122	36056	36964	36886
166.6	36668	36574	36480	36387	36293	36200	36107	36014	35922
166.8	36668	36574	36480	36387	36293	36200	36107	36014	35922
167	37629	35686	36969	36666	36381	36111	35856	35614	35384
167.2	38591	34798	37457	36946	36469	36022	35604	35213	34845
167.4	39552	33910	37946	37226	36557	35934	35353	34812	34307
167.6	40513	34995	38434	37506	36645	35845	35102	34411	33768
167.8	41474	36080	38923	37786	36733	35756	34850	34010	33230
168	42436	37165	39411	38066	36821	35667	34599	33609	32691
168.2	43397	38250	39900	38346	36909	35579	34348	33208	32153
168.4	44358	39336	40389	38626	36997	35490	34096	32807	31615
168.6	45320	40421	40877	38906	37085	35401	33845	32406	31076
168.8	46281	41506	41366	39186	37172	35312	33594	32005	30538
169	47242	42591	41854	39466	37260	35223	33342	31605	29999
169.2	48203	43676	42343	39746	37348	35135	33091	31204	29461

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
169.4	49165	44761	42831	40026	37436	35046	32840	30803	28922
169.6	50126	45846	43320	40306	37524	34957	32588	30402	28384
169.8	51087	46931	43808	40586	37612	34868	32337	30001	27846
170	52048	48017	44297	40866	37700	34780	32085	29600	27307
170.2	50064	47275	43917	40614	37673	34693	32092	29699	27497
170.4	48079	46533	43536	40362	37647	34606	32099	29798	27687
170.6	46094	45792	43156	40109	37620	34519	32106	29897	27878
170.8	44109	45050	42776	39857	37593	34433	32112	29996	28068
171	42124	44309	42395	39605	37567	34346	32119	30094	28258
171.2	40139	43567	42015	39353	37540	34259	32126	30193	28448
171.4	38155	42826	41635	39101	37513	34172	32133	30292	28639
171.6	36170	42084	41254	38849	37487	34086	32139	30391	28829
171.8	34185	41342	40874	38597	37460	33999	32146	30490	29019
172	32200	40601	40494	38345	37433	33912	32153	30589	29209
172.2	32007	39859	40113	38093	37407	33826	32159	30688	29399
172.4	31813	39118	39733	37841	37380	33739	32166	30787	29590
172.6	31620	38376	39353	37589	37353	33652	32173	30885	29780
172.8	31427	37635	38972	37337	37327	33565	32180	30984	29970
173	31233	36893	38592	37085	37300	33479	32186	31083	30160
173.2	31040	36152	38212	36833	37053	33392	32193	31182	30350
173.4	30847	35410	37831	36581	36806	33305	32200	31281	30541
173.6	30653	35229	37451	36329	36560	33218	32207	31380	30731
173.8	30460	35047	37071	36077	36313	33132	32213	31479	30921
174	30267	34866	36690	35825	36066	33045	32220	31578	31111
174.2	30073	34684	36310	35573	35819	32958	32227	31676	31301
174.4	29880	34503	35930	35321	35573	32871	32233	31775	31492
174.6	29687	34321	35549	35068	35326	32785	32240	31874	31682
174.8	29493	34140	35169	34816	35079	32698	32247	31973	31872
175	29300	33959	34789	34564	34832	32611	32254	32072	32062
175.2	29012	33777	34408	34312	34585	32524	32260	32171	32253
175.4	28725	33596	34028	34060	34339	32438	32267	32270	32443
175.6	28437	33414	33648	33808	34092	32351	32274	32369	32633
175.8	28149	33233	33267	33556	33845	32264	32281	32467	32823
176	27861	33051	32887	33304	33598	32178	32287	32566	33013
176.2	27574	32870	32507	33052	33352	32091	32294	32665	33204
176.4	27286	32689	32126	32800	33105	32004	32301	32764	33394
176.6	26998	32507	31746	32474	32858	31917	32308	32863	33584
176.8	26710	32326	31366	32147	32611	31831	32314	32962	33774
177	26423	32144	30985	31821	32364	31744	32321	33061	33964
177.2	26135	31963	30605	31495	32118	31657	32328	33160	34155
177.4	25847	31781	30225	31168	31871	31570	32334	33258	34345
177.6	25559	31600	29844	30842	31624	31484	32341	33357	34535
177.8	25272	31419	29464	30516	31377	31397	32348	33456	34725
178	24984	31237	29084	30189	31131	31310	32355	33555	34915
178.2	24696	31056	28703	29863	30884	31223	32361	33654	35106
178.4	24409	30874	28323	29537	30637	31137	32368	33753	35296

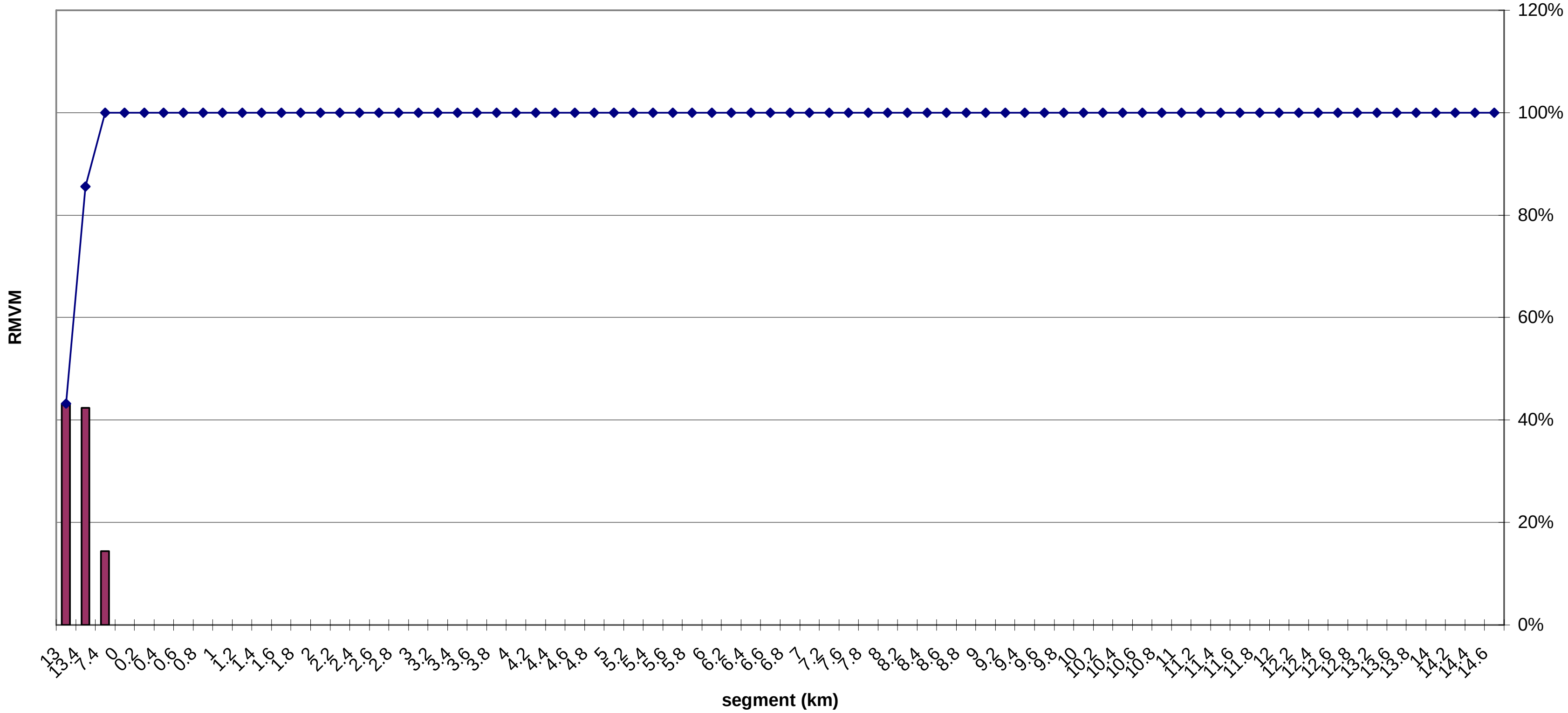
PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
178.6	24121	30693	27943	29211	30390	31050	32375	33852	35486
178.8	23833	30511	27562	28884	30143	30963	32382	33951	35676
179	23545	30330	27182	28558	29897	30877	32388	34049	35867
179.2	23258	31875	26802	28232	29650	30790	32395	34148	36057
179.4	22970	33420	26421	27905	29403	30703	32402	34247	36247
179.6	22682	30892	26041	27579	29156	30616	32408	34346	36437
179.8	22394	28364	25661	27253	28910	30530	32415	34445	36627
180	22107	25836	25280	26926	28663	30443	32422	34544	36818
180.2	21819	23309	24900	26600	28416	30356	32429	34643	37008
180.4	21819	23309	24900	26600	28416	30356	32429	34643	37008
180.6	21734	23140	24640	26239	27944	29762	31700	33767	35972
180.8	21648	22972	24380	25878	27471	29167	30971	32892	34936
181	21563	22804	24120	25517	26999	28573	30243	32016	33899
181.2	21478	22635	23860	25156	26527	27978	29514	31141	32863
181.4	21392	22467	23600	24795	26055	27384	28786	30265	31827
181.6	21307	22299	23340	24434	25582	26789	28057	29390	30791
181.8	21222	22130	23080	24072	25110	26195	27329	28515	29755
182	21136	21962	22820	23711	24638	25600	26600	27639	28719
182.2	21136	21962	22820	23711	24638	25600	26600	27639	28719
182.4	21957	22685	23438	24218	25025	25860	26725	27621	28548
182.6	22778	23408	24057	24725	25413	26121	26851	27602	28377
182.8	23600	24131	24675	25231	25800	26381	26976	27584	28206
183	21148	21966	22816	23698	24615	25568	26557	27584	28651
183.2	21300	22468	23700	25000	26370	27816	29342	30951	32648
183.4	21209	22363	23688	24866	26220	27986	29155	30743	32389
183.6	21117	22259	23675	24732	26070	28155	28967	30535	32131
183.8	21026	22155	23663	24598	25919	28324	28780	30327	31872
184	20935	22050	23650	24464	25769	28493	28593	30120	31614
184.2	20843	21946	23638	24330	25618	28662	28406	29912	31355
184.4	20752	21841	23625	24196	25468	28831	28218	29704	31097
184.6	20661	21737	23613	24062	25318	29000	28031	29497	30838
184.8	20569	21632	23600	23928	25167	28744	27844	29289	30580
185	20478	21528	23588	23794	25017	28489	27657	29081	30321
185.2	20386	21423	23575	23660	24866	28233	27470	28873	30063
185.4	20295	21319	23563	23526	24716	27978	27282	28666	29804
185.6	20204	21214	23550	23392	24566	27722	27095	28458	29545
185.8	20112	21110	23538	23258	24415	27467	26908	28250	29287
186	20021	21005	23525	23125	24265	27211	26721	28042	29028
186.2	19930	20901	23513	22991	24114	26956	26534	27835	28770
186.4	19838	20796	23500	22857	23964	26700	26346	27627	28511
186.6	19747	20692	23287	22723	23814	26444	26159	27419	28253
186.8	19656	20587	23074	22589	23663	26189	25972	27212	27994
187	19564	20483	22861	22455	23513	25933	25785	27004	27736
187.2	19473	20378	22648	22321	23362	25678	25598	26796	27477
187.4	19382	20274	22435	22187	23212	25422	25410	26588	27219
187.6	19290	20169	22222	22053	23062	25167	25223	26381	26960

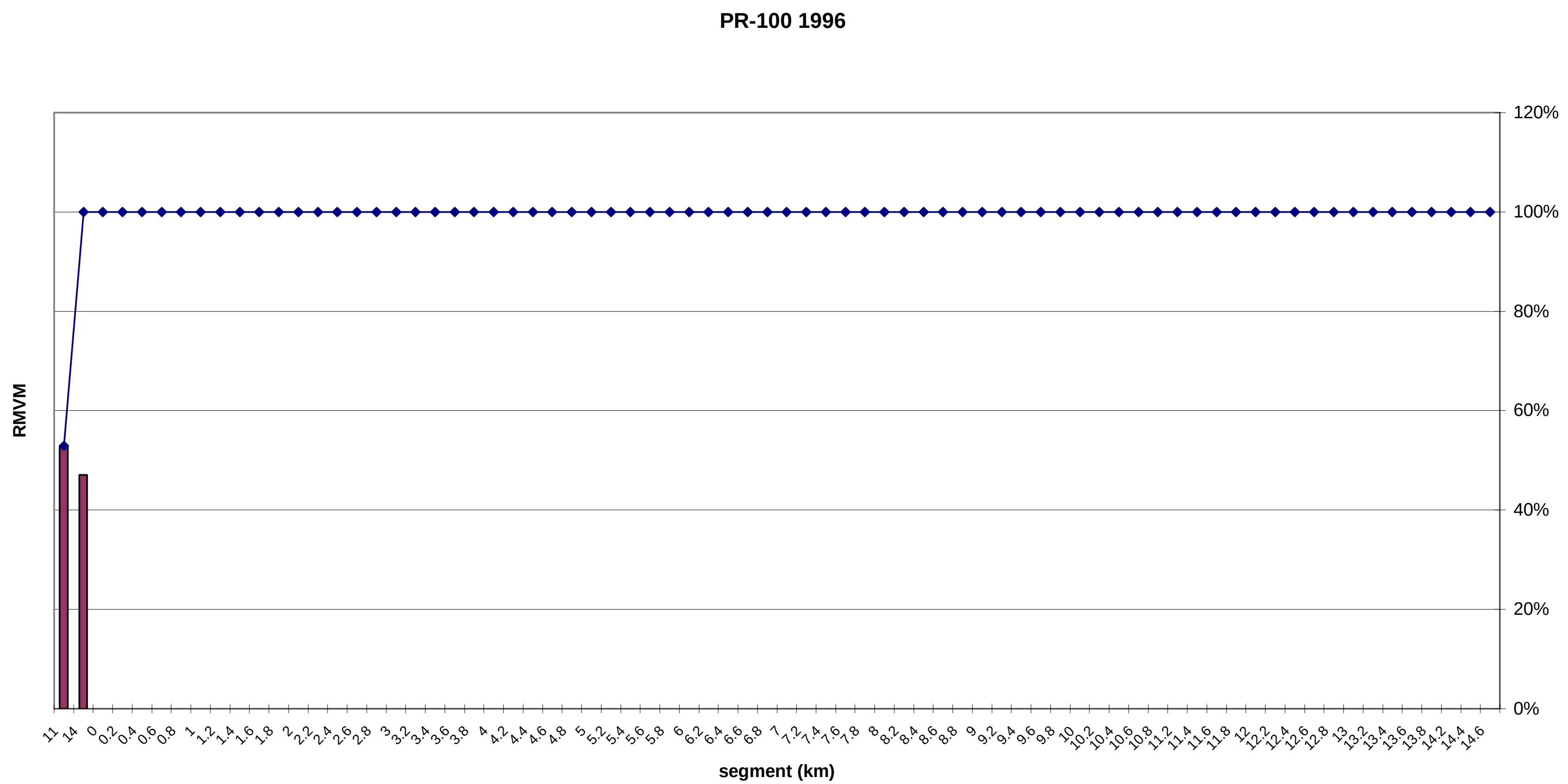
PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
187.8	19199	20065	22009	21919	22911	24911	25036	26173	26702
188	19108	19960	21796	21785	22761	24656	24849	25965	26443
188.2	19016	19856	21583	21651	22610	24400	24661	25757	26185
188.4	18925	19752	21370	21517	22460	24144	24474	25550	25926
188.6	18834	19647	21157	21383	22310	23889	24287	25342	25790
188.8	18742	19543	20944	21250	22159	23633	24100	25134	25653
189	18651	19438	20731	21116	22009	23378	23913	24926	25517
189.2	18559	19334	20518	20982	21858	23122	23725	24719	25381
189.4	18468	19229	20305	20848	21708	22867	23538	24511	25244
189.6	18377	19125	20092	20714	21558	22611	23351	24303	25108
189.8	18285	19020	19879	20580	21407	22356	23164	24096	24972
190	18194	18916	19666	20446	21257	22100	22977	23888	24835
190.2	18204	21274	19733	20546	21324	22145	22953	23913	24917
190.4	18213	23633	19800	20646	21391	22190	22929	23939	24998
190.6	18223	25991	19867	20747	21458	22235	22905	23965	25079
190.8	18232	28350	19933	20847	21526	22280	22881	23990	25160
191	18242	30709	20000	20947	21593	22325	22857	24016	25242
191.2	18251	33067	20067	21047	21660	22370	22834	24041	25323
191.4	18261	35426	20134	21147	21727	22415	22810	24067	25404
191.6	18270	37784	20201	21248	21794	22460	22786	24093	25485
191.8	18280	40143	20268	21348	21861	22505	22762	24118	25567
192	18289	42501	20335	21448	21928	22550	22738	24144	25648
192.2	18299	44860	20402	21548	21996	22595	22714	24170	25729
192.4	18308	42059	20469	21648	22063	22640	22691	24195	25810
192.6	18318	39258	20535	21749	22130	22685	22667	24221	25892
192.8	18327	36457	20602	21849	22197	22730	22643	24246	25973
193	18337	33656	20669	21949	22264	22775	22619	24272	26054
193.2	18346	30855	20736	22049	22331	22820	22595	24298	26135
193.4	18356	28054	20803	22149	22399	22865	22571	24323	26217
193.6	18365	25253	20870	22250	22466	22910	22548	24349	26298
193.8	18375	22452	20937	22350	22533	22955	22524	24374	26379
194	18384	19650	21004	22450	22600	23000	22500	24400	26460
194.2	18772	20712	21956	23326	23530	23961	23583	25367	27297
194.4	19160	21773	22909	24201	24460	24922	24666	26334	28134
194.6	20417	22834	23862	25077	25390	25882	25749	27301	28970
194.8	21675	23895	24814	25953	26320	26843	26833	28268	29807
195	22932	24956	25767	26829	27250	27804	27916	29236	30644
195.2	24189	26018	26719	27704	28180	28765	28999	30203	31480
195.4	25447	27079	27672	28580	29110	29726	30082	31170	32317
195.6	26704	28140	28625	29456	30040	30686	31165	32137	33154
195.8	27962	29004	29577	30332	30970	31647	32248	33104	33990
196	29219	29867	30530	31207	31900	32608	33331	34071	34827
196.2	28532	29664	30892	30586	31879	32466	33068	33686	34321
196.4	27846	29461	31253	29964	31859	32323	32804	33301	33814
196.6	27159	29258	31615	29343	31838	32181	32540	32915	33307
196.8	26473	29055	31977	28721	31818	32039	32276	32530	32801

PR-2	AADT								
km	1995	1996	1997	1998	1999	2000	2001	2002	2003
197	25786	28852	32338	28100	31797	31896	32012	32145	32294
197.2	25100	28649	32700	28718	31776	31754	31748	31760	31787
197.4	26725	29545	32786	29335	31756	31612	31485	31374	31281
197.6	28350	30440	32871	29953	31735	31469	31221	30989	30774
197.8	29976	31336	32957	30571	31714	31327	30957	30604	30268
198	31601	32231	33042	31188	31694	31185	30693	30218	29761
198.2	33226	33127	33128	31806	31673	31042	30429	29833	29254
198.4	34851	34022	33213	32424	31653	30900	30165	29448	28748
198.6	34851	34022	33213	32424	31653	30900	30165	29448	28748
198.8	31295	32479	33857	33742	33642	33556	33483	33423	33377
199	27738	30935	34500	35061	35631	36211	36800	37399	38007
199.2	28768	31678	34805	35589	36445	37196	37964	38751	39557
199.4	29798	32420	35109	36117	37259	38180	39128	40103	41106
199.6	30829	33087	35414	36644	38073	39165	40292	41455	42656
199.8	31859	33753	35718	37172	38886	40150	41456	42808	44205
200	32889	34420	36023	37700	39700	41134	42620	44160	45755

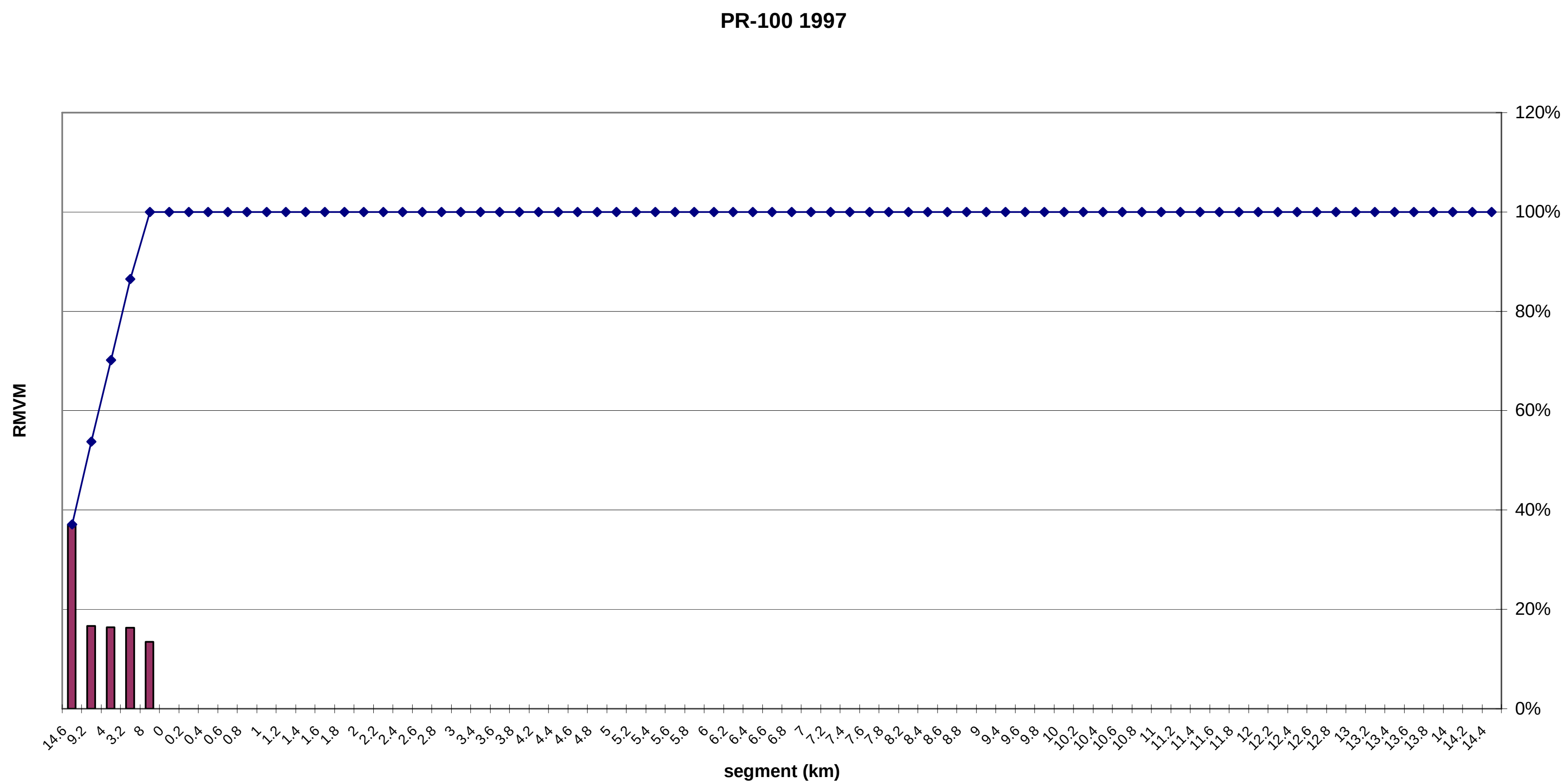
Appendix C: Pareto Diagrams

PR-100 1995



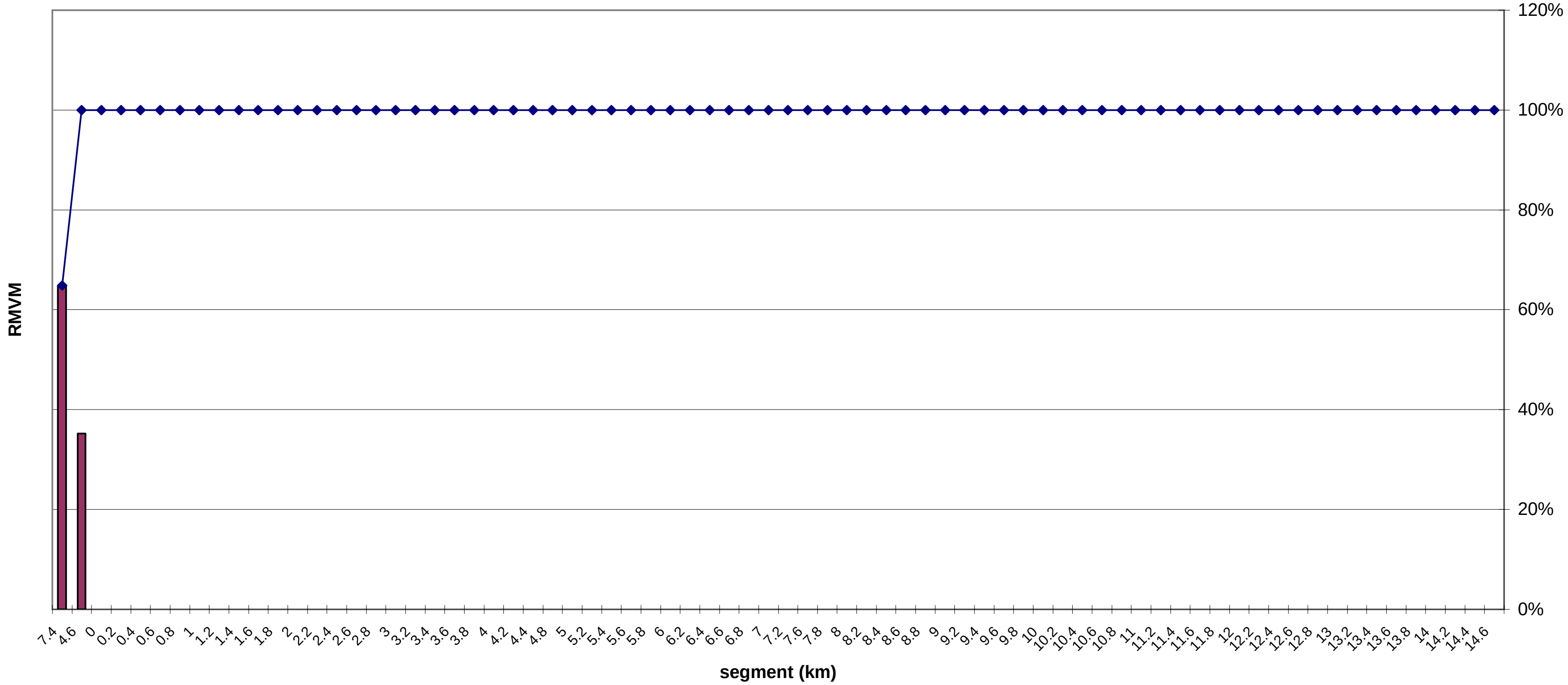


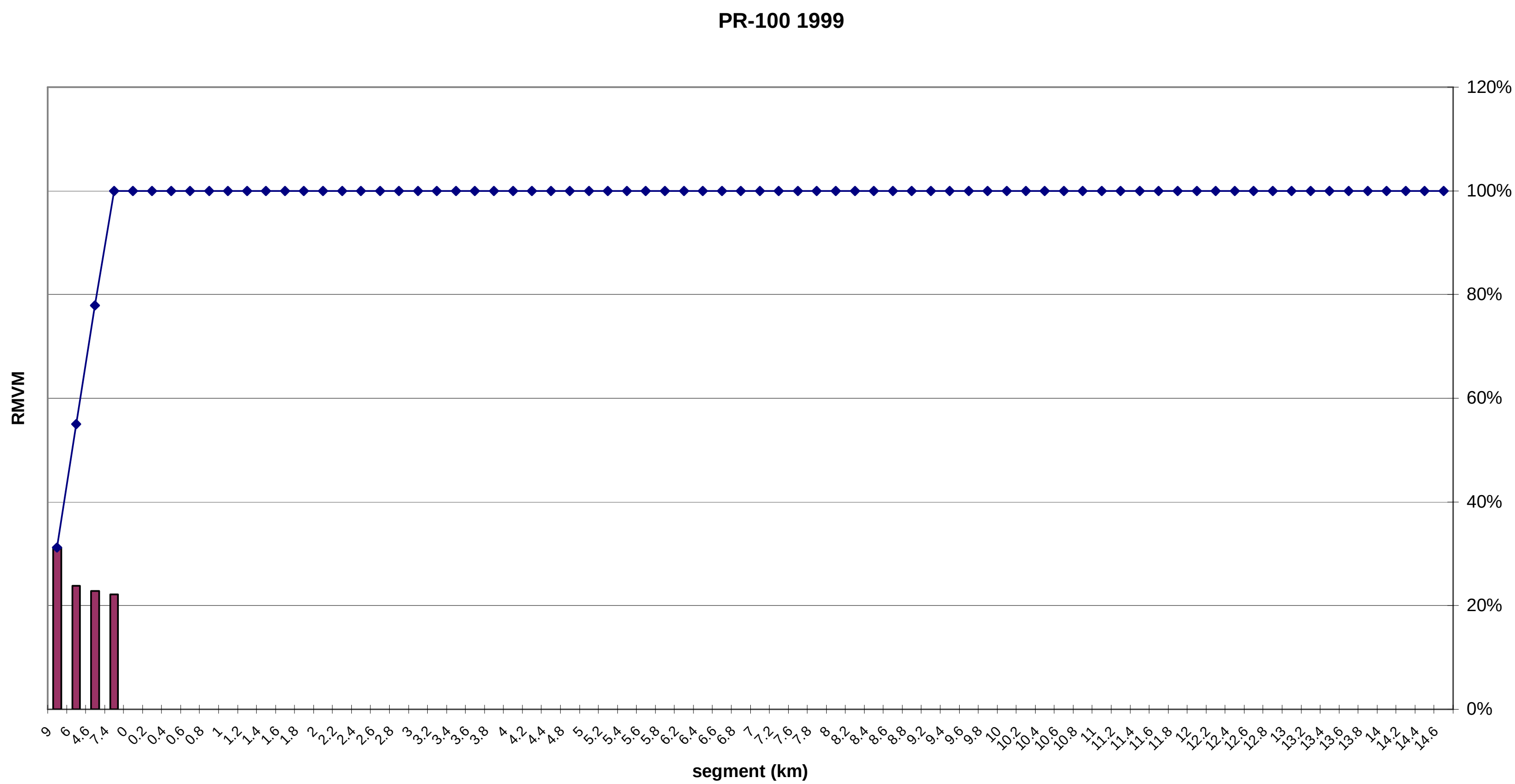
PR-100 1996
RMVM
120%
100%
80%
60%
40%
20%
0%
segment (km)



