TP 12966E

Development of a Computerized Moving Vehicle Sizing System Using Imaging Technology

Prepared for
Transportation Development Centre
Safety and Security
Transport Canada

by
International Road Dynamics Inc.

December 1996

TP 12966E

Development of a Computerized Moving Vehicle Sizing System Using Imaging Technology

Authors:

Art Bergan, IRD
Brian Taylor, IRD
Aman Kishore, IRD
John Fung, Constance Consultants

International Road Dynamics Inc.
702 43rd Street East
Saskatoon, Saskatchewan
S7K 3T9

December 1996

This report reflects the views of the authors and not necessarily those of the Transportation Development Centre.

Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 12966E	2. Project No. 8689	3. Recipient's Catalogue No.
4. Title and Subtitle Development of a Computerized Moving Vehicle Sizing System Using Imaging Technology		5. Publication Date December 1996 6. Performing Organization Document No.
7. Author(s) Art Bergan, Brian Taylor, Aman Kishore, and John Fung		8. Transport Canada File No. ZCD1465-638
9. Performing Organization Name and Address International Road Dynamics Inc. 702 43rd Street East Saskatoon, Saskatchewan S7K 3T9		10. PWGSC File No. XSD94-00318-(651) 11. PWGSC or Transport Canada Contract No. T8200-4-4561/01-XSD
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West 6th Floor Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final 14. Project Officer L. Sabounghi

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

In 1995, International Road Dynamics Inc. (IRD) was contracted by the Transportation Development Centre to develop and test a computerized system to measure speeds and dimensions of moving vehicles using video imaging technology, and to demonstrate its application and integration with the existing Heavy Vehicle Electronic Licence Plate (HELP) Project. Such a system would be a tremendous asset for traffic engineering, highway planning and tracking of vehicles in critical situations.

Different technologies which could be used for measuring speeds and dimensions of moving vehicles were identified and investigated. Each of these technologies was further evaluated for possible development into a vehicle dimensioning system.

The initial results showed that systems employing laser and microwave technologies are not sufficiently price-competitive but devices employing video imaging technology hold great promise. Subsequent investigation into video imaging technology formed the basis for the V-DIM (Video Dimension-In-Motion) system development. Two complete engineering prototypes of the V-DIM system were developed and field tested. Test results showed consistent width and speed measurements of moving vehicles.

The V-DIM system has indicated good performance in the areas of presence detection, speed detection and width measurement, with the potential for effective length measurement. It provides functionality and capabilities beyond those achievable with other existing technologies at comparable prices. The V-DIM system is definitely an important step in applying technology to develop new solutions to traffic management problems.

17. Key Words V-DIM (Video Dimension-In-Motion), highways, technology, development, vehicle	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	x, 32	—

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada
TP 12966E

2. N° de l'étude
8689

3. N° de catalogue du destinataire

4. Titre et sous-titre

Development of a Computerized Moving Vehicle Sizing System Using Imaging Technology

5. Date de la publication
Décembre 1996

6. N° de document de l'organisme exécutant

7. Auteur(s)
Art Bergan, Brian Taylor, Aman Kishore et John Fung

8. N° de dossier - Transports Canada
ZCD1465-638

9. Nom et adresse de l'organisme exécutant
International Road Dynamics Inc.
702 43rd Street East
Saskatoon, Saskatchewan
S7K 3T9

10. N° de dossier - TPSGC
XSD94-00318-(651)

11. N° de contrat - TPSGC ou Transports Canada
T8200-4-4561/01-XSD

12. Nom et adresse de l'organisme parrain
Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
6e étage
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée
Final

14. Agent de projet
L. Sabounghi

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

16. Résumé

En 1995, le Centre de développement des transports confiait à International Road Dynamics Inc. (IRD) le projet de mettre au point un système informatisé de mesure des dimensions et de la vitesse de véhicules en mouvement mettant en oeuvre la technologie de l'imagerie vidéo, et d'en faire la démonstration dans le cadre du programme d'immatriculation électronique des véhicules lourds (PIEVL). Ce système serait d'une grande utilité dans la gestion du trafic, la planification du tracé des routes et la localisation de véhicules en situations critiques.

Les travaux ont commencé par une recherche sur les technologies pouvant être appliquées à la mesure des dimensions et de la vitesse de véhicules en mouvement. Chacune de ces technologies a été évaluée en vue de l'application considérée.

Suite à cette première analyse, les systèmes reposant sur les technologies laser et hyperfréquences ont été jugés trop coûteux et ont été écartés. La technologie de l'imagerie vidéo paraissait plus prometteuse. La recherche sur cette technologie a donc été approfondie pour la mise au point du système V-DIM (Video Dimension-In-Motion). Deux prototypes expérimentaux du système ont été construits et essayés en service. La précision des mesures de la largeur et de la vitesse des véhicules en mouvement s'est avérée constante.