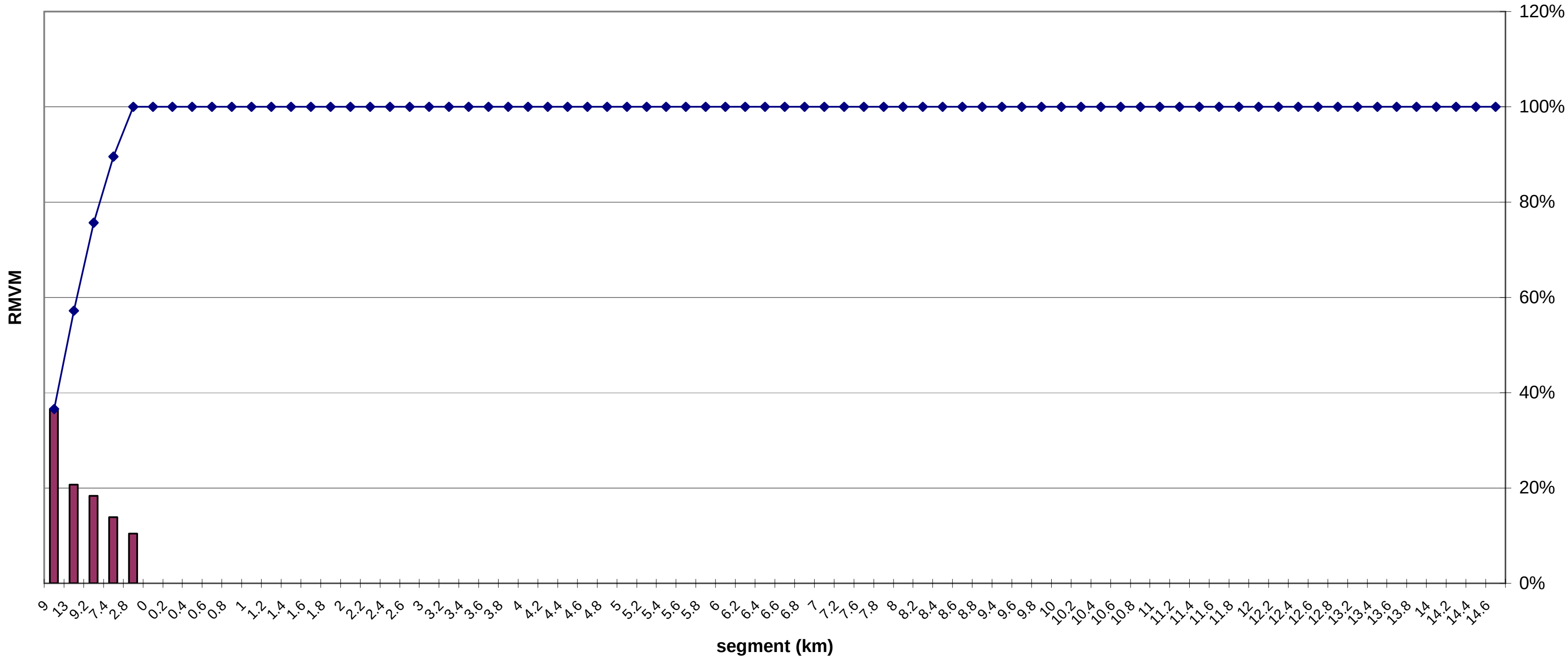
PR-100 1997
RMVM
segment (km)
120%
100%
80%
60%
40%
20%
0%

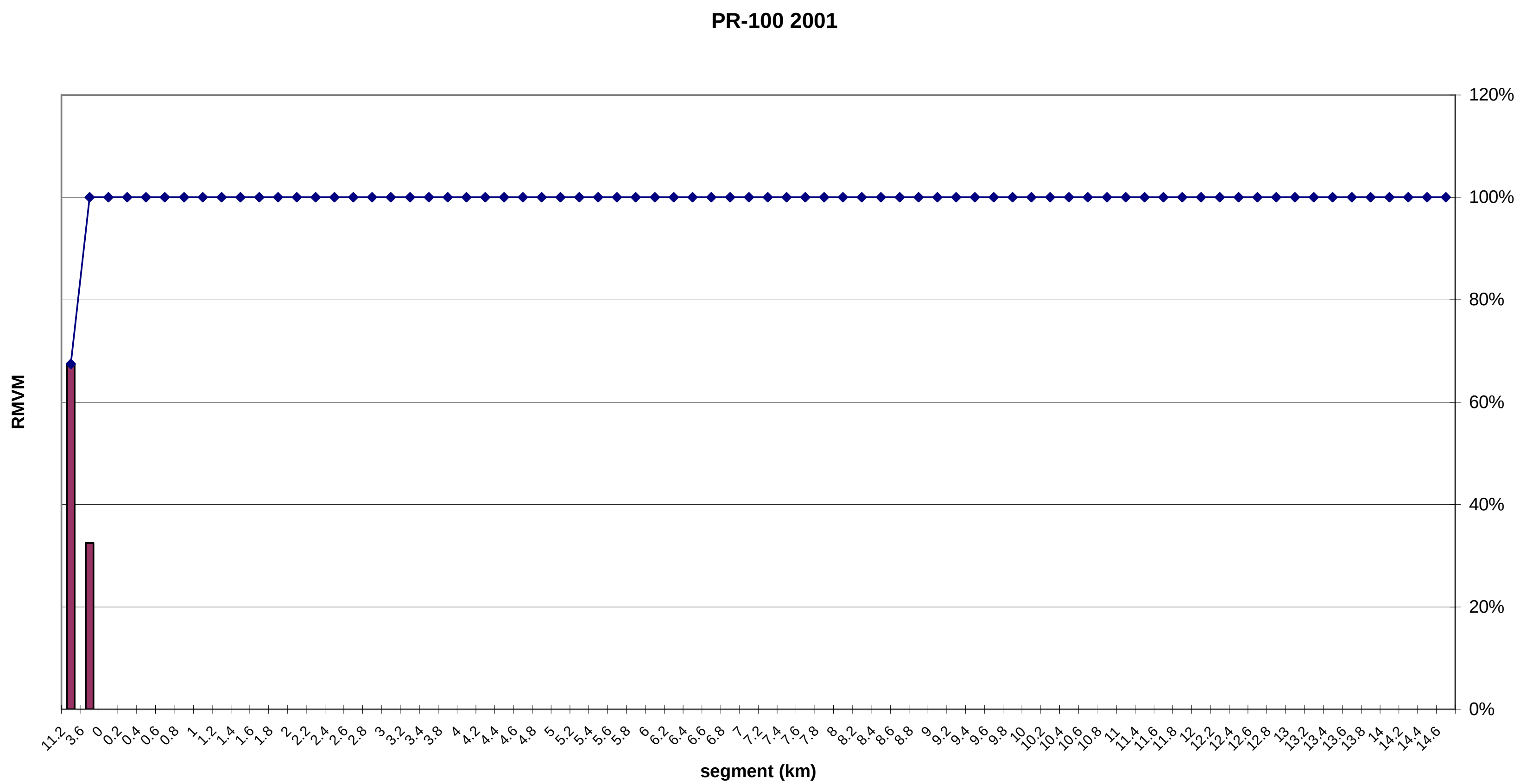
PR-100 1998

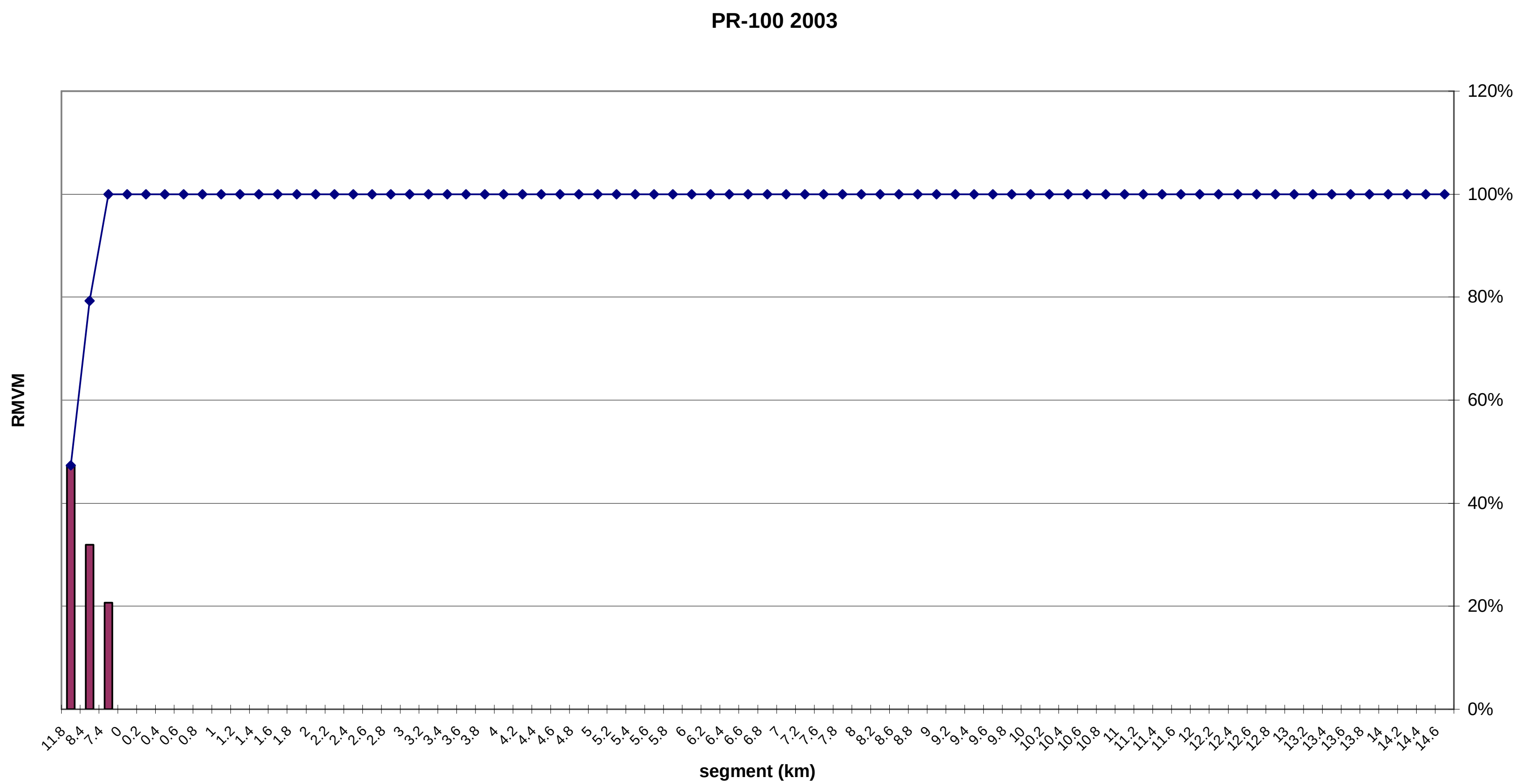


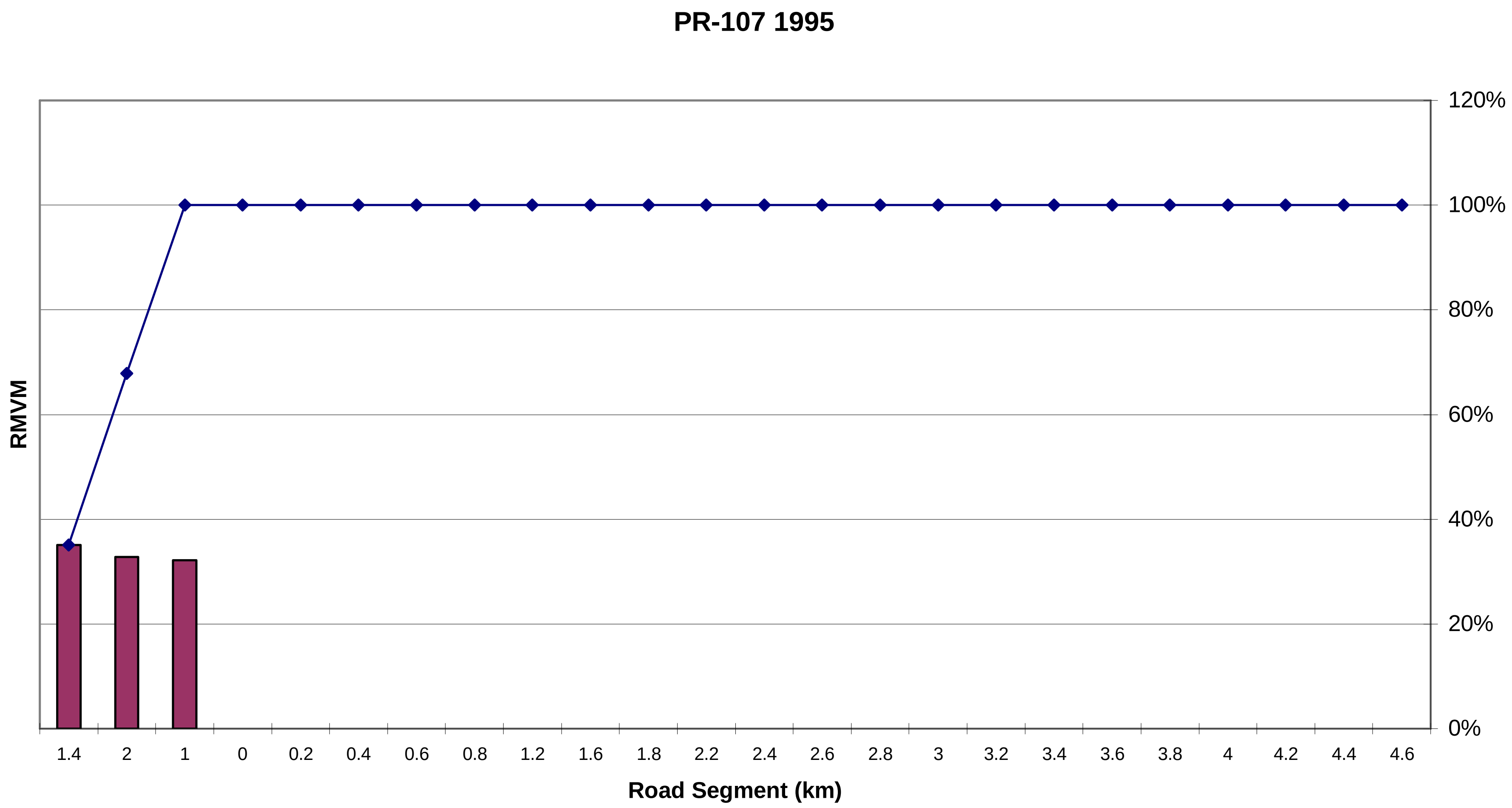

PR-100 1999
RMVM
segment (km)
120%
100%
80%
60%
40%
20%
0%

PR-100 2000



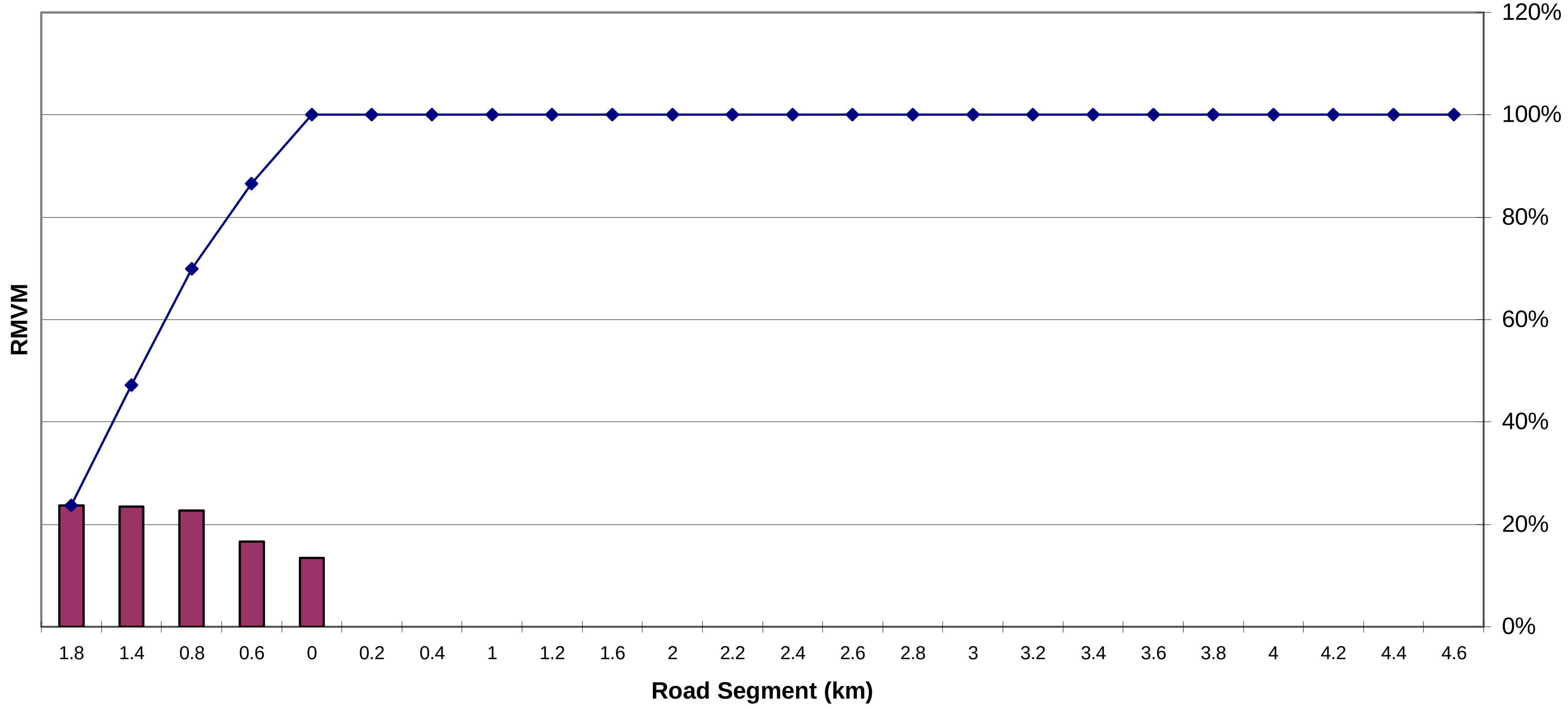

PR-100 2001
RMVM
segment (km)
120%
100%
80%
60%
40%
20%
0%


PR-100 2003
RMVM
segment (km)
120%
100%
80%
60%
40%
20%
0%

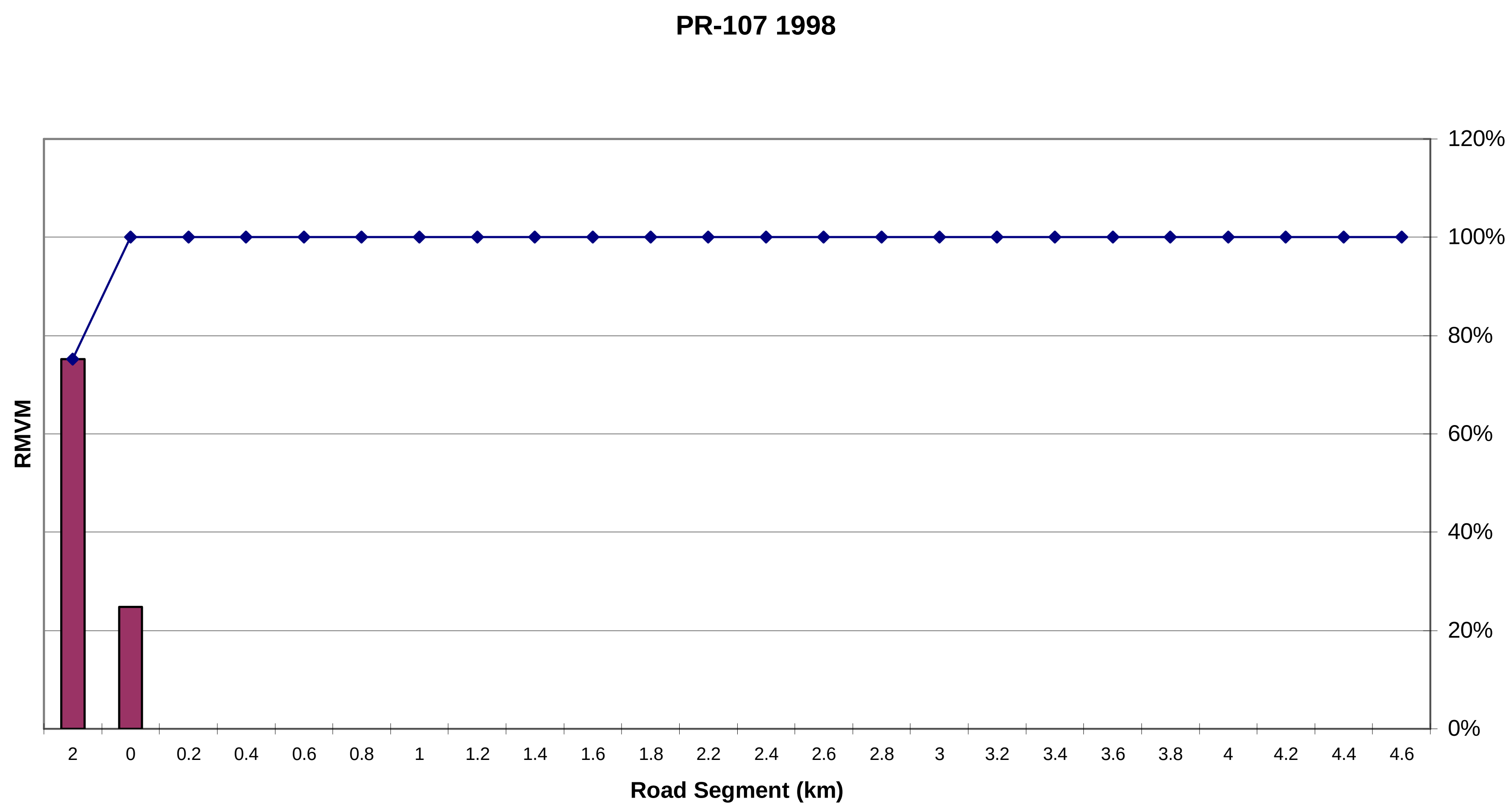


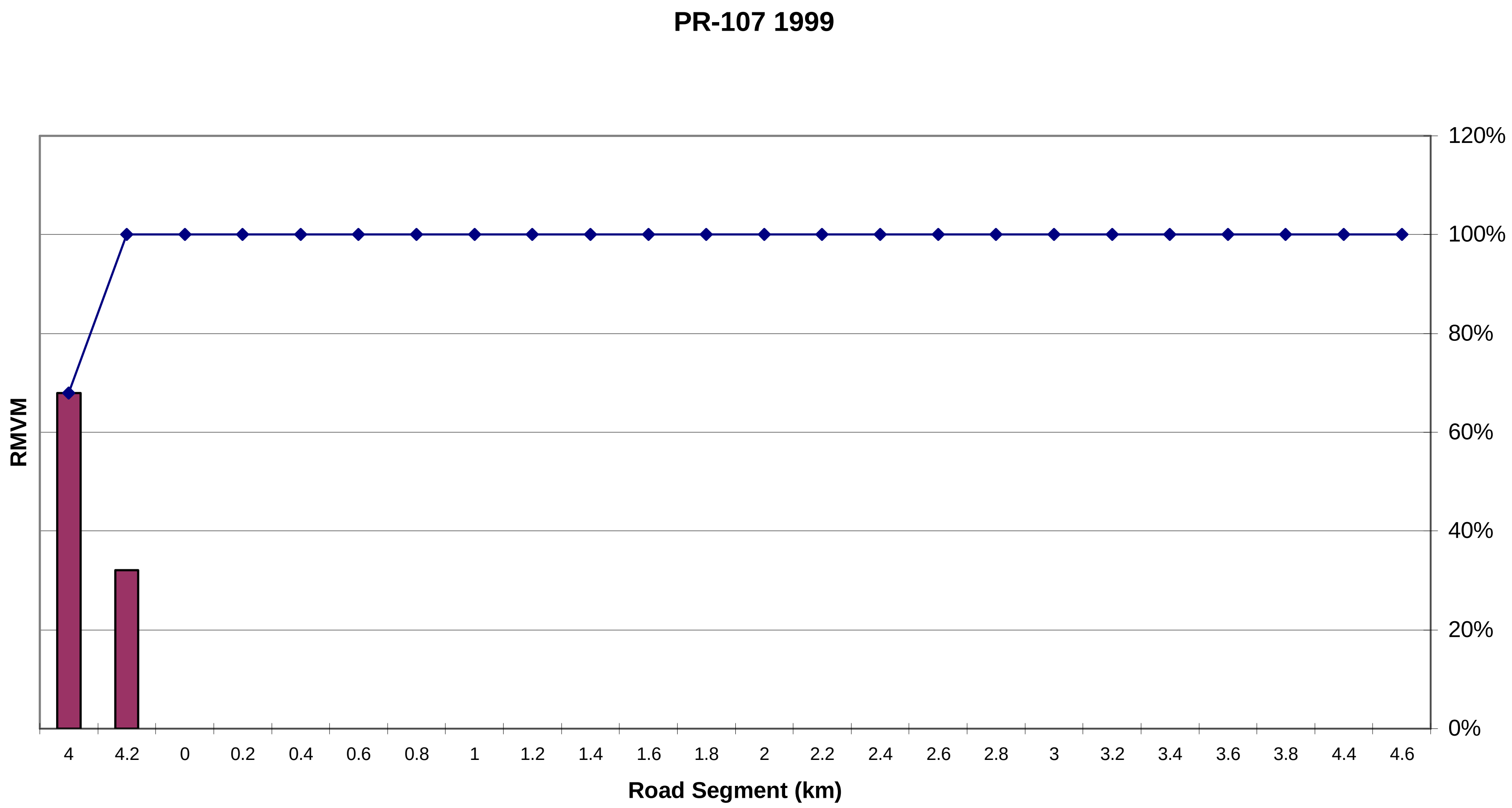
PR-107 1995
RMVM
Road Segment (km)
1.4
2
1
0
0.2
0.4
0.6
0.8
1.2
1.6
1.8
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
0%
20%
40%
60%
80%
100%
120%

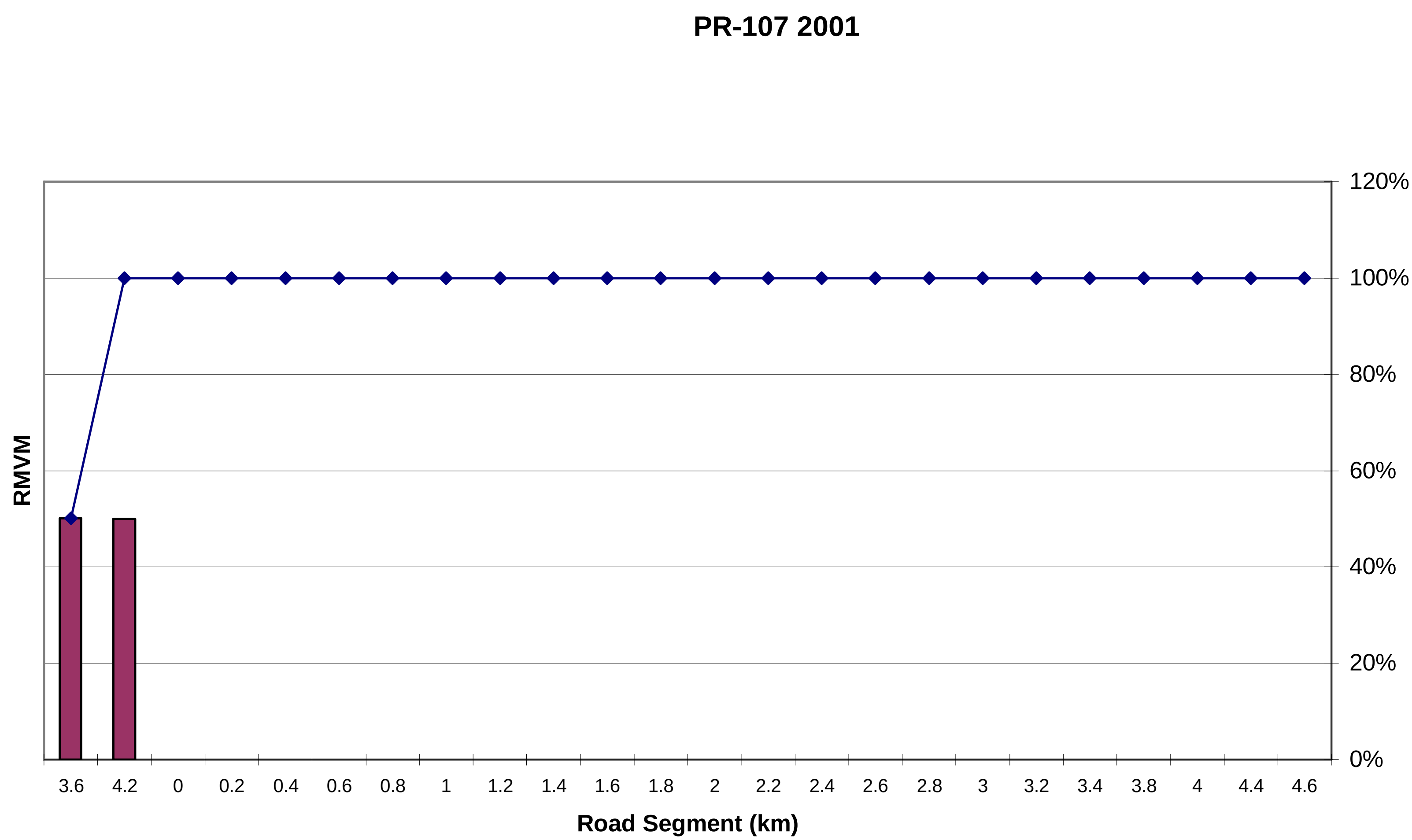
PR-107 1996



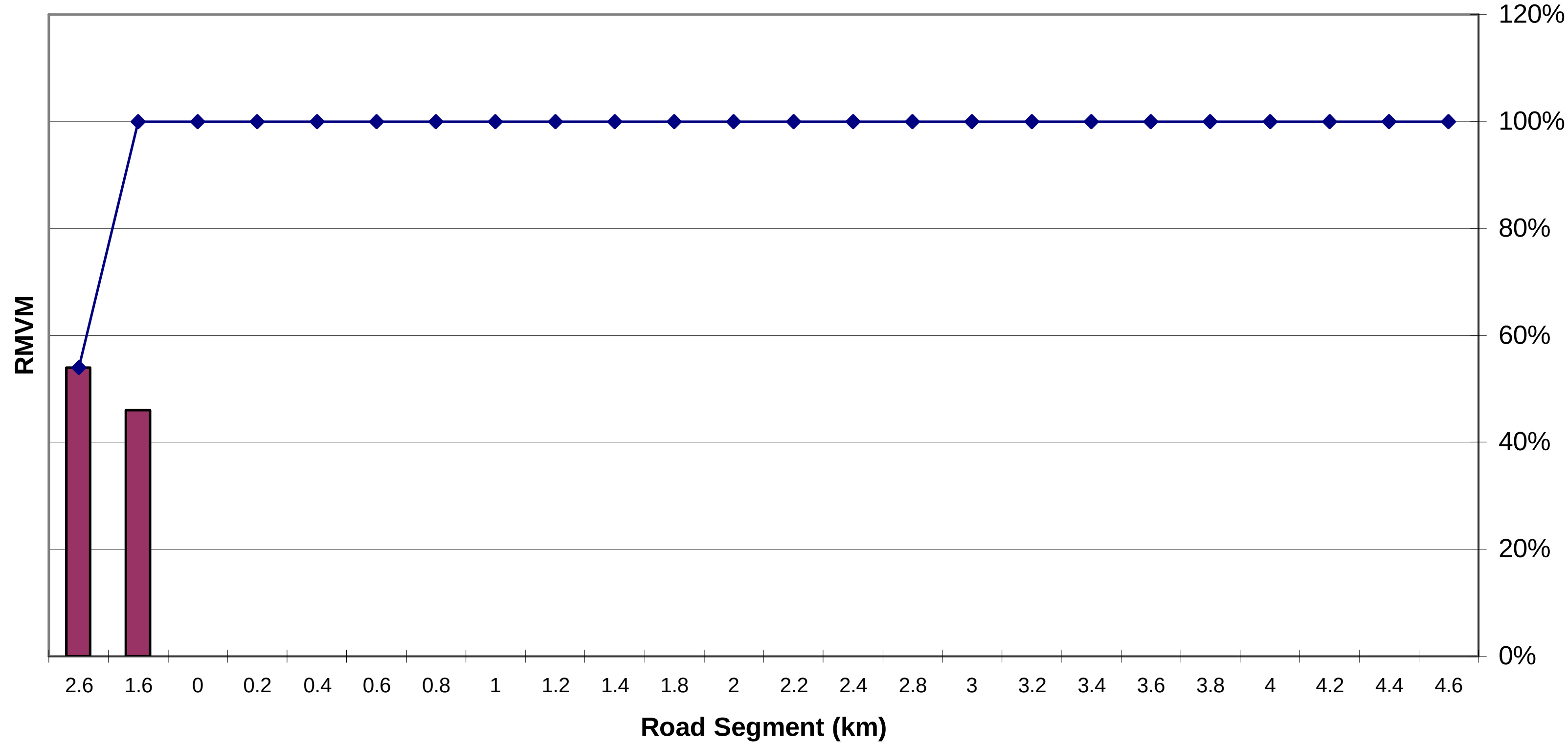
RMVM
120%
100%
80%
60%
40%
20%
0%
1.8
1.4
0.8
0.6
0
0.2
0.4
1
1.2
1.6
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
Road Segment (km)


PR-107 1998
RMVM
120%
100%
80%
60%
40%
20%
0%
2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
Road Segment (km)


PR-107 1999
RMVM
Road Segment (km)
0%
20%
40%
60%
80%
100%
120%
4
4.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4.4
4.6

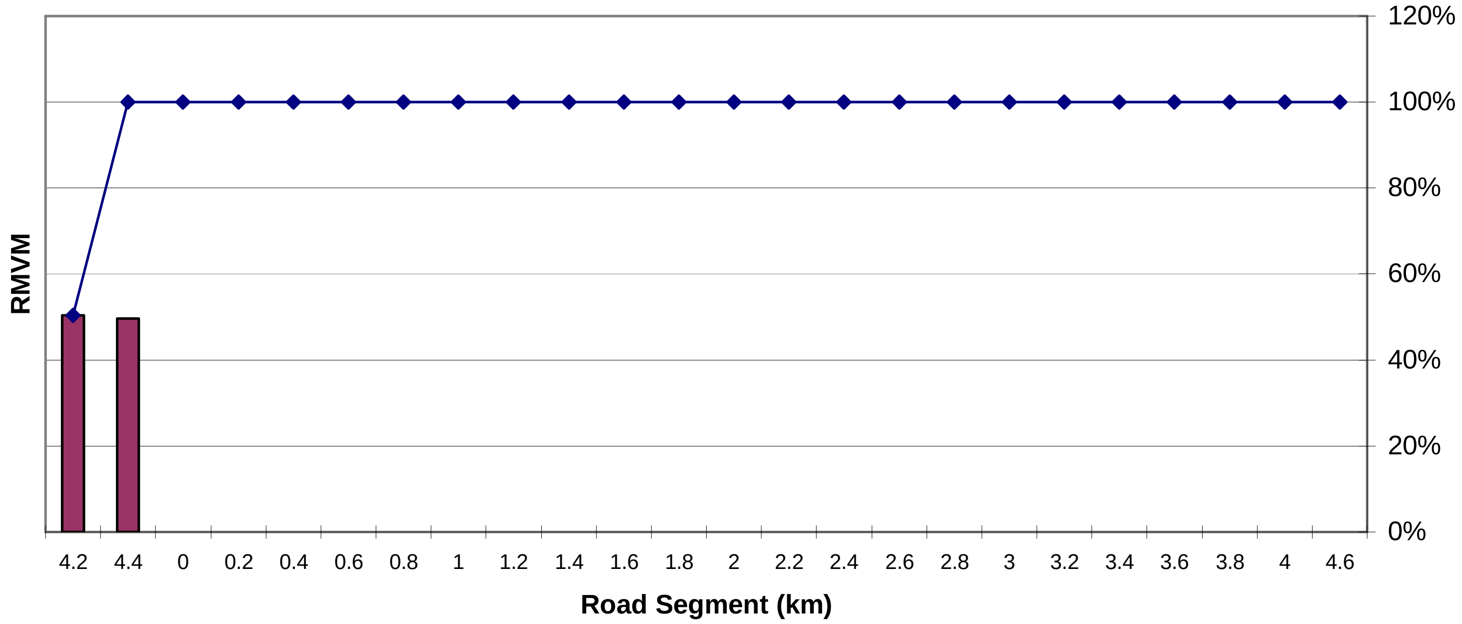

PR-107 2001
RMVM
120%
100%
80%
60%
40%
20%
0%
3.6
4.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.8
4
4.4
4.6
Road Segment (km)

PR-107 2002

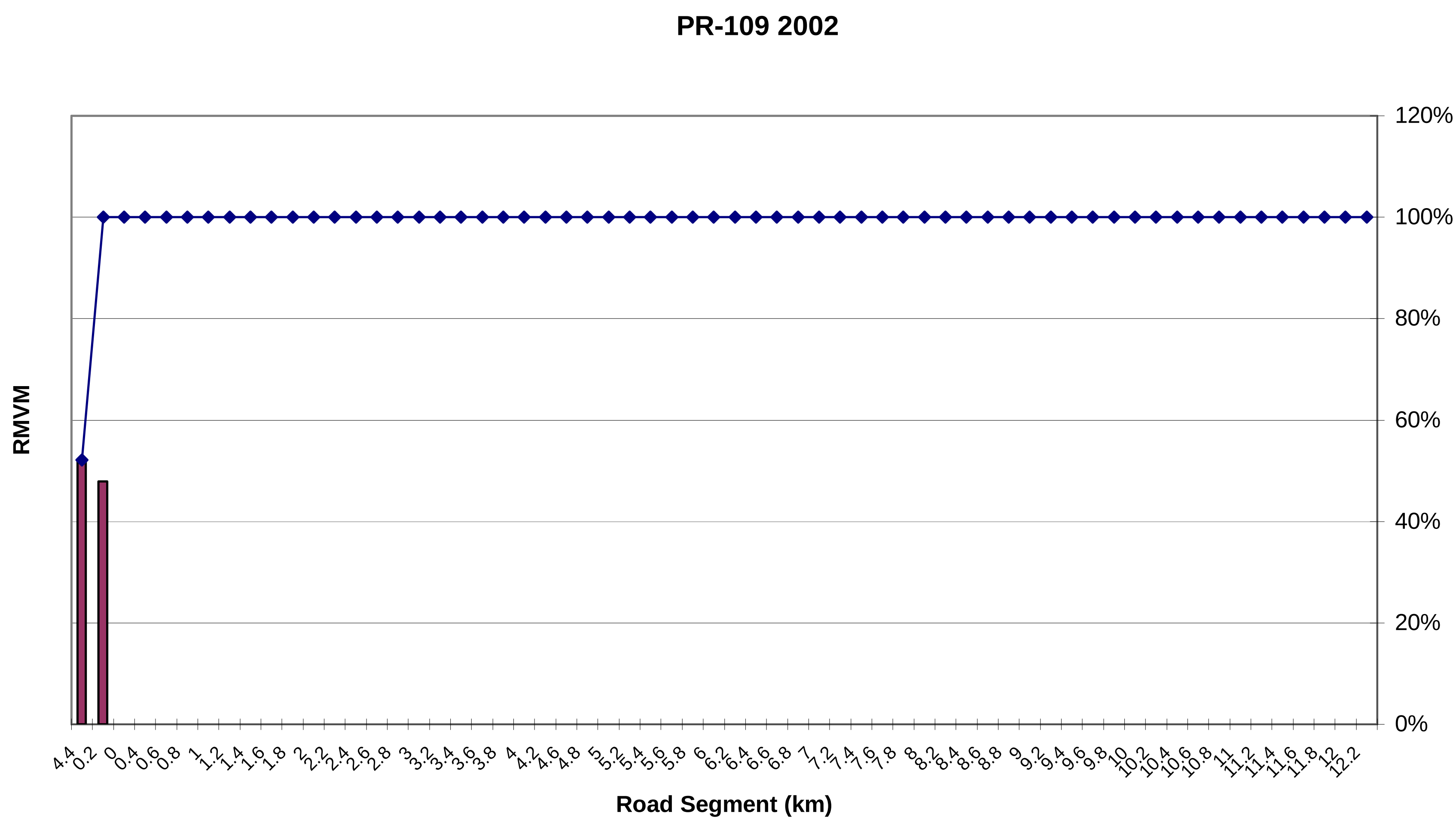


RMVM
120%
100%
80%
60%
40%
20%
0%
2.6
1.6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.8
2
2.2
2.4
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
Road Segment (km)

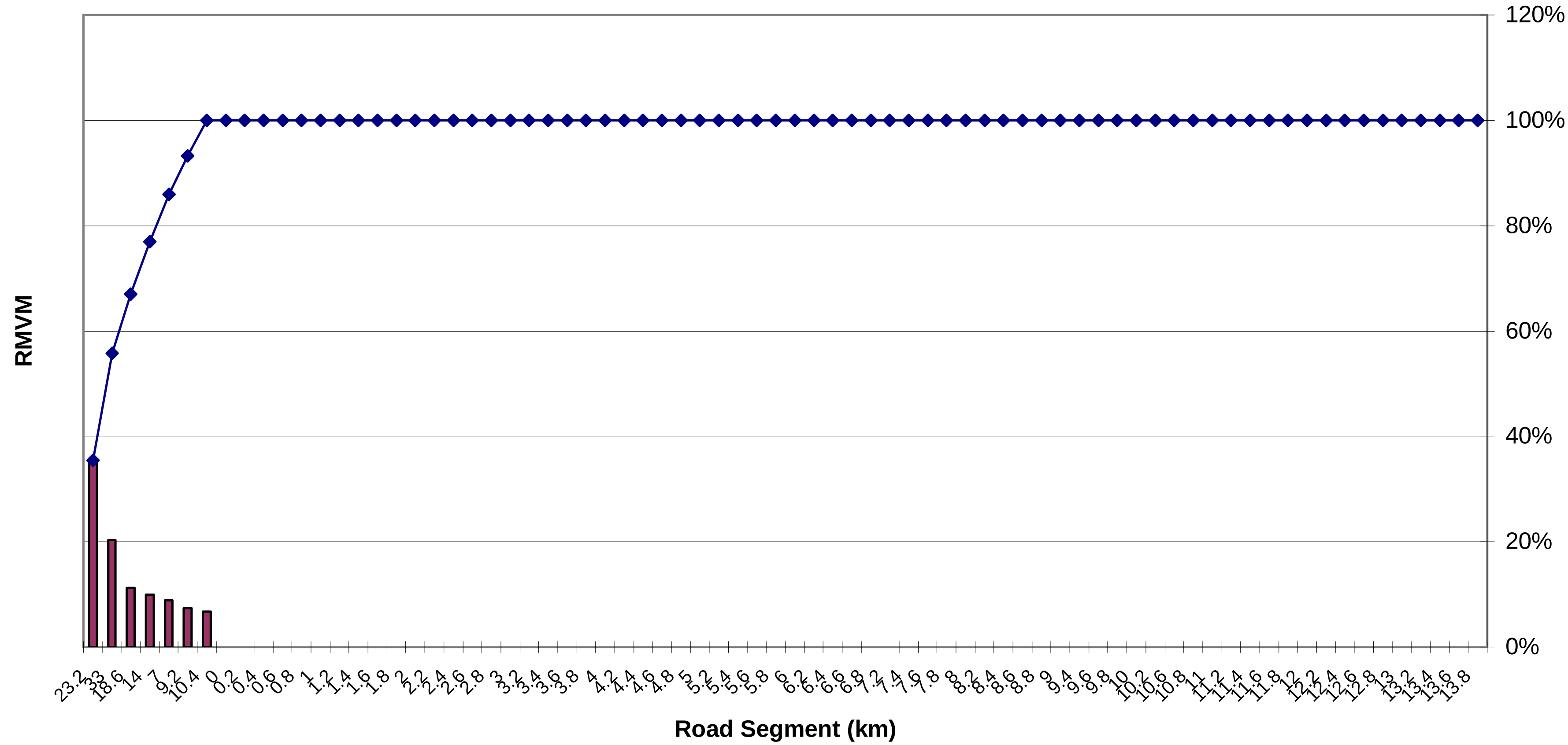
PR-107 2003



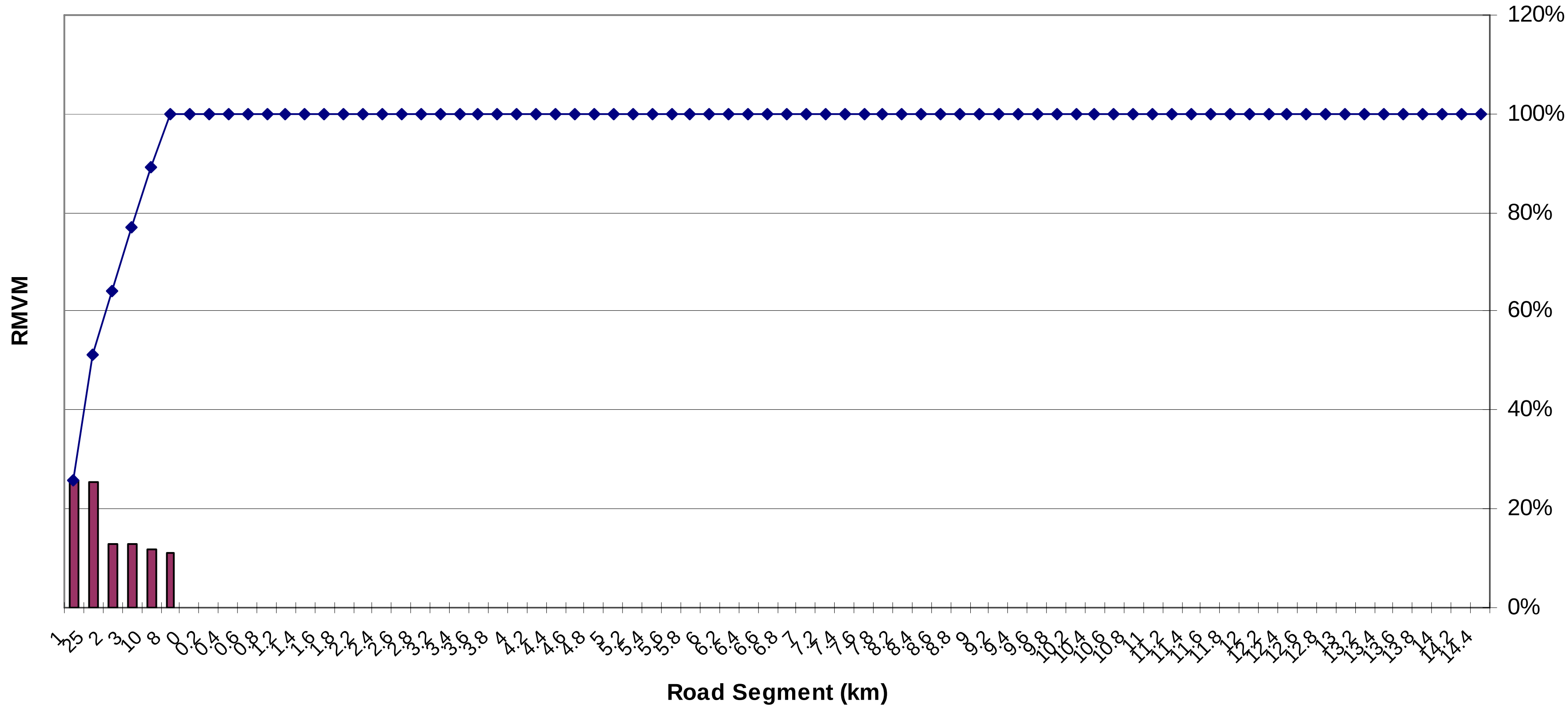
RMVM
120%
100%
80%
60%
40%
20%
0%
4.2
4.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.6
Road Segment (km)

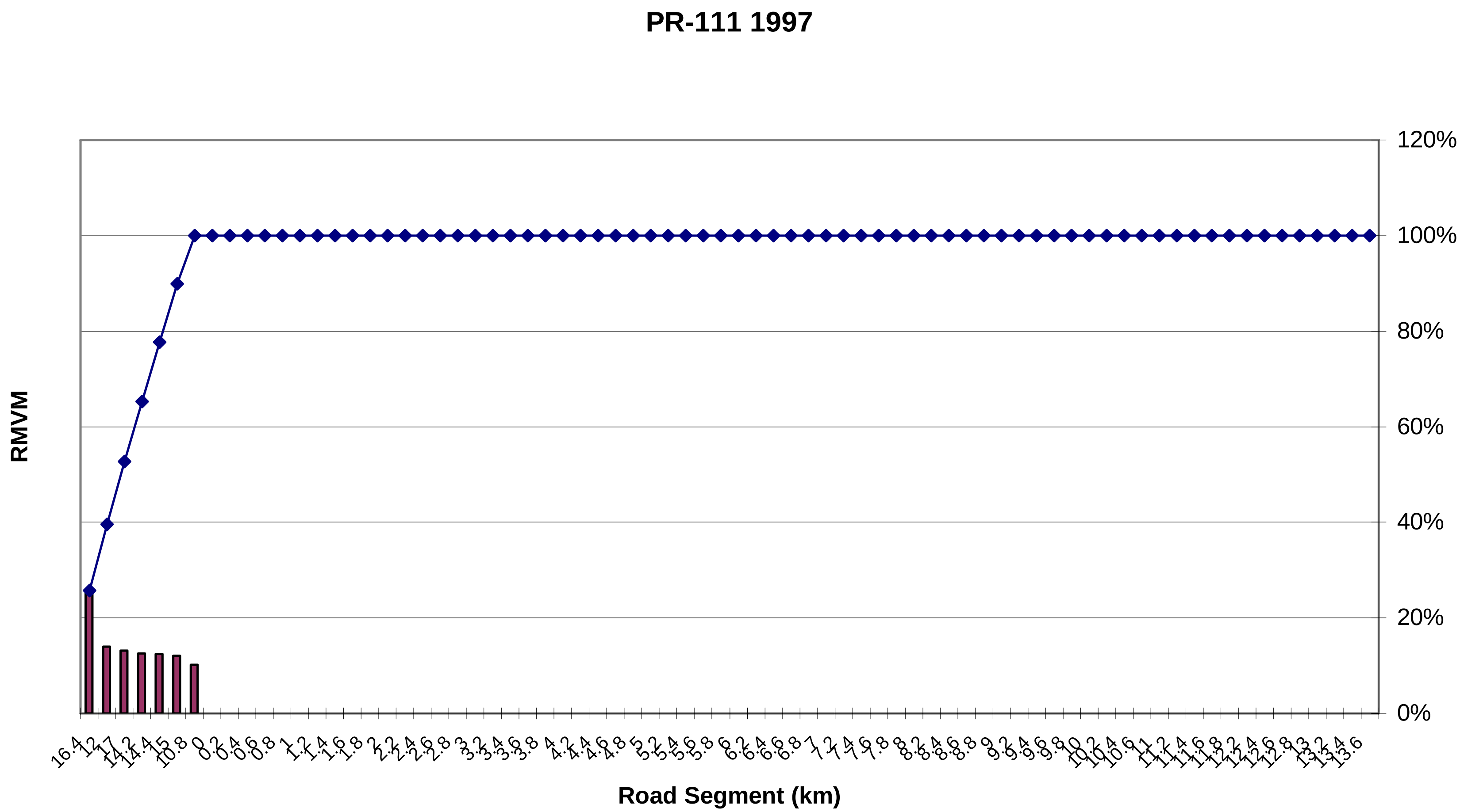

PR-109 2002
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

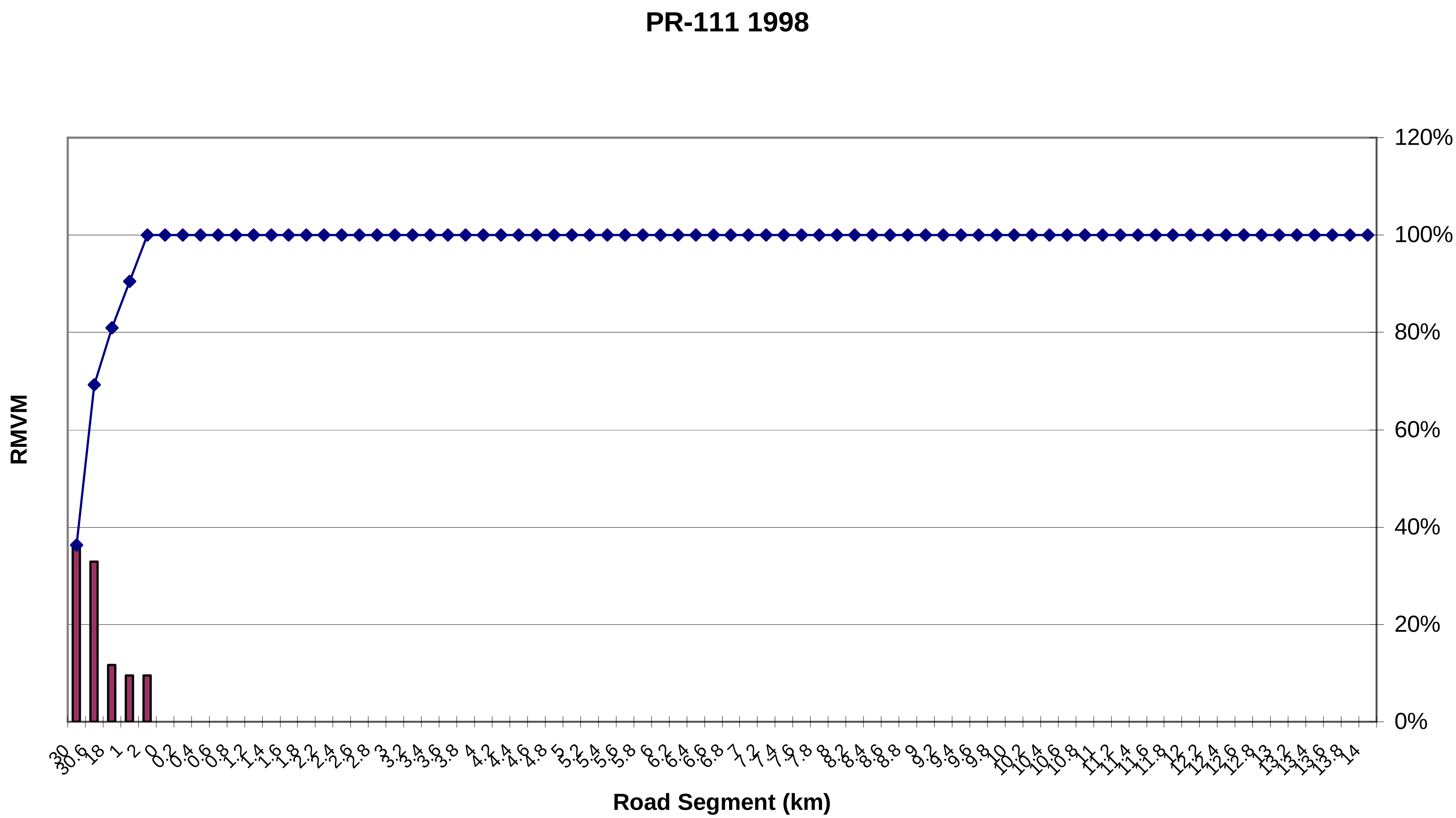
PR-111 1995

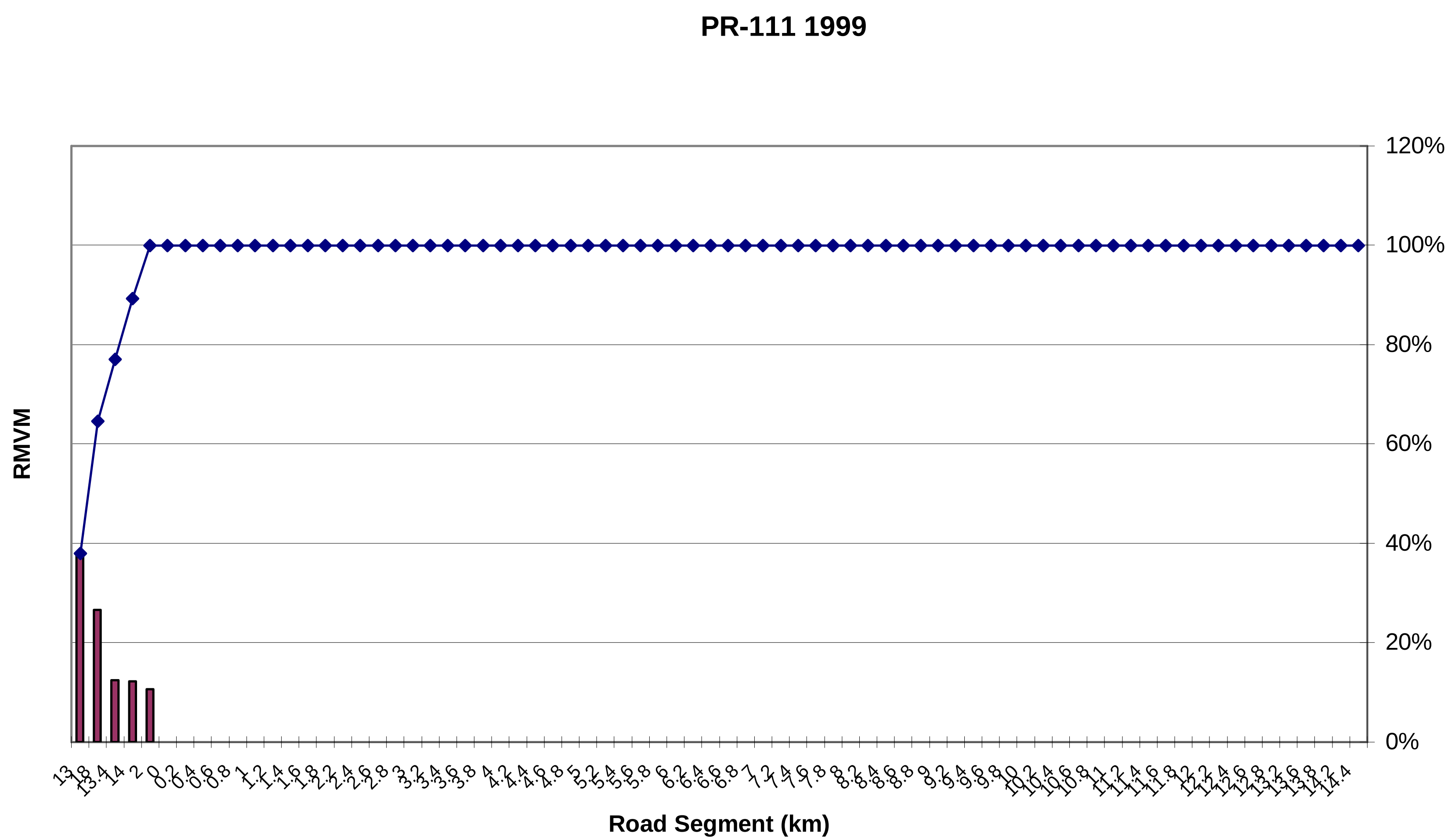


PR-111 1996

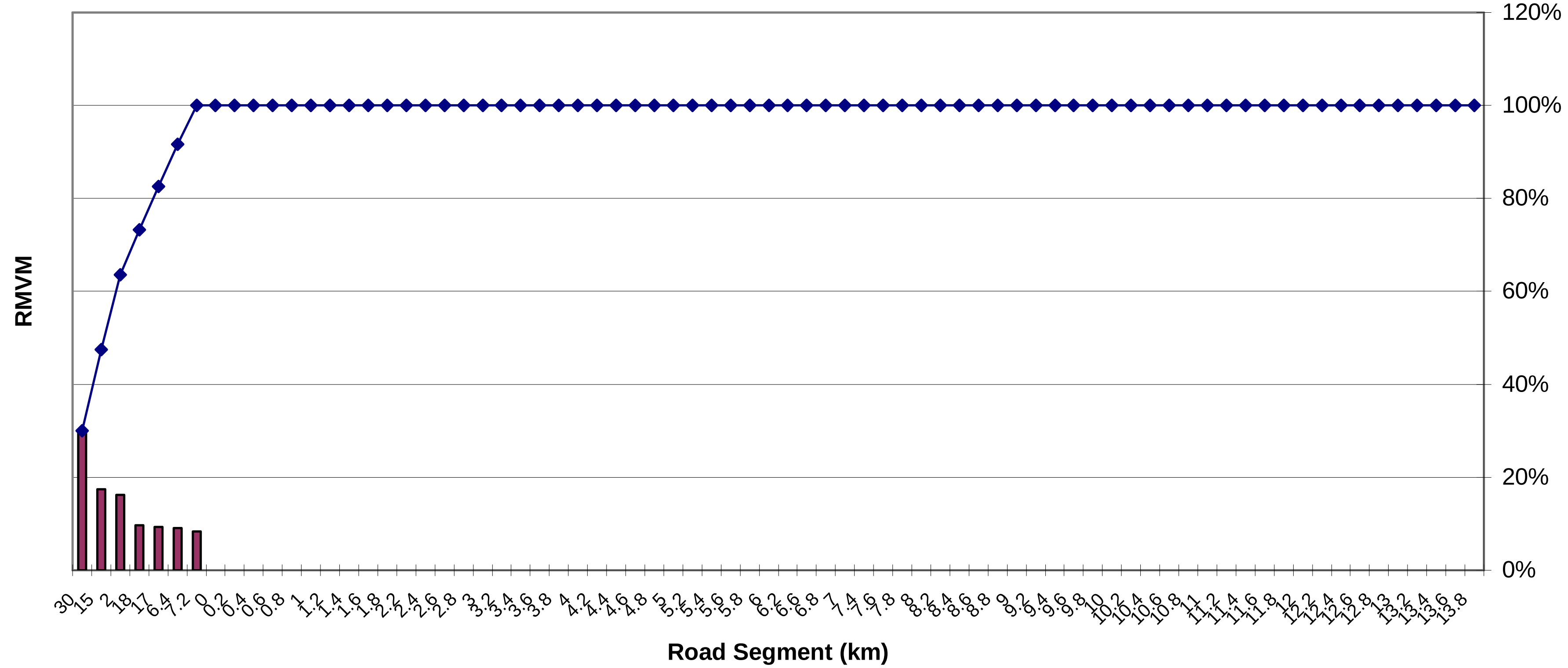



PR-111 1997
RMVM
120%
100%
80%
60%
40%
20%
0%
Road Segment (km)

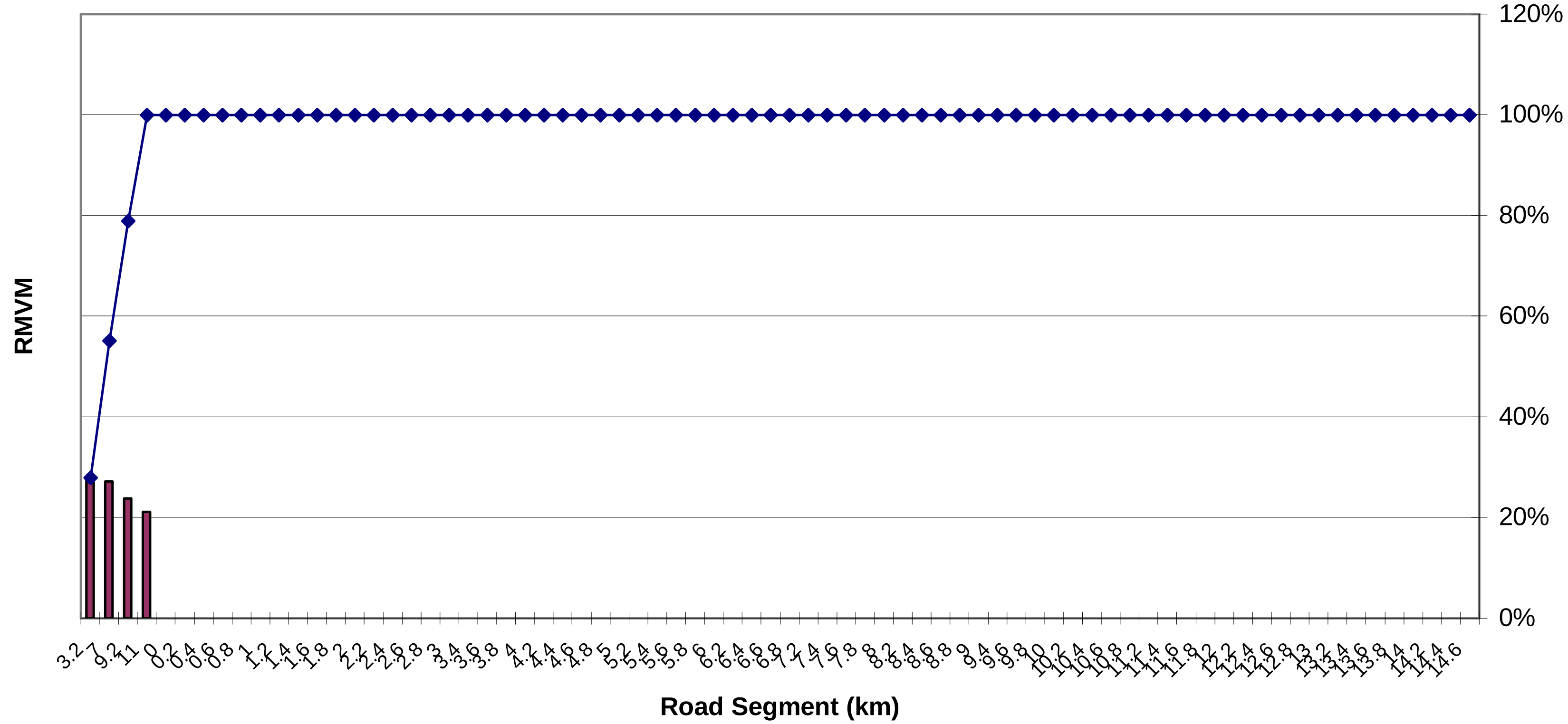

PR-111 1998
RMVM
120%
100%
80%
60%
40%
20%
0%
Road Segment (km)

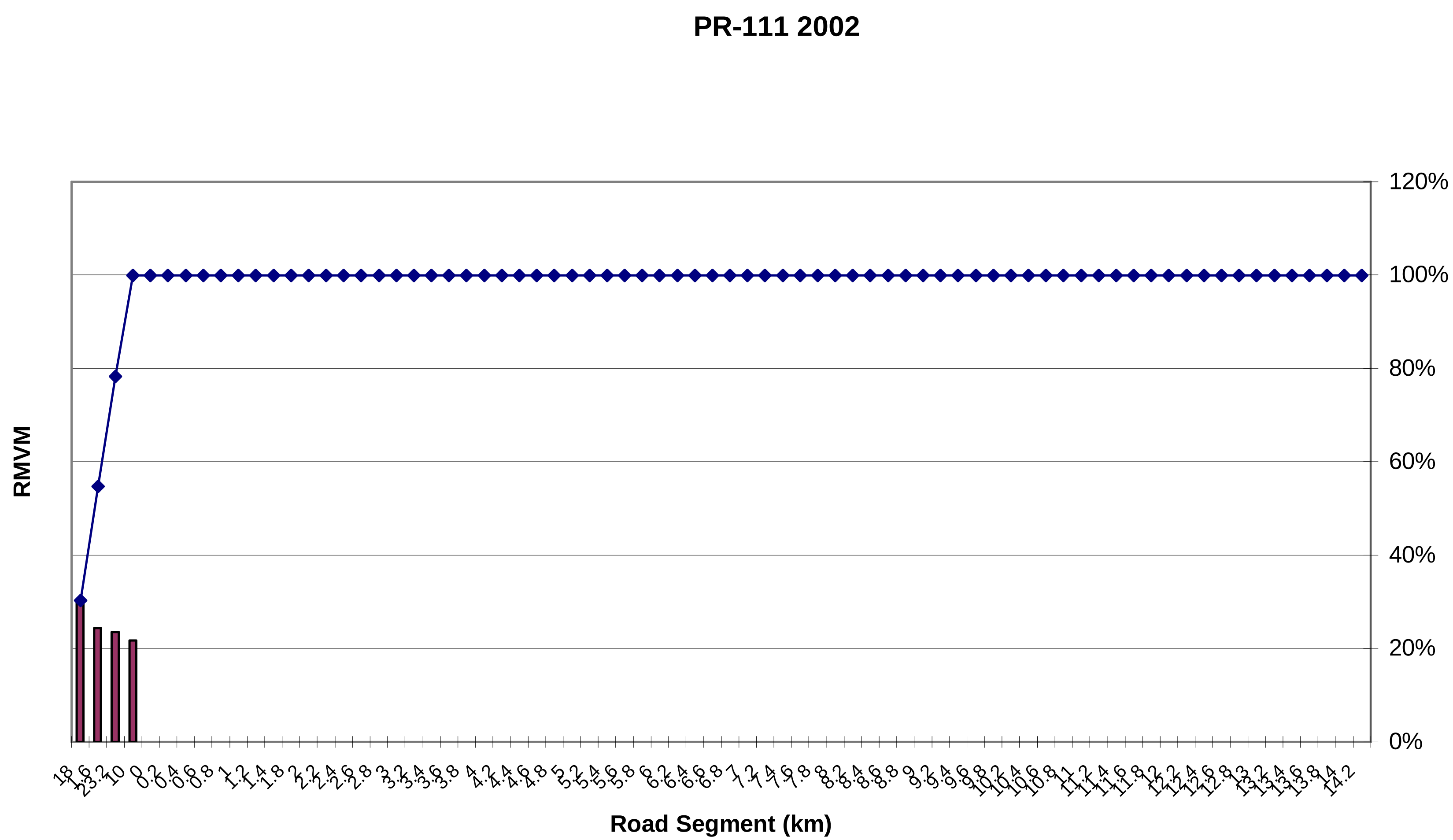

PR-111 1999
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

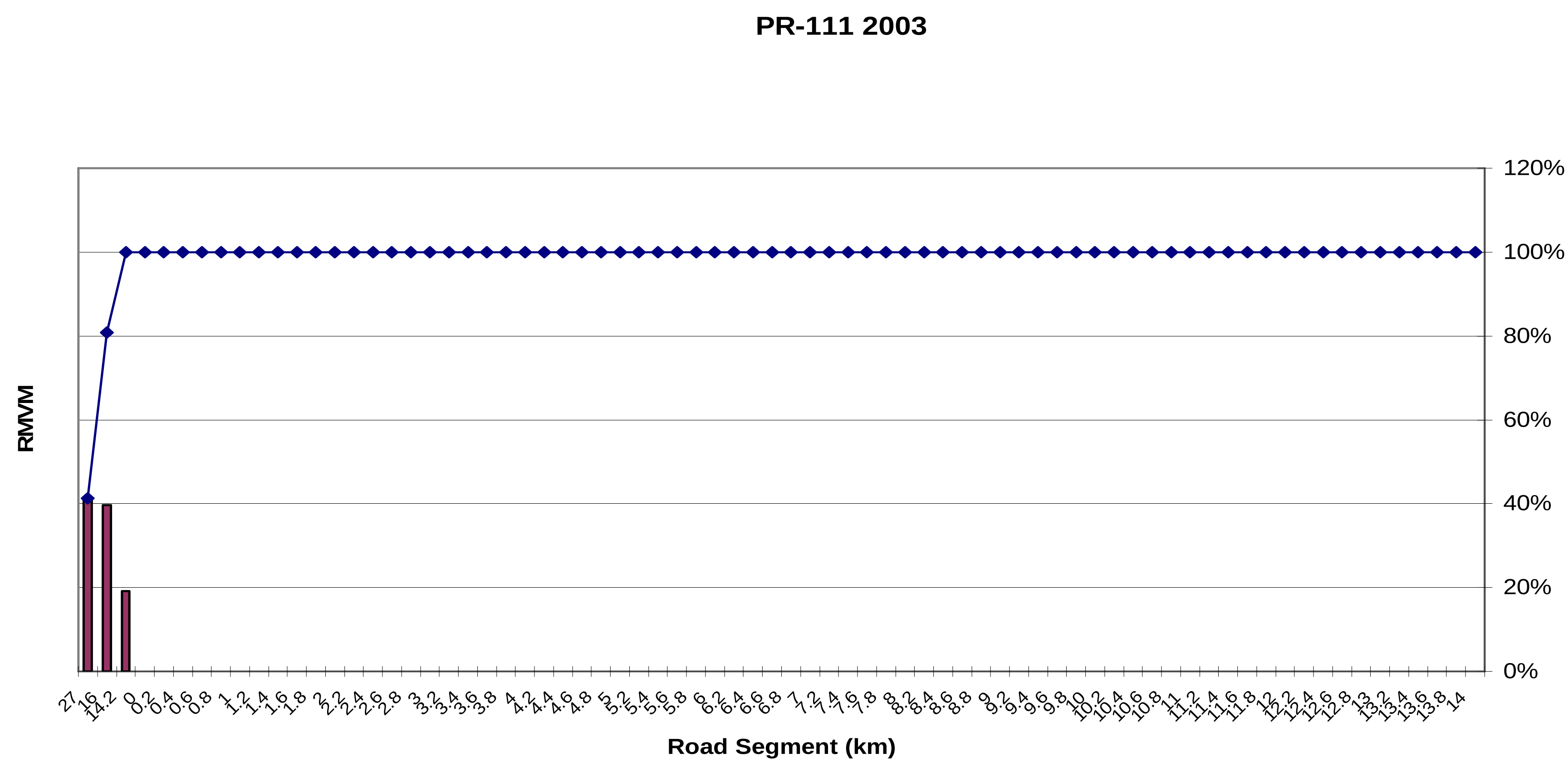
PR-111 2000



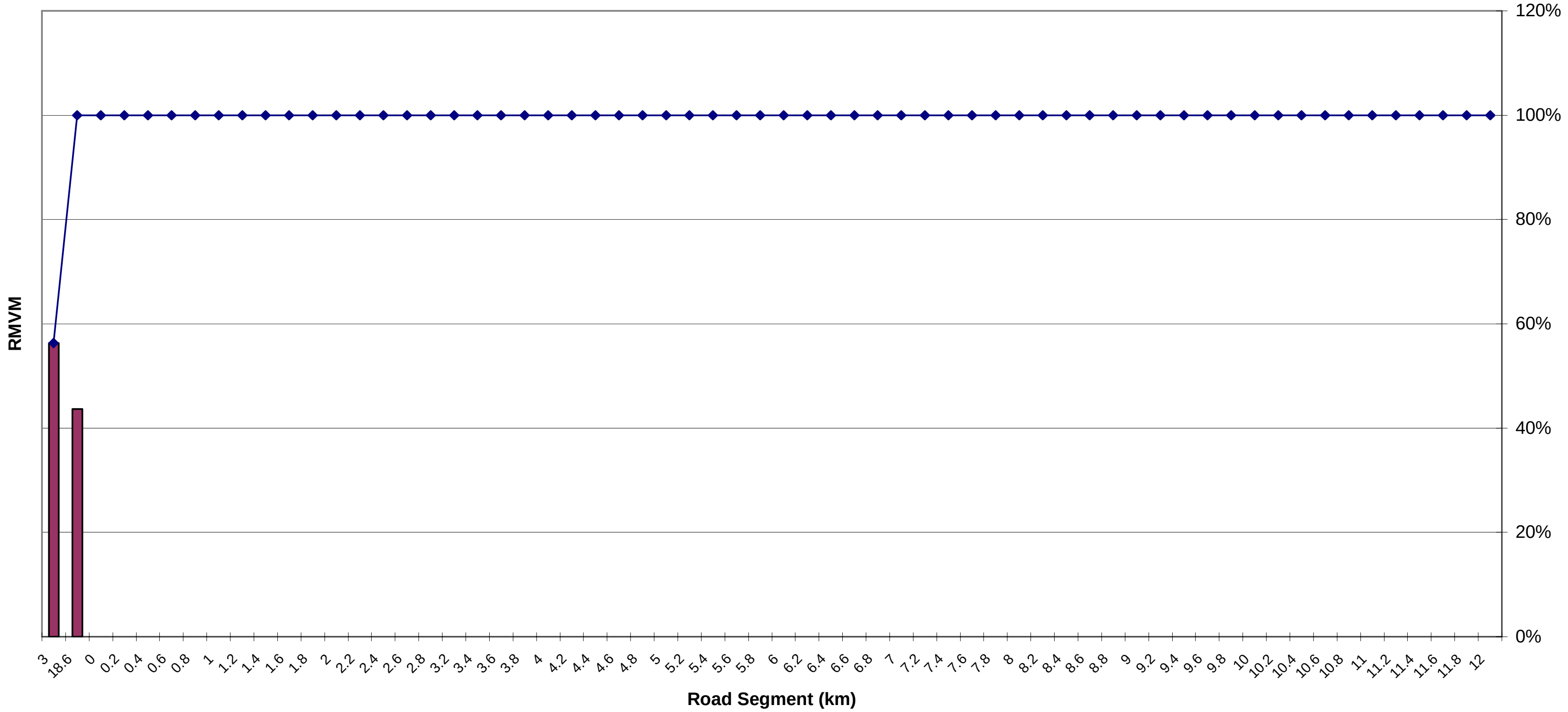
PR-111 2001



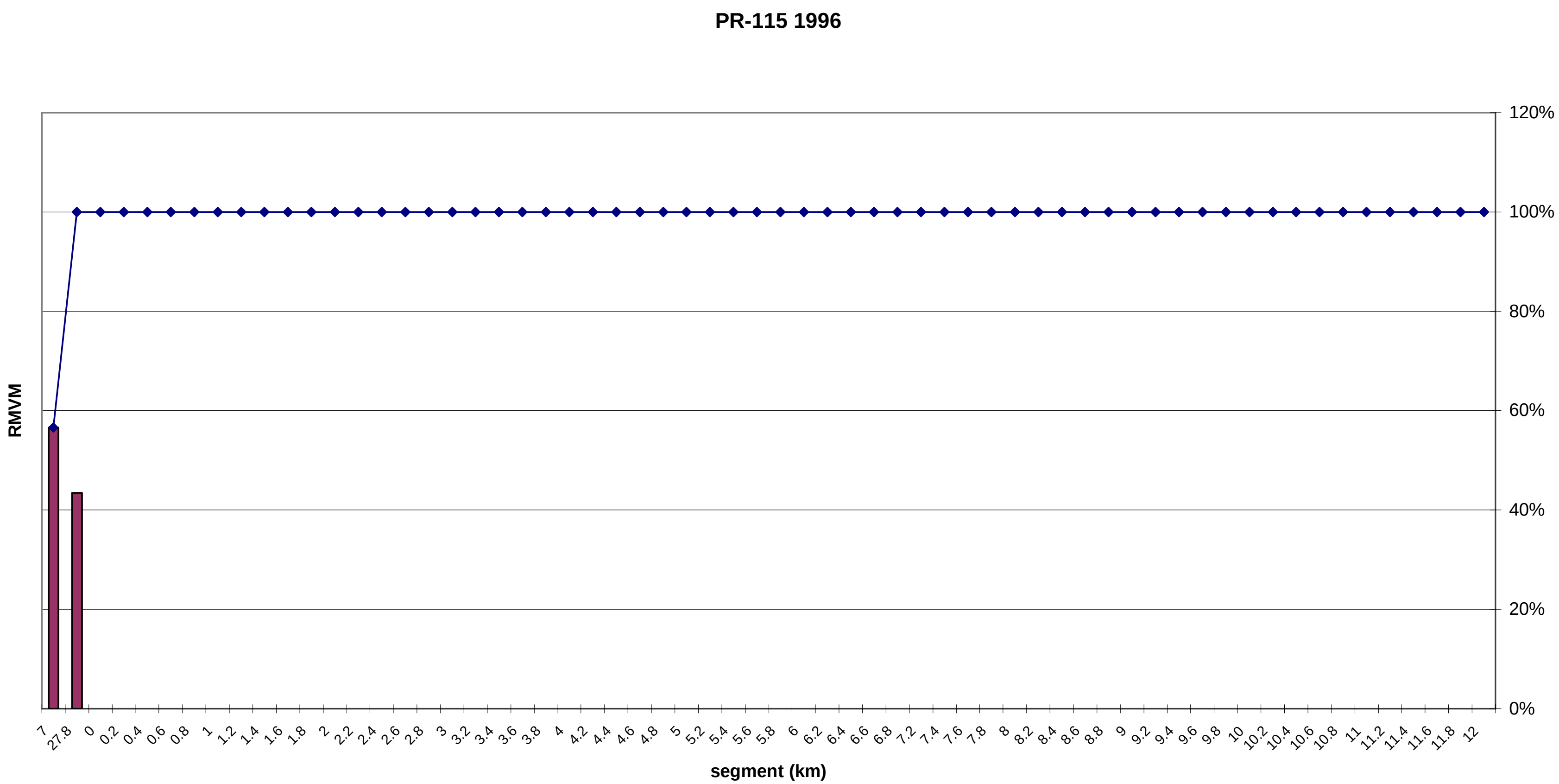

PR-111 2002
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

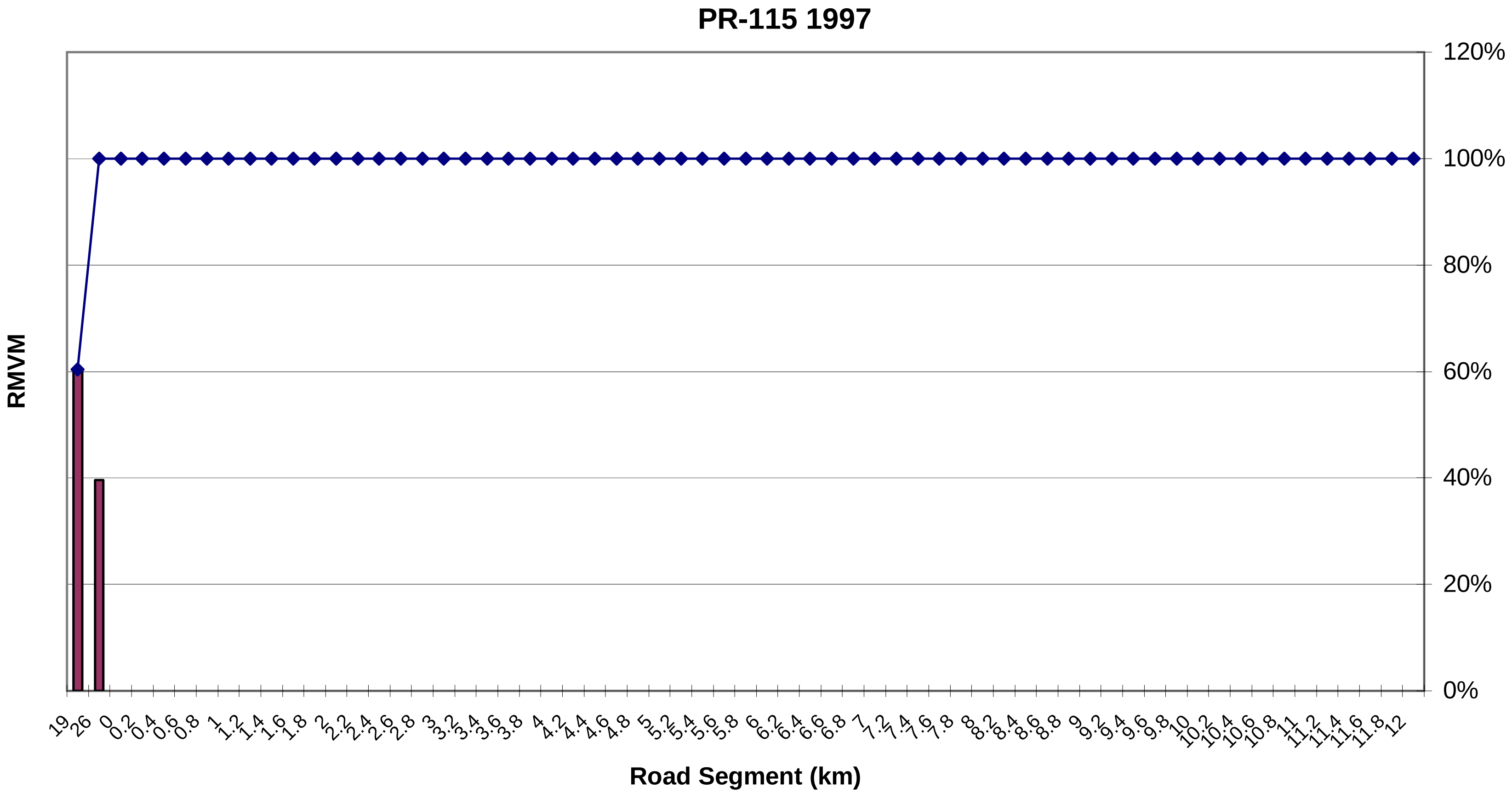

PR-111 2003
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

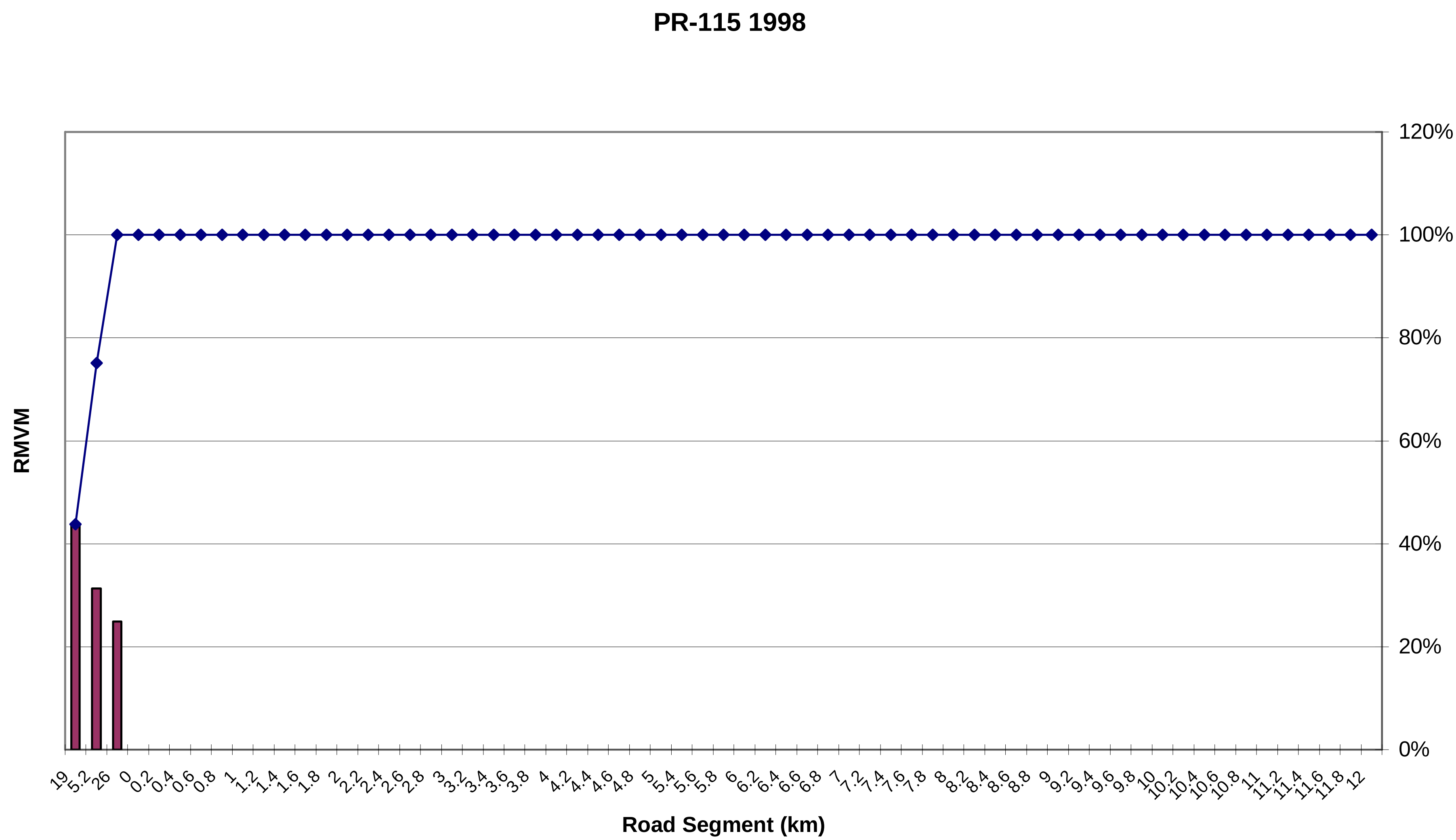
PR-115 1995



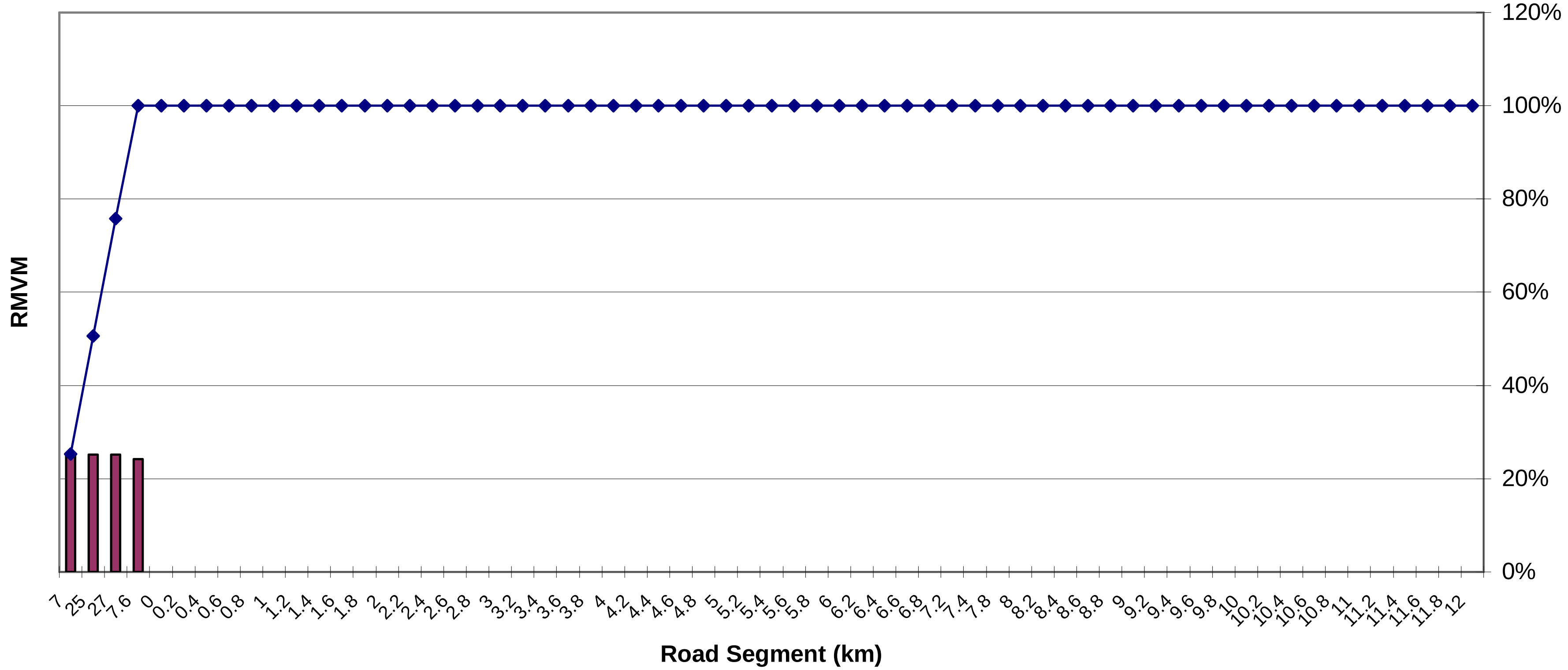
RMVM
120%
100%
80%
60%
40%
20%
0%
3
18.6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6
7.8
8
8.2
8.4
8.6
8.8
9
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Road Segment (km)


PR-115 1996
RMVM
segment (km)
120%
100%
80%
60%
40%
20%
0%
7
27.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8
7.2
7.4
7.6
7.8
8
8.2
8.4
8.6
8.8
9
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12

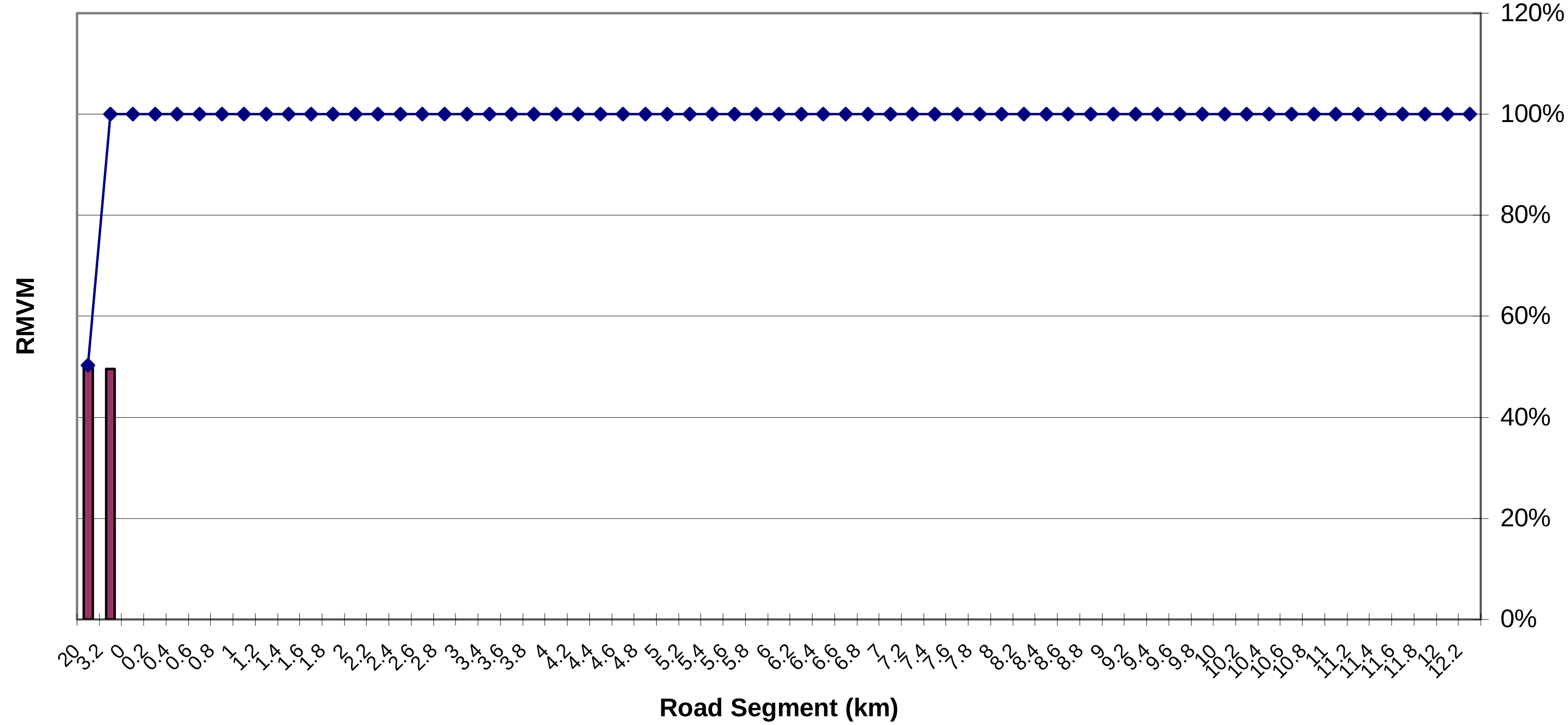

PR-115 1997
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

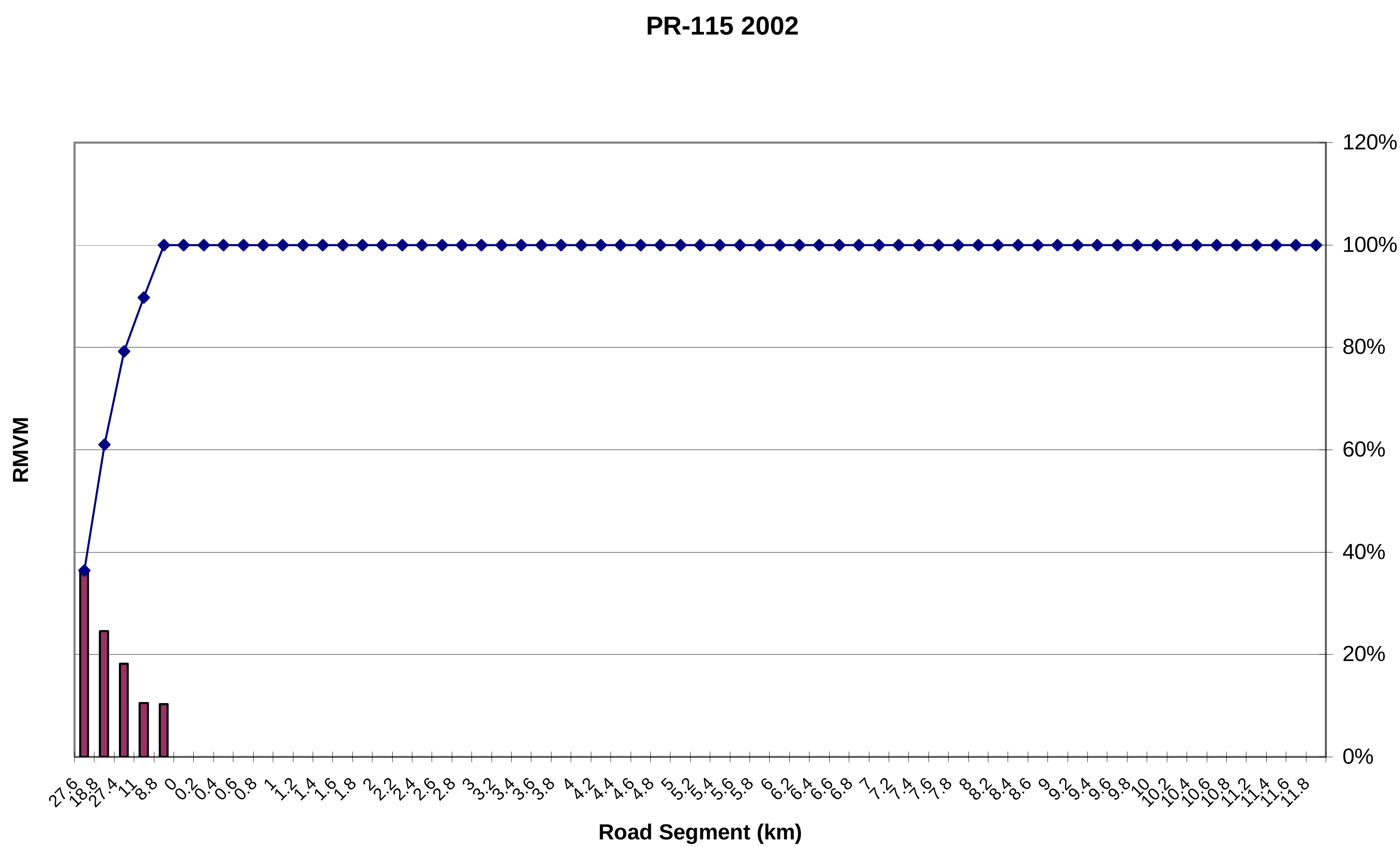

PR-115 1998
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%
19
5.2
26
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6
7.8
8
8.2
8.4
8.6
8.8
9
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12

PR-115 2000

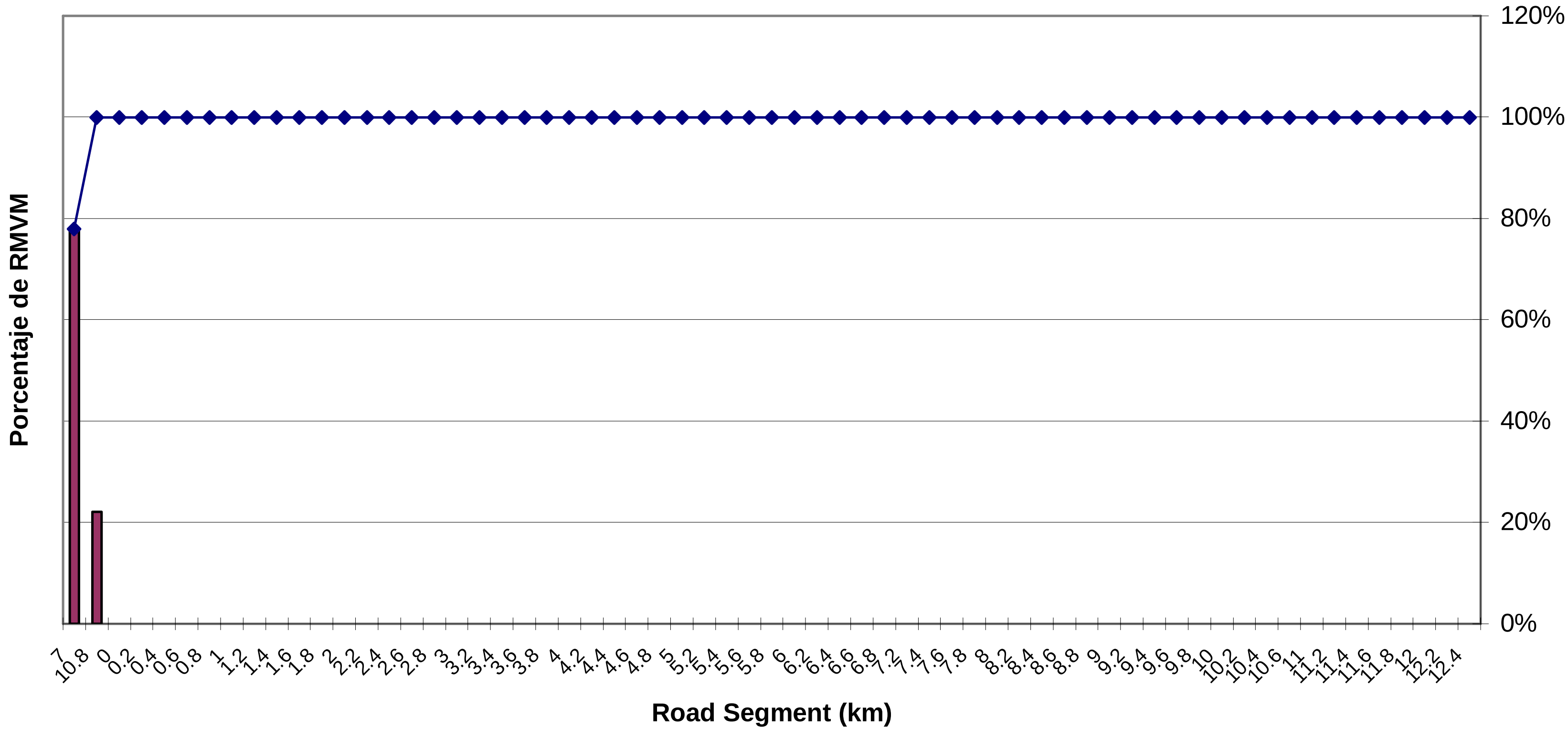


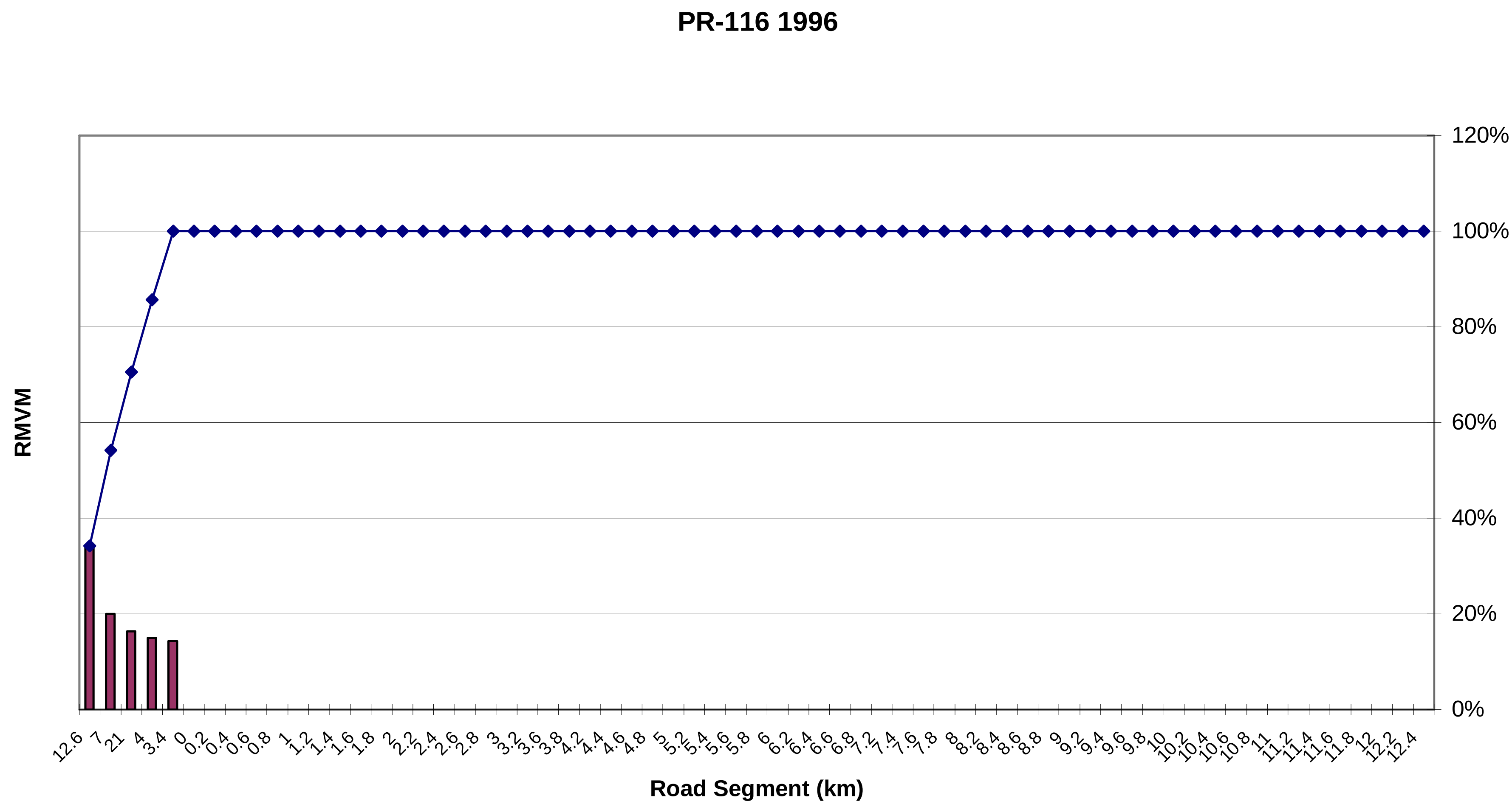
PR-115 2001



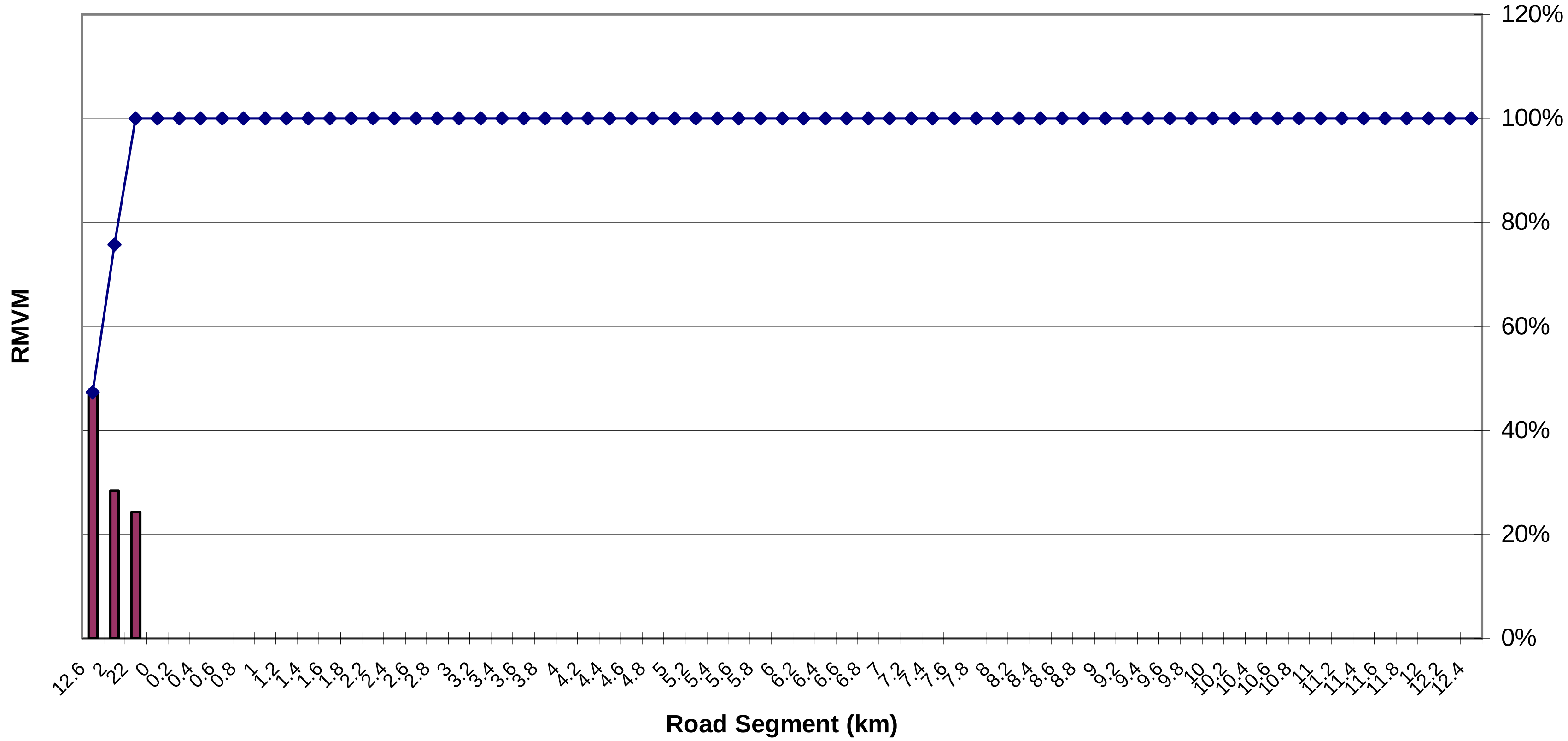

PR-115 2002
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%
27.6
18.8
27.4
11
8.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6
7.8
8
8.2
8.4
8.6
9
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11.2
11.4
11.6
11.8

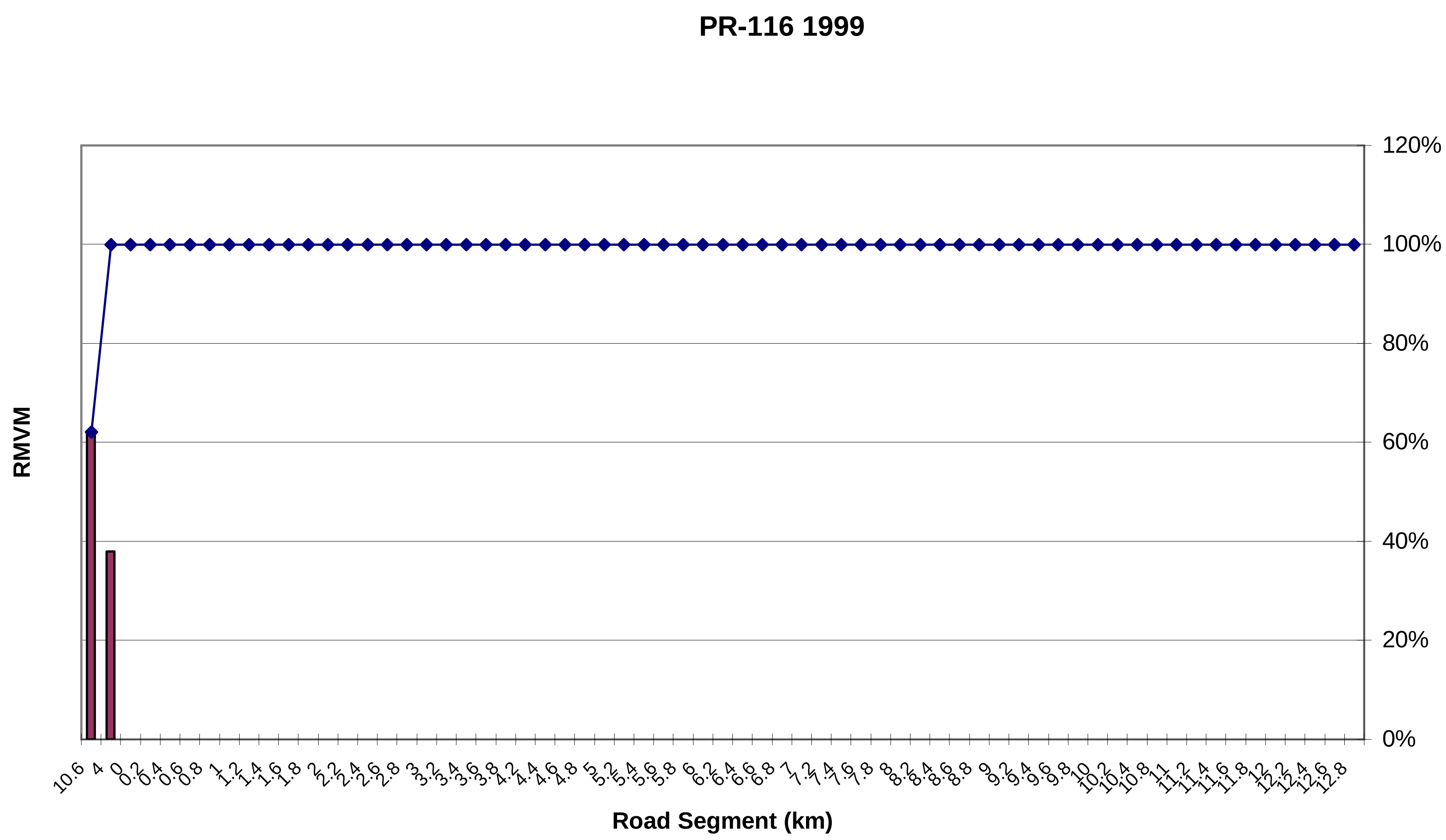
PR-115 2003



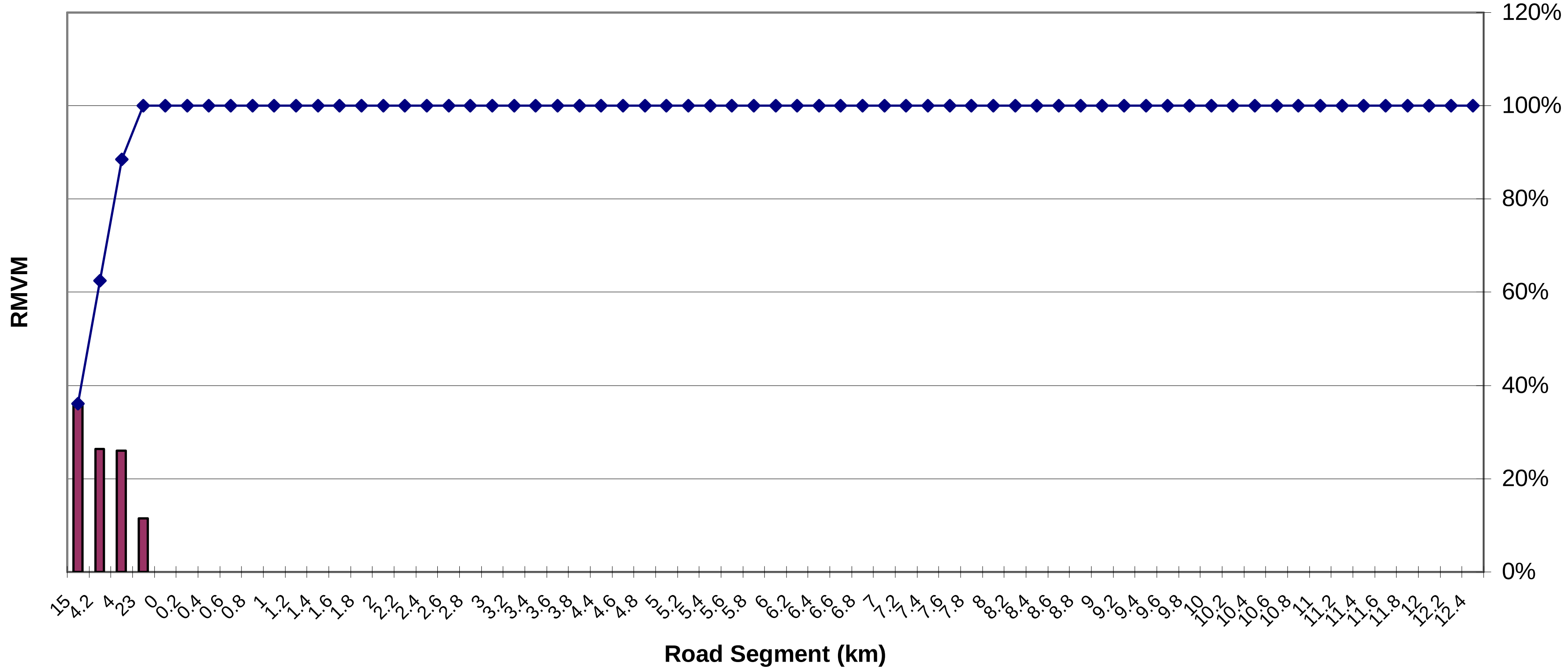

PR-116 1996
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%
12.6
7
21
4
3.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.6
3.8
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8
7.2
7.4
7.6
7.8
8
8.2
8.4
8.6
8.8
9
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
12.2
12.4

PR-116 1998

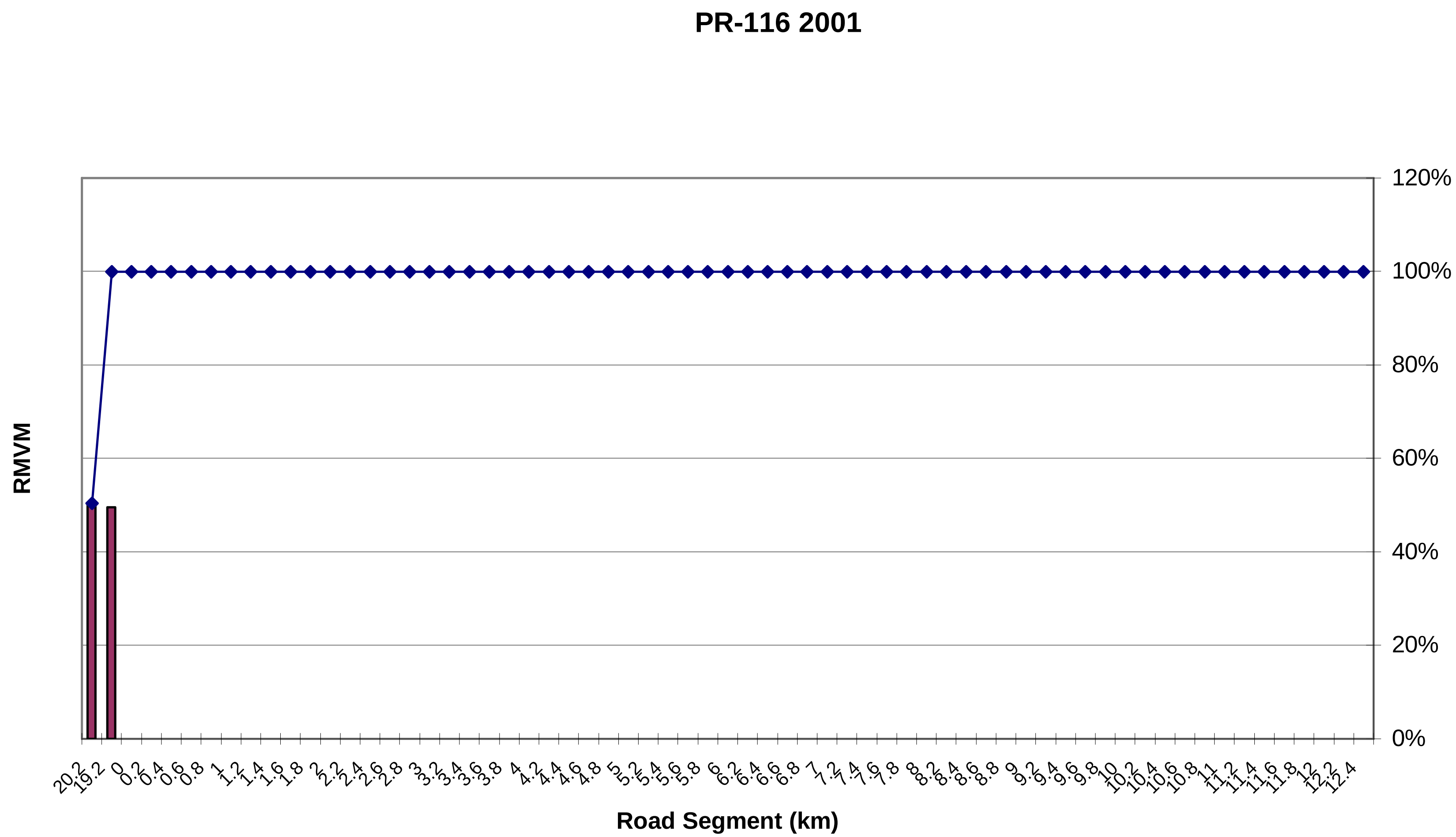



PR-116 1999
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

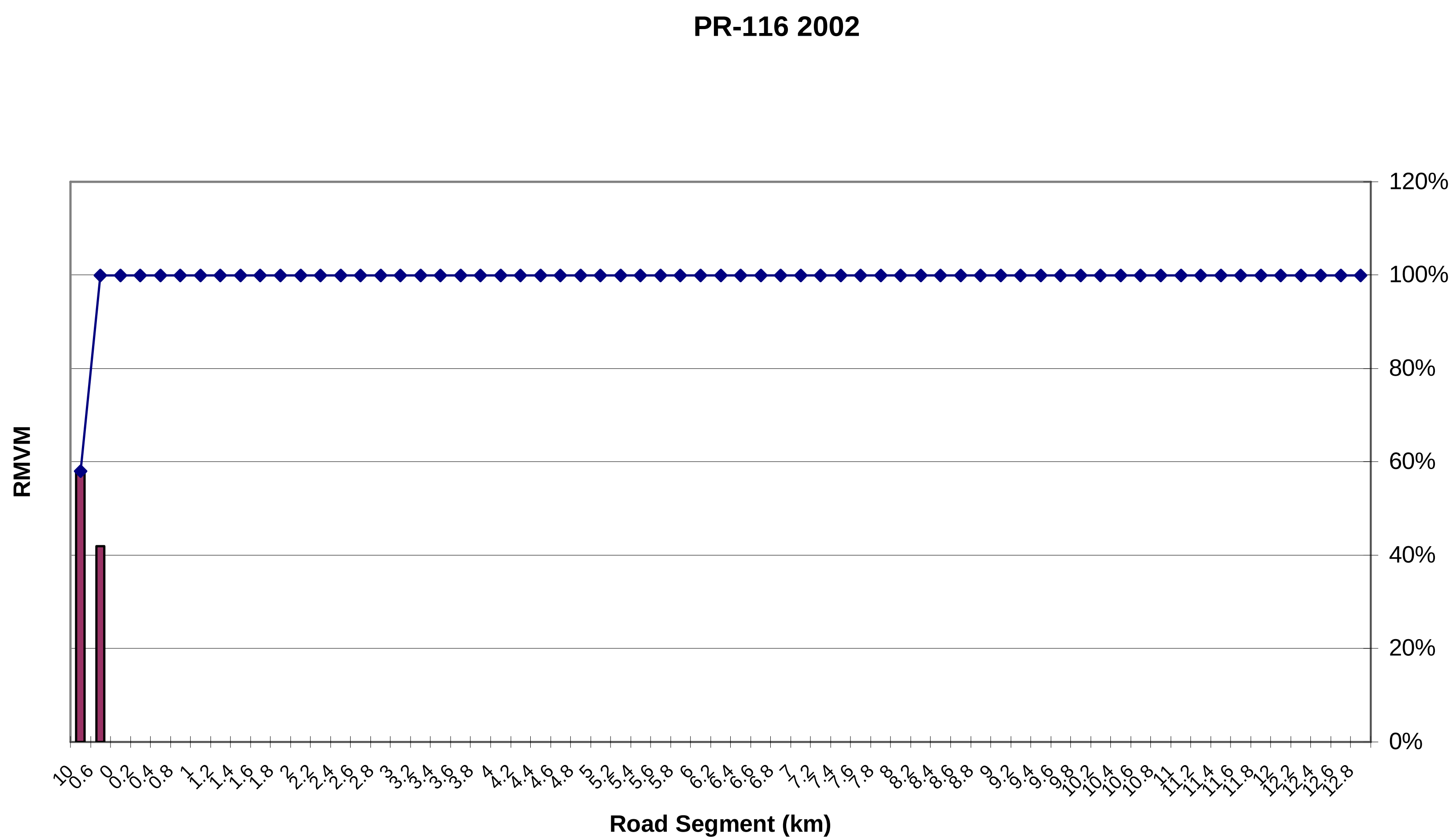
PR-116 2000

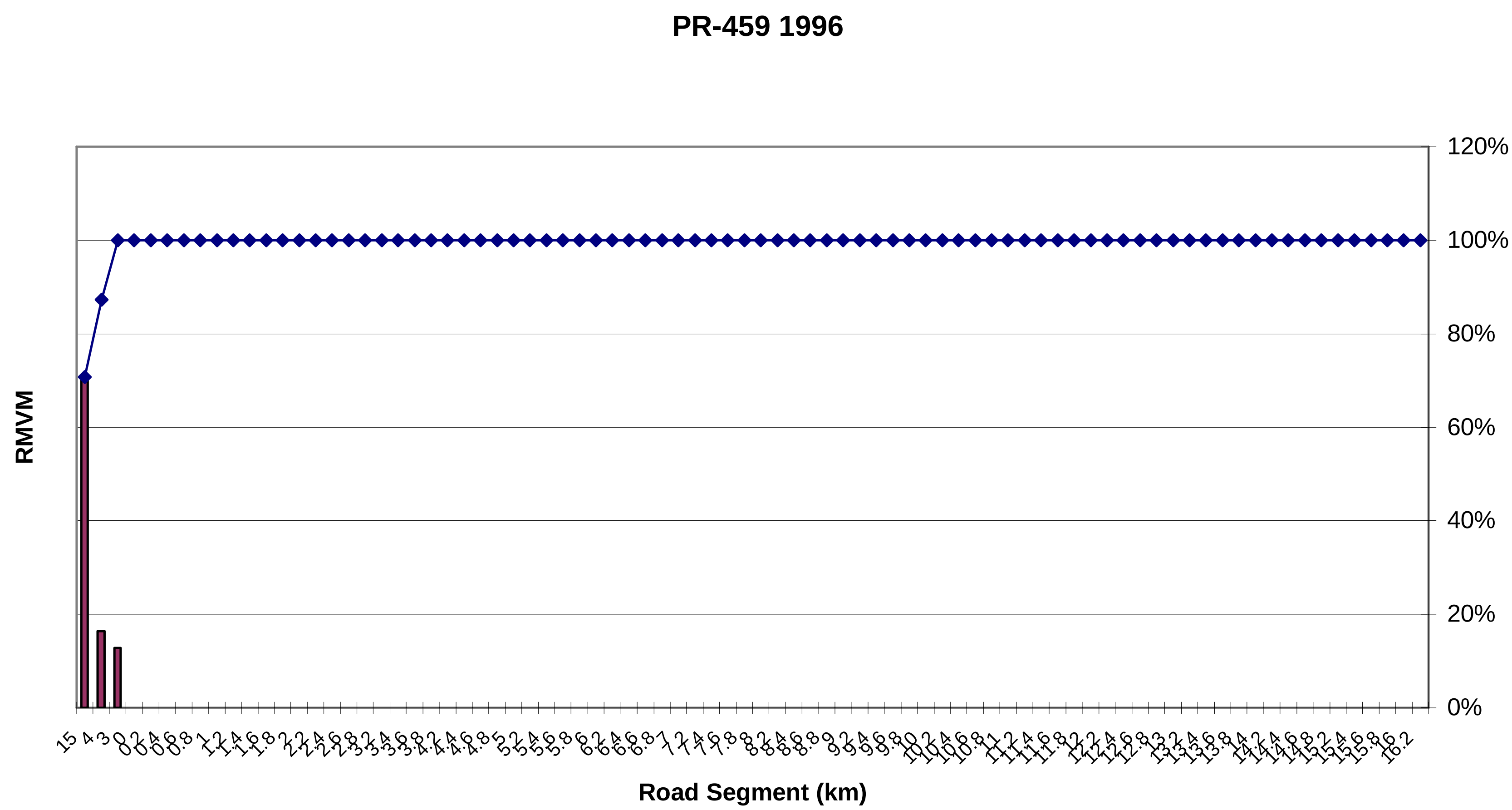


RMVM
120%
100%
80%
60%
40%
20%
0%
15 4.2 4 23 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4 3.6 3.8 4.4 4.6 4.8 5 5.2 5.4 5.6 5.8 6 6.2 6.4 6.6 6.8 7 7.2 7.4 7.6 7.8 8 8.2 8.4 8.6 8.8 9 9.2 9.4 9.6 9.8 10 10.2 10.4 10.6 10.8 11 11.2 11.4 11.6 11.8 12 12.2 12.4
Road Segment (km)



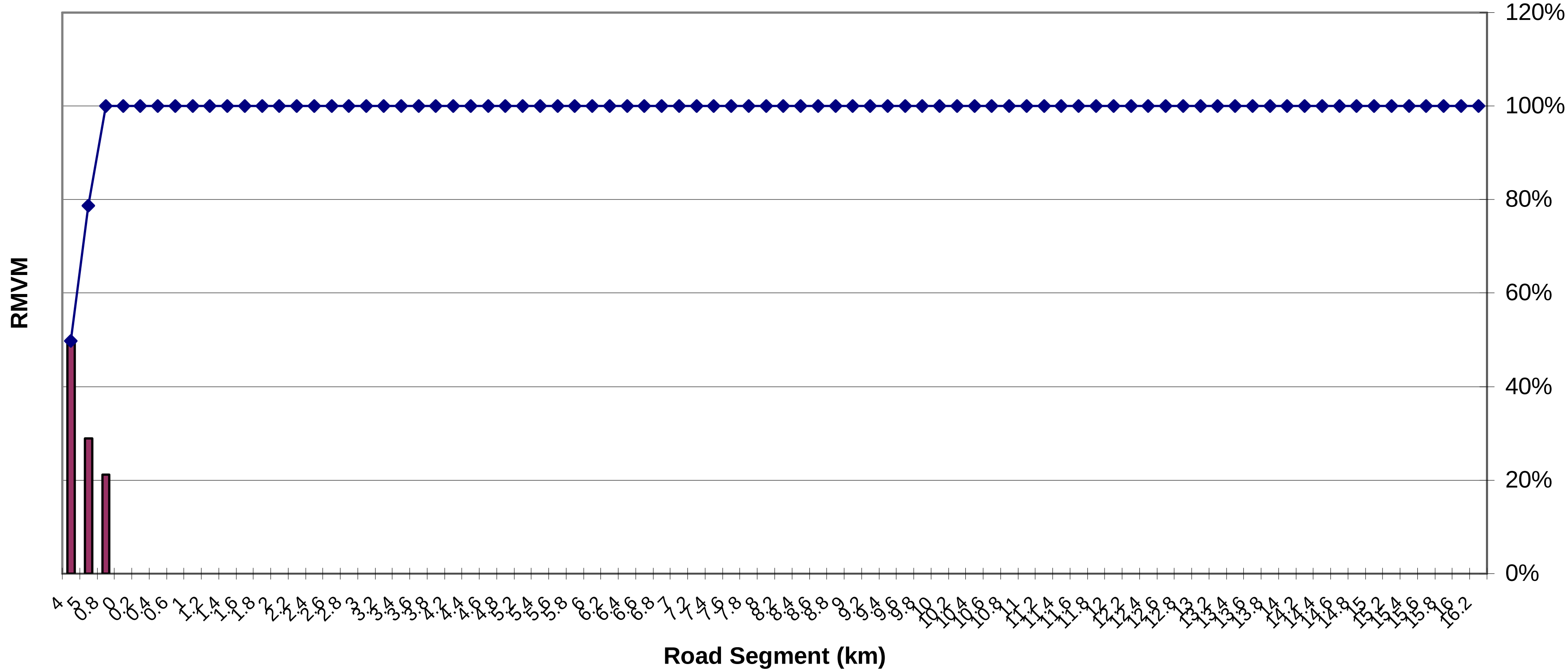
PR-116 2001
RMVM
Road Segment (km)
0%
20%
40%
60%
80%
100%
120%

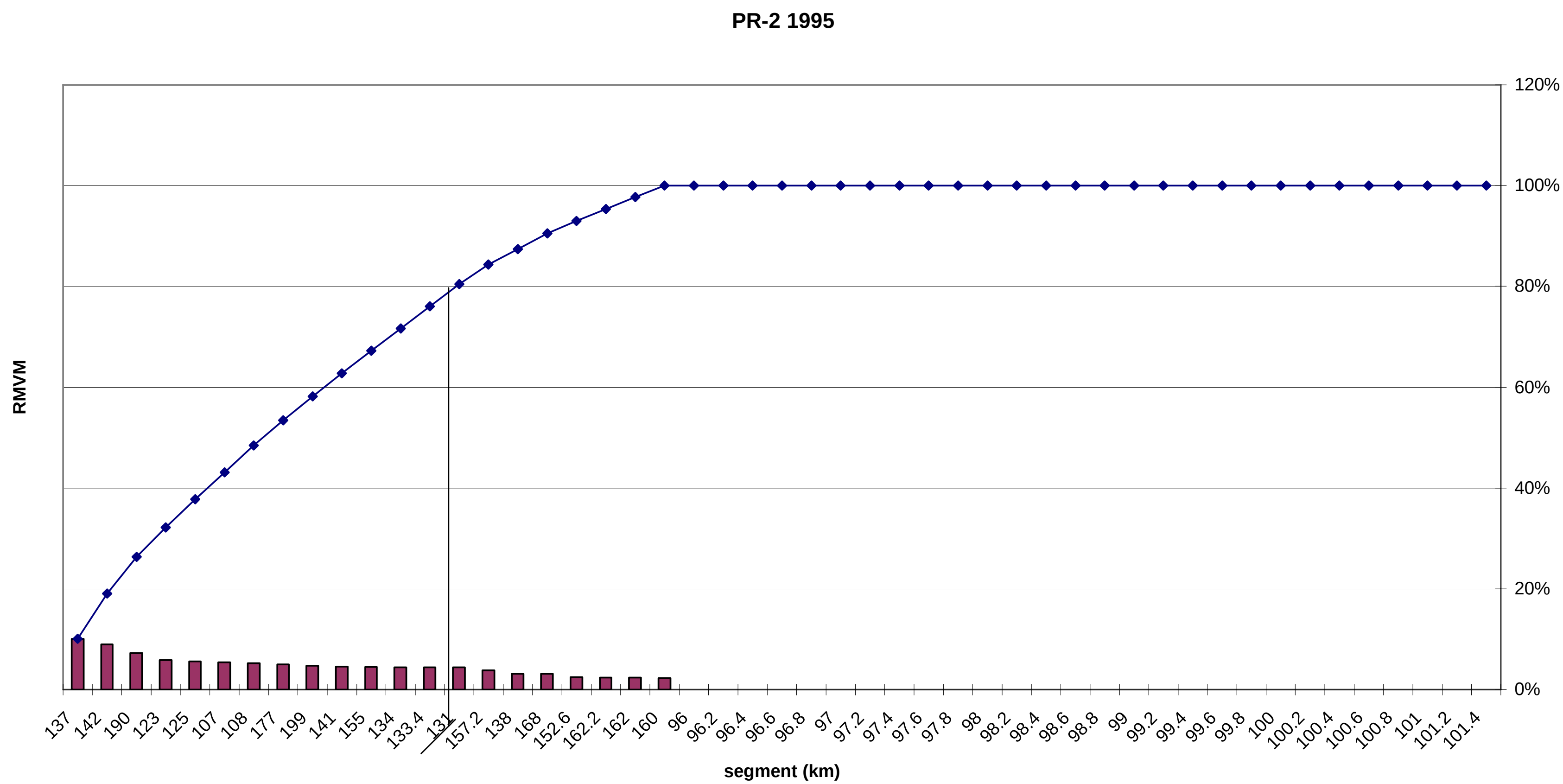

PR-116 2002
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%



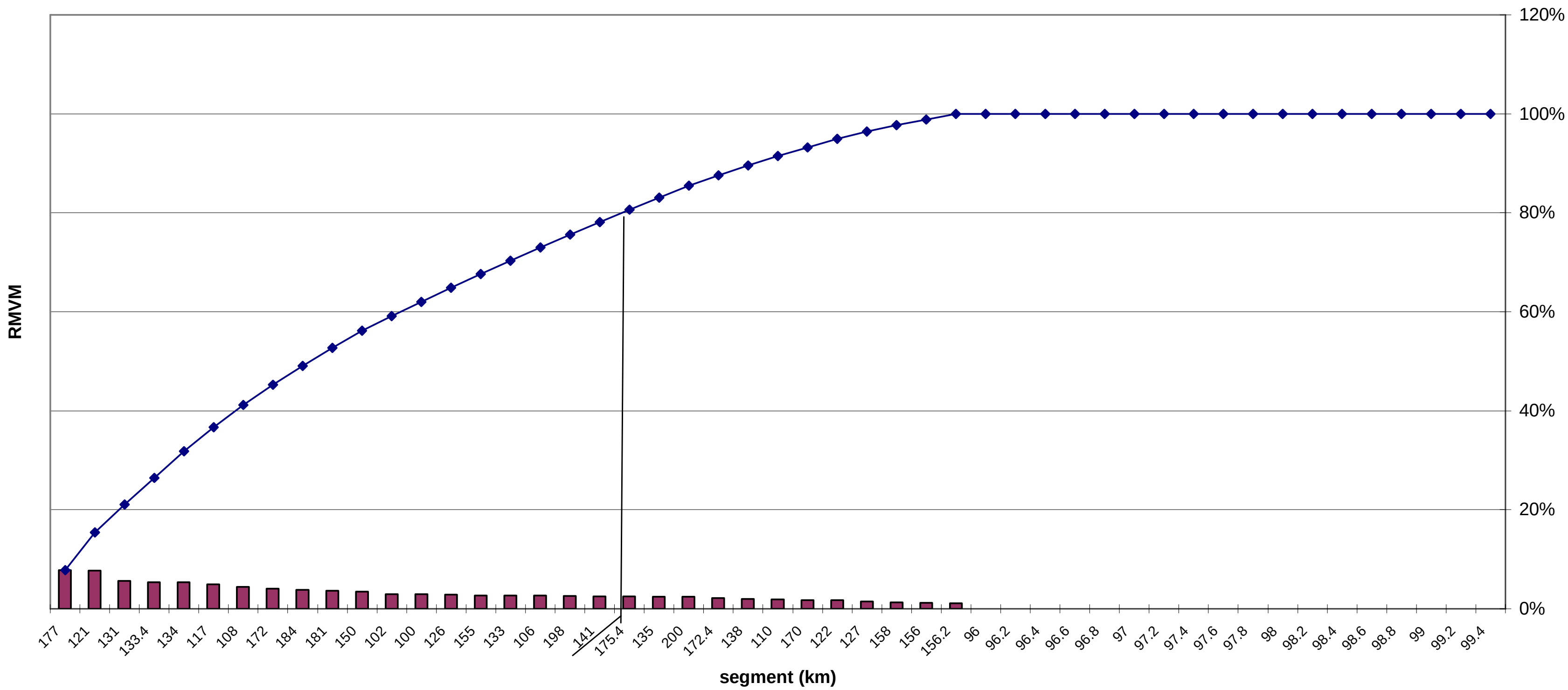
PR-459 1996
RMVM
Road Segment (km)
120%
100%
80%
60%
40%
20%
0%

PR-459 2000



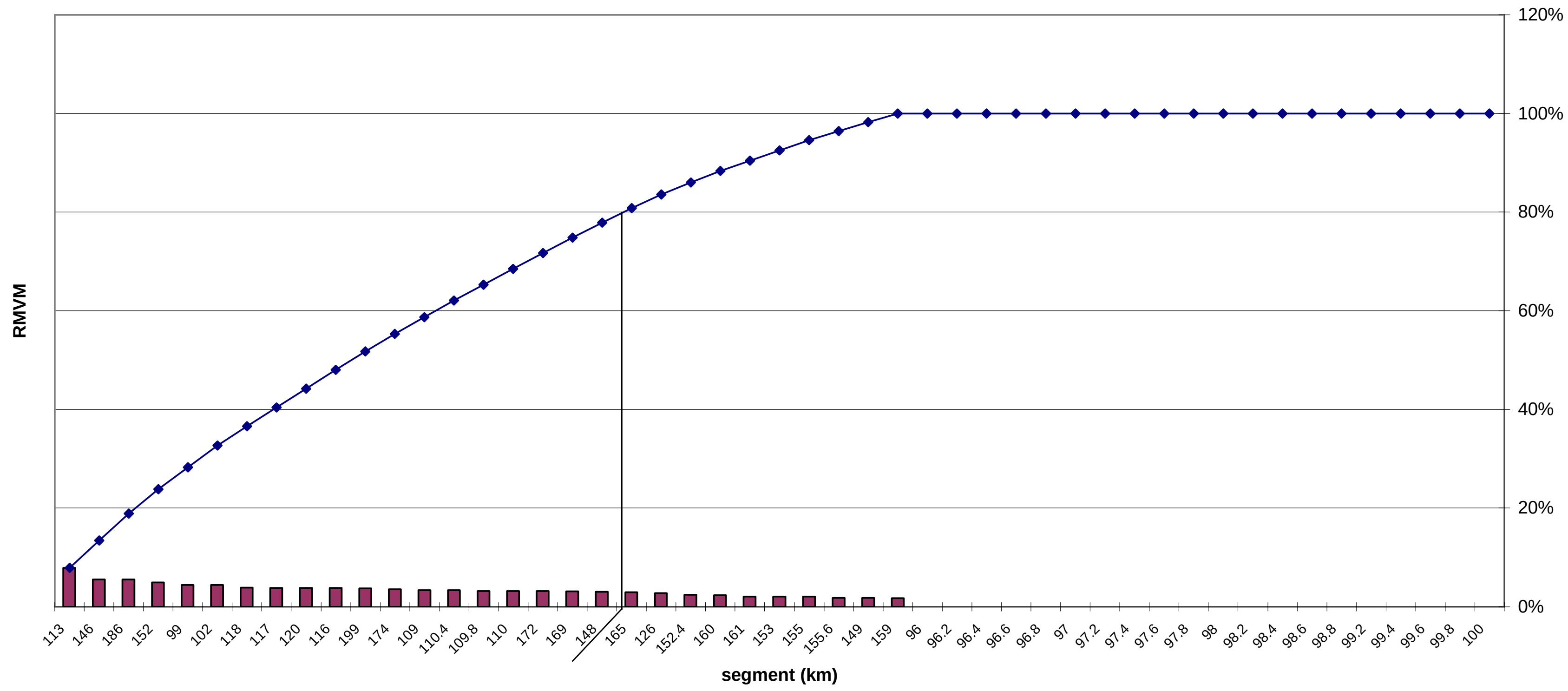

PR-2 1995
RMVM
segment (km)
120%
100%
80%
60%
40%
20%
0%
137
142
190
123
125
107
108
177
199
141
155
134
133.4
131
157.2
138
168
152.6
162.2
162
160
96
96.2
96.4
96.6
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8
99
99.2
99.4
99.6
99.8
100
100.2
100.4
100.6
100.8
101
101.2
101.4

PR-2 1996

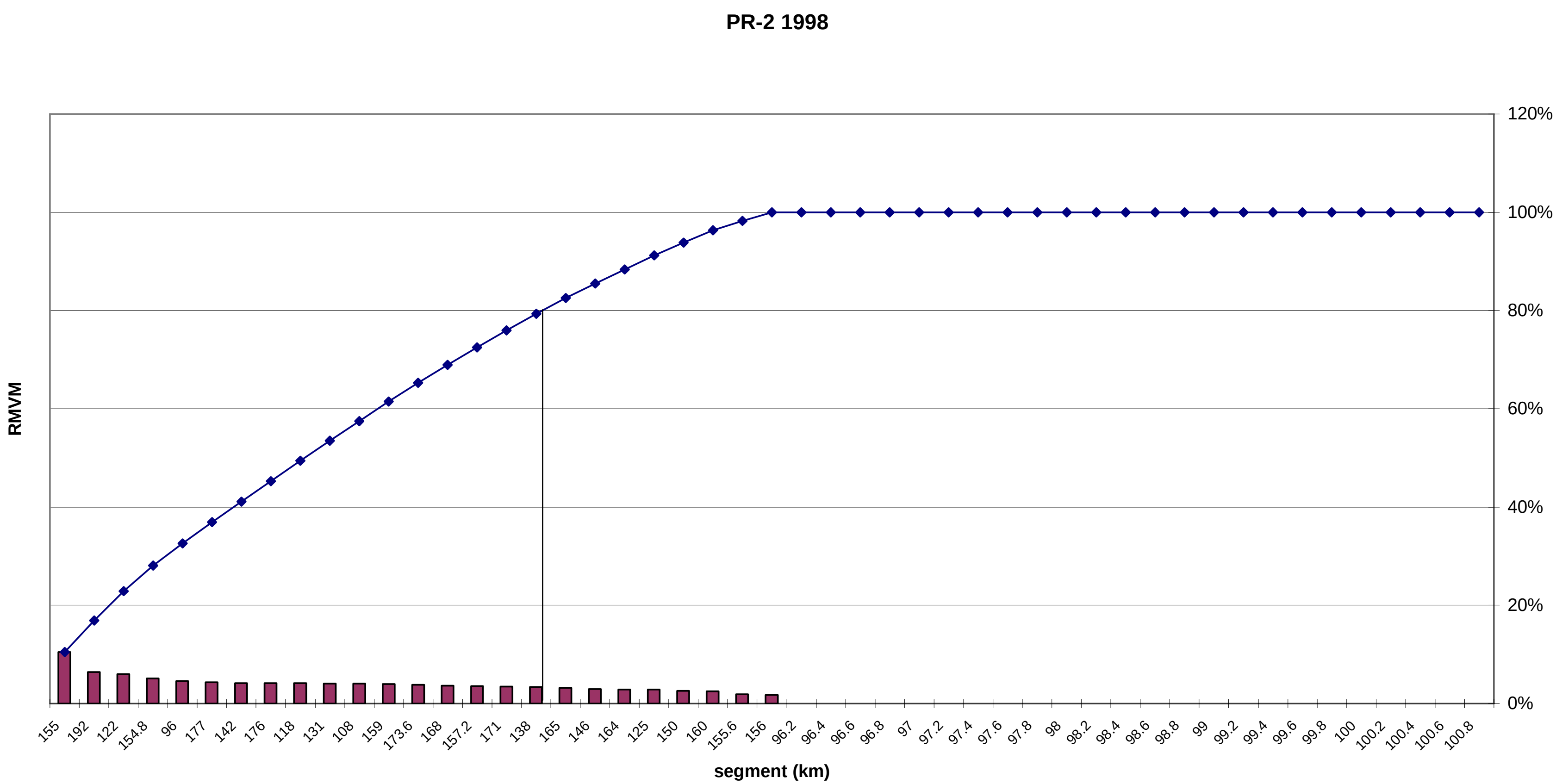


120%
100%
80%
60%
40%
20%
0%
RMVM
177
121
131
133.4
134
117
108
172
184
181
150
102
100
126
155
133
106
198
141
175.4
135
200
172.4
138
110
170
122
127
158
156
156.2
96
96.2
96.4
96.6
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8
99
99.2
99.4
segment (km)

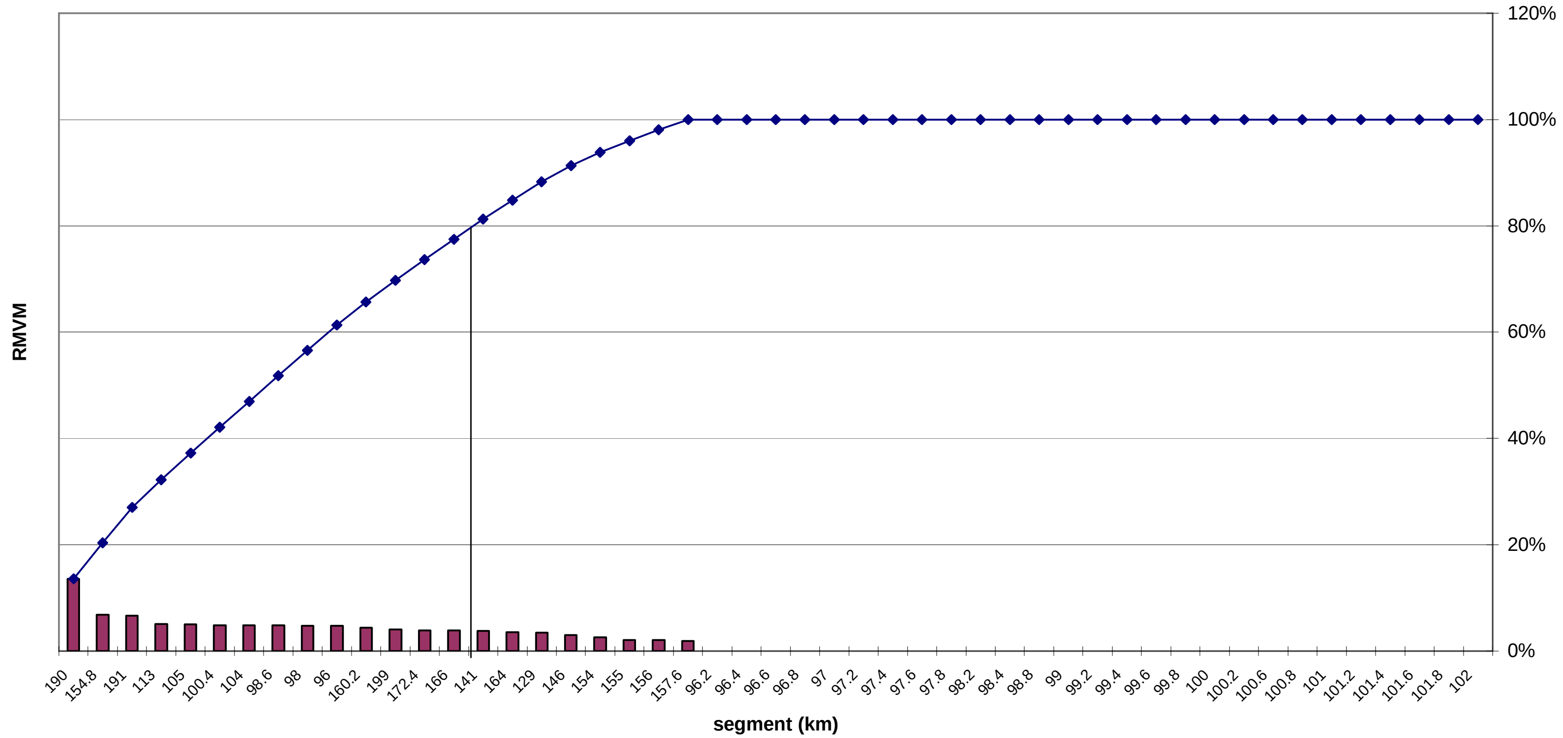
PR-2 1997



RMVM
120%
100%
80%
60%
40%
20%
0%
113 146 186 152 99 102 118 117 120 116 199 174 109 110.4 109.8 110 172 169 148 165 126 152.4 160 161 153 155 155.6 149 159 96 96.2 96.4 96.6 96.8 97 97.2 97.4 97.6 97.8 98 98.2 98.4 98.6 98.8 99.2 99.4 99.6 99.8 100
segment (km)

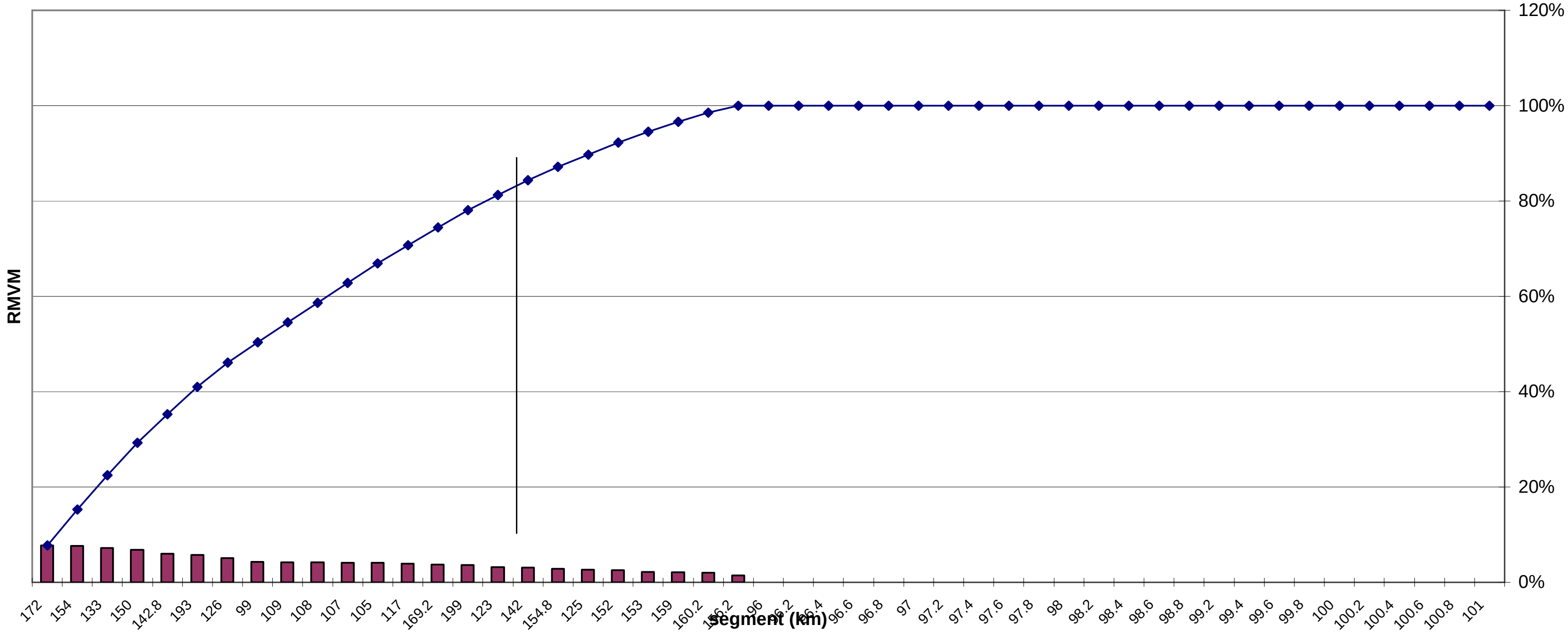

PR-2 1998
RMVM
120%
100%
80%
60%
40%
20%
0%
155
192
122
154.8
96
177
142
176
118
131
108
159
173.6
168
157.2
171
138
165
146
164
125
150
160
155.6
156
96.2
96.4
96.6
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8
99
99.2
99.4
99.6
99.8
100
100.2
100.4
100.6
100.8
segment (km)

PR-2 1999



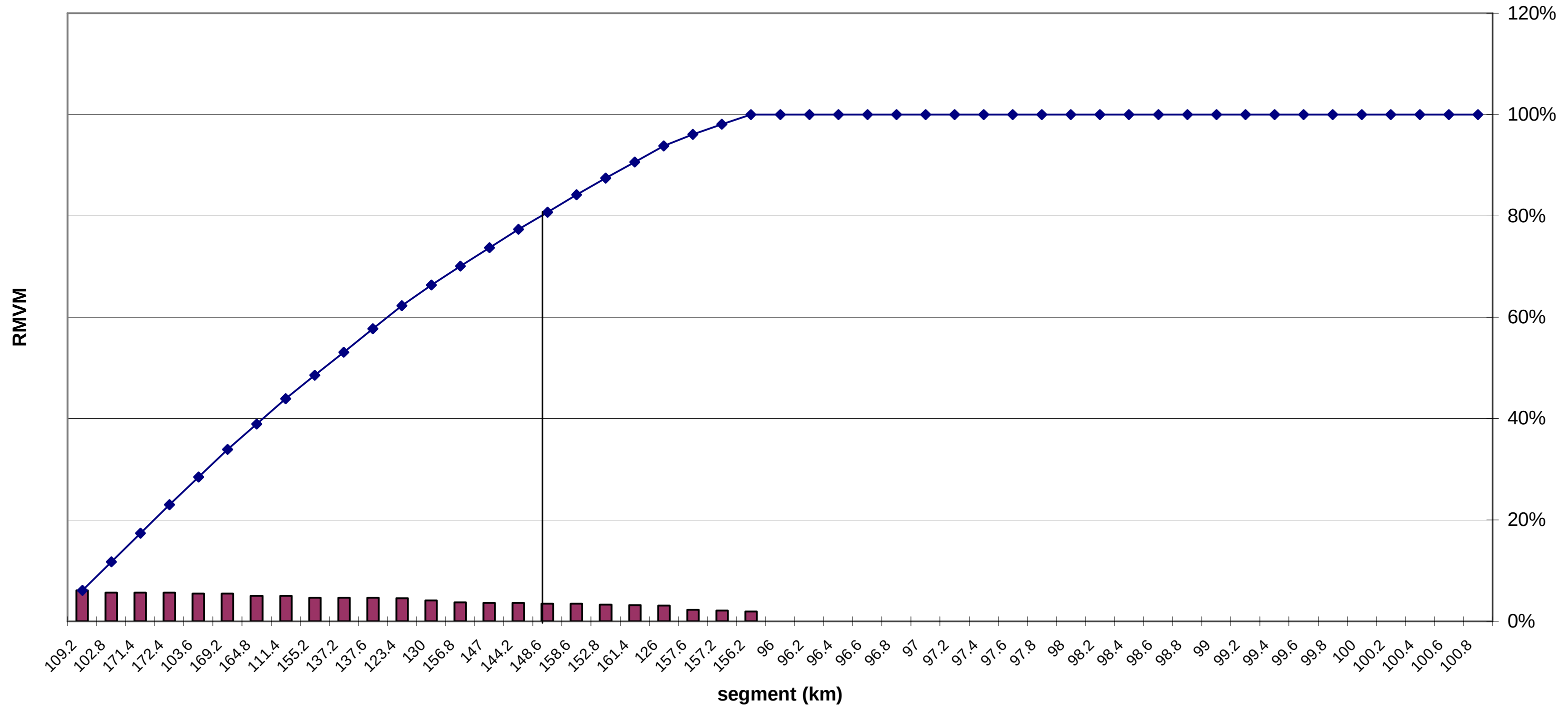
RMVM
120%
100%
80%
60%
40%
20%
0%
190
154.8
191
113
105
100.4
104
98.6
98
96
160.2
199
172.4
166
141
164
129
146
154
155
156
157.6
96.2
96.4
96.6
96.8
97
97.2
97.4
97.6
97.8
98.2
98.4
98.8
99
99.2
99.4
99.6
99.8
100
100.2
100.6
100.8
101
101.2
101.4
101.6
101.8
102
segment (km)

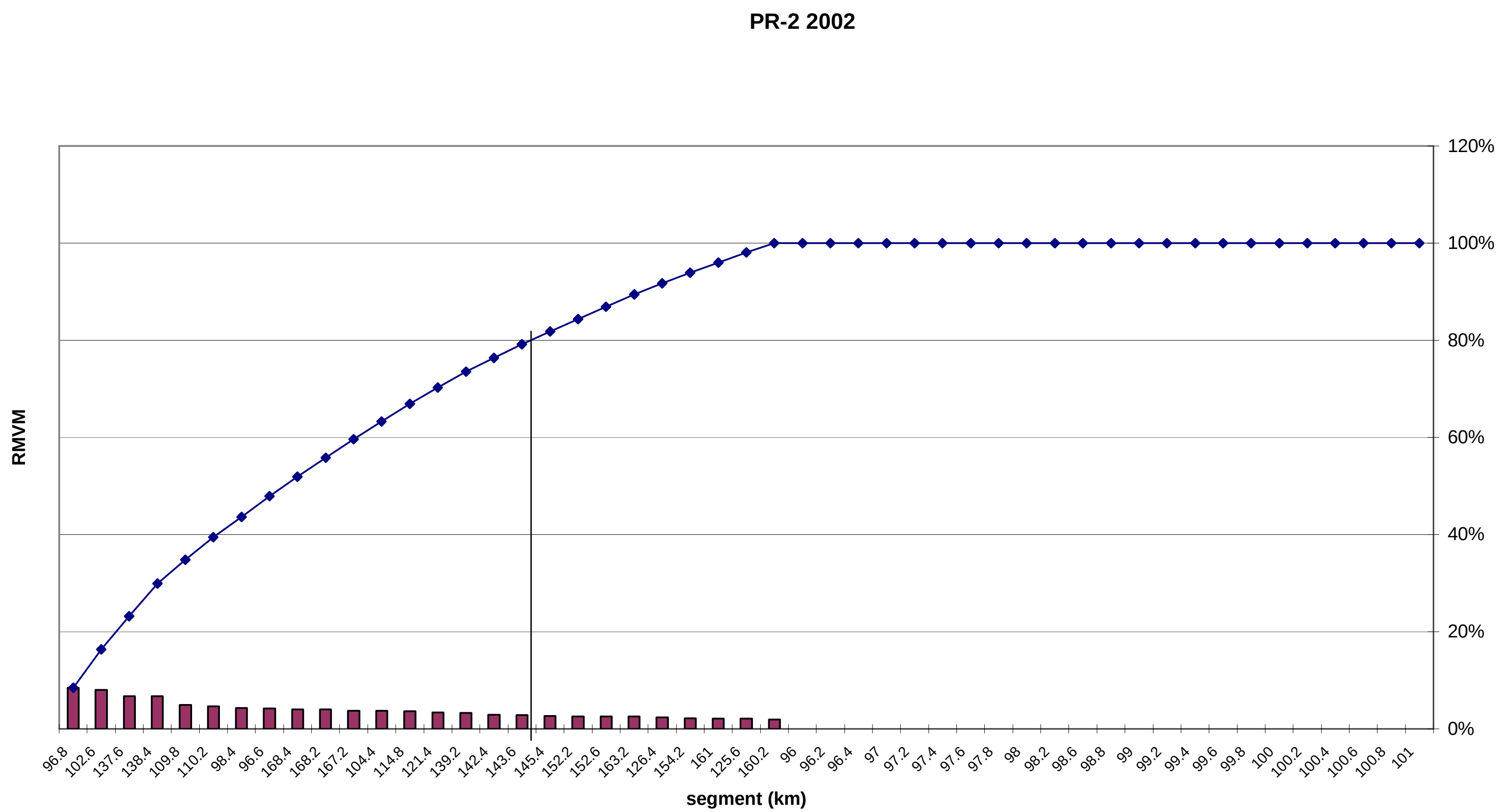
PR-2 2000



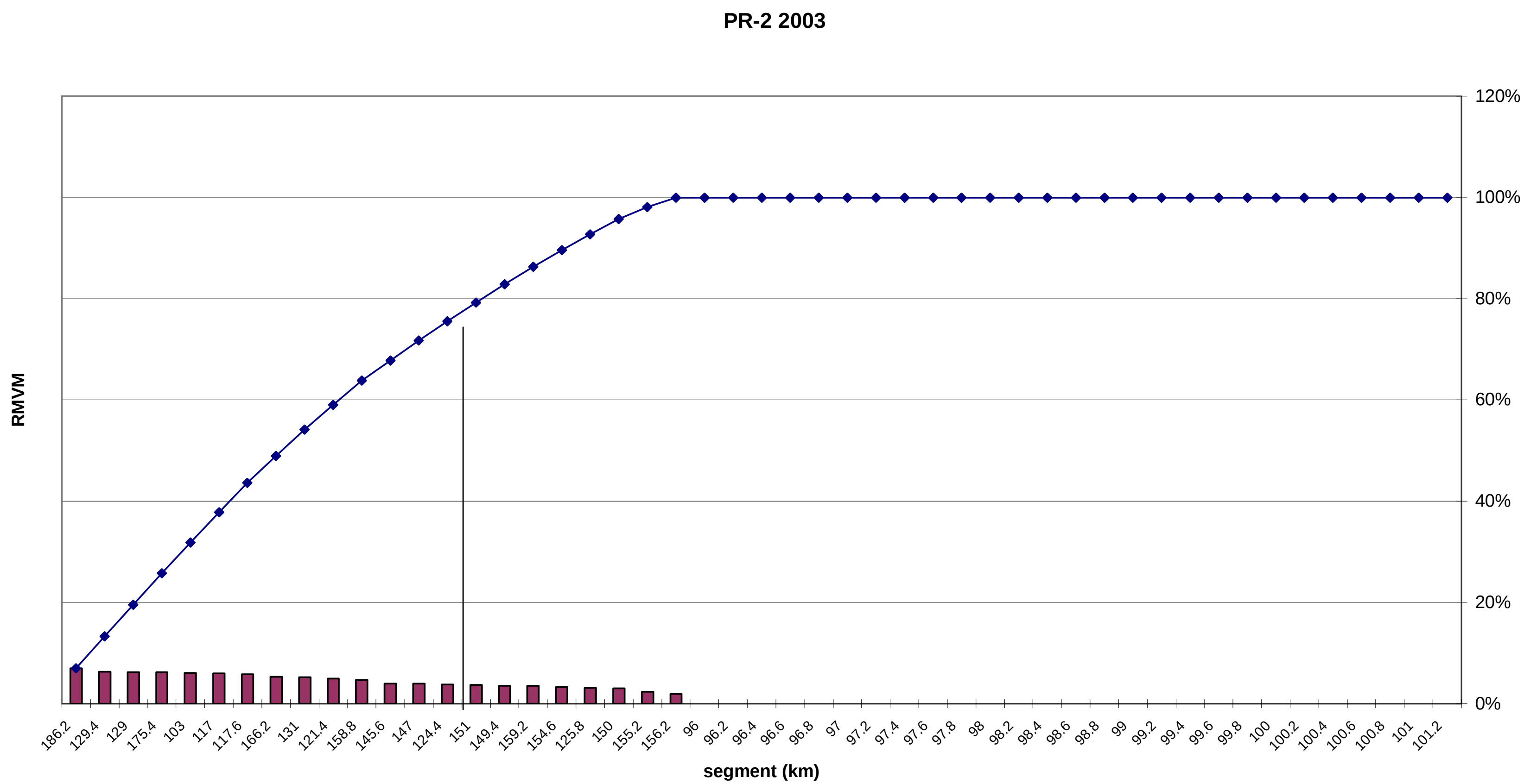
RMVM
120%
100%
80%
60%
40%
20%
0%
segment (km)
172
154
133
150
142.8
193
126
99
109
108
107
105
117
169.2
199
123
142
154.8
125
152
153
159
160.2
96
96.6
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8
99.2
99.4
99.6
99.8
100
100.2
100.4
100.6
100.8
101

PR-2 2001


RMVM
120%
100%
80%
60%
40%
20%
0%
109.2
102.8
171.4
172.4
103.6
169.2
164.8
111.4
155.2
137.2
137.6
123.4
130
156.8
147
144.2
148.6
158.6
152.8
161.4
126
157.6
157.2
156.2
96
96.2
96.4
96.6
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8
99
99.2
99.4
99.6
99.8
100
100.2
100.4
100.6
100.8
segment (km)



PR-2 2002
RMVM
120%
100%
80%
60%
40%
20%
0%
96.8
102.6
137.6
138.4
109.8
110.2
98.4
96.6
168.4
168.2
167.2
104.4
114.8
121.4
139.2
142.4
143.6
145.4
152.2
152.6
163.2
126.4
154.2
161
125.6
160.2
96
96.2
96.4
97
97.2
97.4
97.6
97.8
98
98.2
98.6
98.8
99
99.2
99.4
99.6
99.8
100
100.2
100.4
100.6
100.8
101
segment (km)


PR-2 2003
RMVM
segment (km)
0%
20%
40%
60%
80%
100%
120%
186.2
129.4
129
175.4
103
117
117.6
166.2
131
121.4
158.8
145.6
147
124.4
151
149.4
159.2
154.6
125.8
150
155.2
156.2
96
96.2
96.4
96.6
96.8
97
97.2
97.4
97.6
97.8
98
98.2
98.4
98.6
98.8
99
99.2
99.4
99.6
99.8
100
100.2
100.4
100.6
100.8
101
101.2

Appendix D: Crash Reduction Factors (CRF) Tables

Crash Reduction Factors

Final countermeasure selection should be based on sound engineering judgment and should conform to applicable ODOT and FHWA policies and procedures.

Rural

ID	Countermeasure	Typical Cost	Unit	CollisionType	Crash Reduction Factors Fatal	NF	PDO	Total
Barrier								
3	Install Guardrail At Embankment	$180,600	km	All Crash Types	47%	42%	- 47%	30%
4	Median Cable Barrier (42'+ Median)			All Crash Types	36%	- 20%	- 40%	- 31%
Channelization								
5	Left-Turn Bay, Signalized, curbed/raised	$35,800		All Crash Types	65%	65%	65%	65%
6	Left-Turn Bay, Signalized, Painted	$26,000		All Crash Types	27%	27%	27%	27%
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		All Crash Types	80%	20%	25%	25%
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		Head-on	32%	32%	32%	32%
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		Rear-end	75%	75%	75%	75%
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		Turning Movements	46%	46%	46%	46%
Geometric Improvements								
12	Improve Intersection Sight Distance			All Crash Types	29%	27%	60%	47%
14	Increase Radii at Intersection			All Crash Types	25%	25%		
15	Remove Sight Obstructions			Pedestrian	54%	23%		
Markings, Signs, and Delineation								
23	Delineators	$1,680	km	All Crash Types	47%	20%		30%
23	Delineators	$1,680	km	Head-on	20%	20%	20%	20%
23	Delineators	$1,680	km	Non-collision	10%	10%	10%	10%
23	Delineators	$1,680	km	Sideswipe - Meeting	20%	20%	20%	20%
23	Delineators	$1,680	km	Sideswipe - Overtaking	20%	20%	20%	20%
24	Edge Line	$350	km	Non-collision	15%	15%	15%	15%
30	Warning Signs	$345	sign	All Crash Types	36%	36%	36%	36%
86	Durable Markings			All Crash Types	40%	40%	40%	40%
86	Durable Markings			Fixed or Other Object	56%	56%	56%	56%
Median								
31	Non-Traversable (Curbed/Grass) 16 Foot Median	$183,400	km	All Crash Types	9%	9%	8%	
32	Non-Traversable (Curbed/Grass) 30 Foot Median	$183,400	km	All Crash Types	25%	25%	21%	
33	Non-Traversable (Curbed/Grass) 42 Foot Median	$183,400	km	All Crash Types	30%	30%	28%	
35	Traversable (Painted, 1.2 m or more)	$54,800	km	All Crash Types	30%	30%	20%	20%
Roadside								
44	Clear Gore Area			Fixed or Other Object	50%	50%	25%	
45	Flatten Sideslopes from 1:2 to 1:4			Non-collision	7%	7%	7%	7%
46	Flatten Sideslopes from 1:2 to 1:6			Non-collision	15%	15%	15%	15%
47	Flatten Sideslopes from 1:3 to 1:4			Non-collision	6%	6%	6%	6%
48	Flatten Sideslopes from 1:3 to 1:6			Non-collision	14%	14%	14%	14%
49	Increase Clear Zone by 10 feet			Fixed or Other Object	25%	25%	25%	25%
50	Increase Clear Zone by 15 feet			Fixed or Other Object	35%	35%	35%	35%
51	Increase Clear Zone by 5 feet			Fixed or Other Object	13%	13%	13%	13%
52	Increase Clear Zone by 8 feet			Fixed or Other Object	21%	21%	21%	21%
53	Install Breakaway Sign Supports	$1,200	each	Fixed or Other Object	50%	50%	10%	35%

54	Install Energy Absorption Devices	$10,000		Fixed or Other Object	100%	44%	20%	80%
55	Prohibit Parking	$340	sign	All Crash Types	5%	32%	30%	32%
56	Remove Obstacles (Cut Slope)			Fixed or Other Object	35%	15%	-30%	
57	Remove Obstacles (Fill Slope <1:4)			Fixed or Other Object	73%	23%	-40%	
58	Remove Obstacles (Fill Slope >1:4)			Fixed or Other Object	14%	10%	-18%	
59	Remove Rock Outcroppings			Fixed or Other Object	65%	25%	5%	
60	Remove Utility Poles			Fixed or Other Object	35%	-2%		
61	Tree Removal			Fixed or Other Object	50%	25%	-20%	
91	Shoulder Rumble Strips			All Crash Types	25%	25%	25%	25%
Roadway Cross Section								
62	Add Climbing/Passing Lane			All Crash Types	11%	11%	11%	11%
64	Widen Shoulders from 0 to 2 feet	$6,850	km	Fixed or Other Object	13%	13%	13%	13%
65	Widen Shoulders from 0 to 4 feet	$6,850	km	Fixed or Other Object	25%	25%	25%	25%
66	Widen Shoulders from 0 to 6 feet	$6,850	km	Fixed or Other Object	35%	35%	35%	35%
67	Widen Shoulders from 0 to 8 feet	$6,850	km	Fixed or Other Object	43%	43%	43%	43%
85	Add Additional Lane			All Crash Types	20%	20%	20%	20%
87	Increase shoulder width to AASHTO standards			All Crash Types	17%	17%	17%	17%
Signing								
74	Flashing Beacons w/Warning Signs Before Inters.	$345		All Crash Types	19%	37%	37%	37%
75	Improve Directional/Warning Signs			All Crash Types	19%	37%	37%	37%
76	Provide Slippery When Wet Signs	$345	sign	All Crash Types	36%	36%	36%	36%
77	Stop Ahead Sign	$345	sign	All Crash Types	80%	80%	45%	47%
Unsignalized Intersection								
82	Install Flasher	$28,000		All Crash Types	30%	30%	30%	
Vertical Alignment								
84	Improve from 3-R Threshold to New			All Crash Types	45%	45%	45%	45%

Rural and Urban

ID	Countermeasure	Typical Cost	Unit	CollisionType	Crash Reduction Factors			
					Fatal	NF	PDO	Total
Barrier								
1	Concrete Median Barrier (3-6' Shy)	$132,300	km	All Crash Types	90%	10%	-10%	
2	Concrete Median Barrier (7-12' Shy)	$132,300	km	All Crash Types	85%	5%	-25%	
88	Metal median barrier			All Crash Types	75%	2%	28%	0%
Channelization								
7	Left-Turn Bay, Unsignalized, 4-Leg, curbed/raised	$35,800		All Crash Types	70%	70%	70%	70%
7	Left-Turn Bay, Unsignalized, 4-Leg, curbed/raised	$35,800		Non-collision	50%	50%	50%	50%
7	Left-Turn Bay, Unsignalized, 4-Leg, curbed/raised	$35,800		Rear-end	90%	90%	90%	90%
7	Left-Turn Bay, Unsignalized, 4-Leg, curbed/raised	$35,800		Turning Movements	17%	17%	17%	17%
9	Left-Turn Bay, Unsignalized, T-Intersection	$12,400		All Crash Types	80%	80%	80%	80%
10	Right-Turn Lane, Signalized	$5,400		All Crash Types	40%	40%	10%	
11	Right-Turn Lane, Unsignalized	$5,400		All Crash Types	40%	40%	10%	
Horizontal Alignment								
16	Improve Curve from 10 to 5 degrees			All Crash Types	45%	45%	45%	45%
17	Improve Curve from 15 to 5 degrees			All Crash Types	63%	63%	63%	63%
18	Improve Curve from 20 to 10 degrees			All Crash Types	48%	48%	48%	48%
Markings, Signs, and Delineation								
22	Chevrons on Curves	$300	each	All Crash Types	35%	35%	35%	35%
25	Guide Signs	$1,200	sign	All Crash Types	15%	15%	15%	15%
26	Install Diagrammatic Exit Signs	$2,870	sign	All Crash Types	25%	25%	25%	25%
27	Install Variable Message Sign			All Crash Types	10%	10%	10%	10%
28	Install Warning Signs and Delineators on Curves	$6,450		All Crash Types	41%	22%	22%	22%
29	Raised Centerline Pavement Markers			Head-on	30%	30%	30%	30%
Median								
36	Two-Way Left-Turn Lanes	$54,800	km	Head-on	50%	35%	35%	35%
36	Two-Way Left-Turn Lanes	$54,800	km	Rear-end	43%	43%	43%	43%
36	Two-Way Left-Turn Lanes	$54,800	km	Sideswipe - Meeting	43%	43%	43%	43%
36	Two-Way Left-Turn Lanes	$54,800	km	Sideswipe - Overtaking	43%	43%	43%	43%
Other								
37	Construct Grade Separation			All Crash Types	100%	75%	75%	75%
38	Construct Pedestrian Crossover			Pedestrian	95%	95%	95%	95%
Roadway Cross Section								
63	Provide Deceleration Lane	$5,400	lane	All Crash Types	40%	40%		10%
Unsignalized Intersection								
80	Install 2-Way Stop from Yield Control	$700		All Crash Types interse	20%	20%	68%	
81	Install 4-Way Stop from 2-Way Stop	$700		All Crash Types interse	55%	55%	55%	55%
81	Install 4-Way Stop from 2-Way Stop	$700		Angle interse	72%	72%	72%	72%
81	Install 4-Way Stop from 2-Way Stop	$700		Pedestrian interse	39%	39%	39%	39%
81	Install 4-Way Stop from 2-Way Stop	$700		Rear-end interse	13%	13%	13%	13%
83	Prohibit Parking	$340	sign	All Crash Types	5%	30%	32%	32%
83	Prohibit Parking	$340	sign	Parking Maneuver	90%	90%	90%	90%
83	Prohibit Parking	$340	sign	Rear-end	10%	10%	10%	10%
83	Prohibit Parking	$340	sign	Sideswipe - Meeting	30%	30%	30%	30%
83	Prohibit Parking	$340	sign	Sideswipe - Overtaking	30%	30%	30%	30%

Urban

ID	Countermeasure	Typical Cost	Unit	CollisionType	Crash Reduction Factors Fatal	NF	PDO	Total
	Barrier							
3	Install Guardrail At Embankment	$180,600	km	All Crash Types	47%	42%	-47%	
4	Median Cable Barrier (42'+ Median)			All Crash Types	36%	-20%	-40%	-41%
	Channelization							
5	Left-Turn Bay, Signalized, curbed/raised	$35,800		All Crash Types	65%	70%	67%	65%
6	Left-Turn Bay, Signalized, Painted	$26,000		All Crash Types	32%	30%	24%	32%
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		All Crash Types	80%	80%	20%	
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		Rear-end	68%	68%	68%	68%
8	Left-Turn Bay, Unsignalized, 4-Leg, Painted	$26,000		Turning Movements	22%	22%	22%	22%
	Geometric Improvements							
12	Improve Intersection Sight Distance			All Crash Types	5%	3%	30%	30%
12	Improve Intersection Sight Distance			Angle	30%	30%	30%	30%
12	Improve Intersection Sight Distance			Head-on	10%	10%	10%	10%
12	Improve Intersection Sight Distance			Pedestrian	10%	10%	10%	10%
13	Increase Curb Radii			All Crash Types	25%	25%		
	Increase Driveway Spacing							
19	Spacing 300-600 Ft.			All Crash Types	44%	44%	44%	44%
20	Spacing 600-1000 Ft.			All Crash Types	60%	60%	60%	60%
21	Spacing Over 1000 Ft.			All Crash Types	68%	68%	68%	68%
	Markings, Signs, and Delineation							
30	Warning Signs	$345	sign	All Crash Types	14%	14%	14%	14%
86	Durable Markings			All Crash Types	40%	40%	40%	40%
86	Durable Markings			Fixed or Other Object	80%	80%	80%	80%
	Median							
34	Non-Traversable (Grass/Curbed) From TWLTL	$183,400	km	All Crash Types	30%	30%	30%	30%
35	Traversable (Painted, 1.2 m or more)	$54,800	km	All Crash Types	30%	30%		12%
	Other							
41	Prohibit/Restrict Parking Near Driveways			Pedestrian	3%	32%	32%	32%
43	Remove Sight Obstructions			Pedestrian	54%	23%		
	Roadside							
89	Prohibit Parking			All Crash Types	5%	32%	30%	32%
89	Prohibit Parking			All Crash Types	24%	24%	24%	24%
89	Prohibit Parking			Parking Maneuver	90%	90%	90%	90%
89	Prohibit Parking			Rear-end	10%	10%	10%	10%
89	Prohibit Parking			Sideswipe - Meeting	30%	30%	30%	30%
89	Prohibit Parking			Sideswipe - Overtaking	30%	30%	30%	30%
91	Shoulder Rumble Strips			All Crash Types	25%	25%	25%	25%
	Roadway Cross Section							
85	Add Additional Lane			All Crash Types	20%	20%	20%	20%
87	Increase shoulder width to AASHTO standards			Head-on	17%	17%	17%	17%

Signalization

68	Illuminate Crosswalks	$17,500		Pedestrian crossw	59%	59%	59%	59%
69	Improve Signal Head Location	$1,400	each	All Crash Types	35%	35%	30%	31%
70	Install Signal			All Crash Types	18%	18%	18%	18%
71	Install Signal Actuation	$42,000		Angle interse	10%	10%	10%	10%
71	Install Signal Actuation	$42,000		Rear-end interse	10%	10%	10%	10%
71	Install Signal Actuation	$42,000		Sideswipe - Meeting interse	20%	20%	20%	20%
71	Install Signal Actuation	$42,000		Sideswipe - Overtaking interse	20%	20%	20%	20%
72	Install Signal and Left Turn Lane			All Crash Types	35%	35%	35%	35%
73	Interconnect Signals	$23,000	km	All Crash Types	29%	10%	10%	10%
73	Interconnect Signals	$23,000	km	Angle	10%	10%	20%	10%
73	Interconnect Signals	$23,000	km	Pedestrian	10%	10%	10%	10%
73	Interconnect Signals	$23,000	km	Rear-end	20%	20%	20%	20%
73	Interconnect Signals	$23,000	km	Turning Movements	37%	37%	37%	37%

Signing

74	Flashing Beacons w/Warning Signs Before Inters.	$345		All Crash Types	30%	30%	30%	30%
75	Improve Directional/Warning Signs			All Crash Types	51%	26%		29%
76	Provide Slippery When Wet Signs	$345	sign	All Crash Types	14%	14%	14%	14%
77	Stop Ahead Sign	$345	sign	All Crash Types	29%	51%	51%	51%

Unsignalized Intersection

78	Illuminate Roadway			All Crash Types	25%	25%	25%	25%
79	Illuminate Unsignalized Intersection			All Crash Types	50%	50%	50%	50%
82	Install Flasher	$28,000		All Crash Types	30%	30%		

Appendix E: Accident Modification Factors (AMF) Tables

Accident Modification Factors

Reference: Transportation Center Research Report KTC 96-13

1 - TRAFFIC SIGNS

Warning Signs	% Reduction
1-1 Warning Signs-General	25%
1-2 Curve Warning Run-off-road Accidents	30%
1-3 Intersection-Related Warning (Side road, stop ahead, etc.)	30%
1-4 Railroad Crossing Train Accidents	30%
1-5 Pavement Condition Surface Condition-Related Accident	20%
1-6 School Zone	15%

Regulatory Signs	% Reduction
1-7 Stop Sign (Two-way)	35%
1-8 All-Way Stop	55%
1-9 Yield	45%

Guide Signs	% Reduction
1-10 Guide Sign - General	
1-11 Variable Message Sign	15%
	15%

2 - TRAFFIC SIGNALS	% Reduction
2-1 Install Signal	
Angle Accidents	25%
2-2 Signal Upgrade - General	65%
2-2a 12-inch lens	20%
2-2b Backplates	10%
Right Angle Accidents	20%
2-2c Optically Programmed Signal Lenses	15%
2-3 Remove Unwarranted Signal	50%

Signal Phasing	% Reduction
2-4 Signal Phasing-General	25%
2-5 Add Exclusive Left Turn Phase	25%
Left Turn Accidents	70%
2-6 Add Protected/Permissive Left Turn Phase	10%
Left Turn Accidents	40%
2-7 Improve Timing	10%
2-8 Add Pedestrian Phase	25%
Pedestrian Accidents	55%
2-9 Add All-Red Interval/Increase Yellow Time	15%
Right-Angle Accidents	30%
2-10 Interconnect Traffic Signals	15%

Flashing Beacon	% Reduction
2-11 Flashing Beacon - General	30%
2-12 Install Flashing Beacon at Intersection	30%

2-13 Intersection Advance Warning Flasher	25%
2-14 General Advance Warning Flasher	35%

Railroad Crossings	% Reduction
2-15 Railroad Crossings - General	
Train Accidents	70%
2-16 Flashing Lights	
Train Accidents	65%
2-17 Flashing Lights and Automatic Gates	
Train Accidents	75%
2-18 Automatic Gates	
Train Accidents	75%

3 - ROADWAY DELINEATION/PAVEMENT MARKINGS	% Reduction
3-1 General	15%
3-2 Edgeline Markings	15%
Off Road	30%
3-3 Centerline Markings	35%
3-4 Wide Markings	
Night Accidents	25%
3-5 No Passing Zone	
Passing Accidents	40%
3-6 Crosswalk	
Pedestrian Accidents	25%
3-7 Raised Pavement Markers	10%
Night Accidents	20%
Wet Night	25%
3-8 Post Delineators	
Night Accidents	30%
3-9 Railroad	
Train Accidents	15%

4 - LIGHTING	% Reduction
4-1 General	25%
Night Accidents	50%
4-2 Roadway Segment	25%
Night Accidents	45%
4-3 Intersection	30%
Night Accidents	50%
4-4 Interchange	25%
Night Accidents	50%
4-5 Railroad Crossing	30%
Night Accidents	60%

5 - CHANNELIZATION	% Reduction
5-1 General Intersection	25%
5-2 Left Turn Lane - with Signal	25%
Left Turn Related	45%

5-3 Left Turn Lane - without Signal	35%
Left Turn Related	50%
5-4 Right Turn Lane	25%
Right Turn Related	50%
5-5 Increase Turn Lane Length	15%

6 - PAVEMENT TREATMENT	% Reduction
6-1 General	25%
Wet Pavement	50%
6-2 Resurfacing	25%
Wet Pavement	45%
6-3 Pavement Grooving	25%
Wet Pavement	60%
6-4 Rumble Strips	25%
6-5 Shoulder Grooving	25%

7 - ROADSIDE IMPROVEMENT (APPURTENANCES/CLEAR ZONE)	% Reduction
7-1 Install Guardrail	5%
Fatal Accidents	65%
Injury Accidents	40%
7-2 Install Median Barrier	5%
Fatal Accidents	65%
Injury Accidents	40%
7-3 General Guardrail Upgrade	5%
Fatal Accidents	50%
Injury Accidents	35%
7-4 Impact Attenuator	5%
Fatal Accidents	75%
Injury Accidents	50%
7-5 Remove Fixed Objects	30%
Fatal Accidents	50%
Injury Accidents	30%
7-6 Relocate Fixed Objects	25%
Fatal Accidents	40%
Injury Accidents	25%
7-7 Flatten Side Slopes	30%
7-8 Convert Hardware to Breakaway	5%
Fatal Accidents	60%
Injury Accidents	30%
7-9 Upgrade Bridge Railing	5%
Fatal Accidents	60%
Injury Accidents	30%
7-10 Gore Improvements	25%

8 - CONSTRUCTION/RECONSTRUCTION	% Reduction
Realignment	
8-1 Horizontal Realignment/Curve Reconstruction	40%

8-2 Vertical Realignment	40%
8-3 Modify Horizontal and Vertical Realignment	50%
8-4 Realign Intersection	40%
8-5 Modify Superelevation	40%
8-6 Sight Distance Improvement	30%
Pavement Widening	
8-7 Widen Pavement	25%
8-8 Widen Shoulder	20%
4 Feet or Less	20%
Over 4 Feet	35%
8-9 Shoulder Stabilization/Shoulder Dropoff	25%
8-10 Pave Shoulder	15%
Additional Lanes	
8-11 Add Passing/Climbing Lane	20%
8-12 Add Acceleration/Deceleration Lane	10%
8-13 Add Left-Turn Lane	25%
Left-turn Related Accidents	50%
8-14 Add Right-Turn Lane	25%
Right-turn Related Accidents	50%
8-15 Add Two Way Left Turn Lane	30%
Median	
8-16 Add Mountable Median	15%
8-17 Add Non-mountable Median	25%
Bridge	
8-18 Widen Bridge	45%
8-19 Replace Bridge	45%
8-20 Bridge Deck Repair	15%
Intersection	
8-21 Increase Turning Radii	15%
8-22 Sight Distance Improvements	30%
Freeway	
8-23 Construct Interchange	55%
8-24 Modify Entrance/Exit Ramp	25%
8-25 Frontage Road	40%
8-26 Glare Screen	
Night Accidents	15%
Pedestrian	
8-27 Construct Pedestrian Grade Separation	
Pedestrian Accidents	90%
8-28 Add Sidewalk	
Pedestrian Accidents	65%
Roundabouts	71%

Other	
8-29 Drainage Improvements	20%
Wet Pavement	40%
8-30 Install Animal Fencing	
Animal Related	90%

9 - REGULATIONS	% Reduction
9-1 Eliminate Parking	
Parking Related	35%
9-2 Prohibit Turns	
Turning Accidents	45%
9-3 Modify Speed Limits	20%
9-4 Two-way to One-way Operation	30%