Le système V-DIM a donné un bon rendement quant à la détection de la présence et la mesure de la largeur et de la vitesse des véhicules en mouvement, et a montré du potentiel quant à la mesure de la longueur des véhicules. Le système V-DIM offre des possibilités supérieures à celles des autres systèmes existants, à un coût comparable. Il marque très sûrement un important progrès dans l'application de technologies à la résolution des problèmes de la circulation.

17. Mots clés
V-DIM (Video Dimension-In-Motion), autoroutes, technologie, mise au point, véhicules

18. Diffusion
Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	x, 32	—

EXECUTIVE SUMMARY

This project was initiated in February 1995 by International Road Dynamics Inc. (IRD) following the acceptance of an unsolicited proposal to the Transportation Development Centre of Transport Canada to develop a computerized system to measure speeds and dimensions of moving vehicles using video imaging technology and demonstrate its application and integration with the existing Heavy Vehicle Electronic Licence Plate (HELP) Project. IRD developed a video imaging system, the V-DIM (Video Dimension-In-Motion) system, into an accurate, reliable, low-cost, multi-purpose system to be used in traffic engineering and planning applications. In the development of the V-DIM system, certain aspects of its design and its multi-purpose intent have shown the potential for an interesting application in tracking vehicles in critical situations. The tracking of a specific vehicle is possible based on its vehicle profile dimensions, its colour pattern and the colour depth in its image processing.

The objective of this research project was to develop a non-intrusive computerized device or system to measure speeds and dimensions of vehicles in traffic. The system would:

- reliably determine the speeds and dimensions of moving vehicles,
- be a low-cost and non-intrusive detection system, and
- operate in all environments under normal ambient and lighting conditions.

Research for the project included identification and investigation of existing technologies and devices for measuring speeds and dimensions of moving vehicles. Commonly employed technologies for non-intrusive vehicle detection included laser, microwave and video imaging technologies.

Each of these technologies was evaluated for possible application development into a vehicle dimensioning system. In each case the evaluation process examined equipment costs, use of materials, achievable measurement accuracies, reliability, ease of installation, maintenance and operational requirements.

Initial results of the evaluation process indicated that devices/systems employing laser and microwave technologies were not sufficiently price-competitive to warrant further investigation, but that devices/systems using video imaging technology held promise. Subsequent investigations into video imaging technology formed the basis for the V-DIM system development.

Two engineering prototypes of the V-DIM system were developed and field tested. Test results showed consistent width and speed measurements of moving vehicles. However, accurate length

measurements of moving vehicles were not consistently achievable; therefore, more development work needs to be done to refine length measurement algorithms to yield consistent results.

In summary, the V-DIM system has been developed and shown with the features of vehicle detection typical of other traffic sensing detectors, as well as a number of additional features, including length and width measurements. Tests of the V-DIM system have indicated good performance in the areas of presence detection, speed detection and width measurement, with the potential for effective length measurement. The V-DIM technology provides functionality and capabilities beyond those achievable with other existing technologies at comparable prices. The V-DIM system is an important step in applying technology to develop new solutions to traffic management problems.

SOMMAIRE

Ce projet a été lancé en février 1995 suite à une proposition spontanée présentée au Centre de développement des transports de Transports Canada par International Road Dynamics Inc. (IRD). Il avait pour objet la conception d'un système informatisé de mesure des dimensions et de la vitesse de véhicules en mouvement faisant appel à l'imagerie vidéo, et sa démonstration expérimentale dans le cadre du projet d'immatriculation électronique des véhicules lourds (PIEVL). Le système mis au point par IRD, appelé V-DIM, est un système précis, fiable et économique, se prêtant à de multiples applications en technique de la circulation. Certaines caractéristiques du système ainsi que son caractère polyvalent permettent d'envisager notamment son application à la localisation de véhicules en situation critique. Il serait possible en effet de localiser un véhicule d'après ses dimensions, ses couleurs et la profondeur des couleurs de l'image vidéo obtenue.

L'objet de cette recherche était donc de concevoir un appareil ou un système informatisé permettant de mesurer sans intervention aucune du conducteur ou d'un contrôleur, les dimensions et la vitesse d'un véhicule dans un courant de circulation. Cet appareil ou système devait :

- être capable de déterminer de façon précise et fiable les dimensions et la vitesse d'un véhicule en mouvement;

- être peu onéreux et non intrusif;

- être fonctionnel dans toutes les conditions normales d'utilisation (conditions ambiantes, éclairage, etc.).

Les travaux de mise au point ont été précédés d'une recherche sur les appareils et les technologies déjà employés dans la mesure des dimensions et de la vitesse des véhicules en mouvement. Les technologies laser et hyperfréquences et l'imagerie vidéo sont au nombre des technologies couramment appliquées à la détection automatique des véhicules.

Chacune de ces technologies a été évaluée en vue de l'application considérée. Elles ont été examinées du point de vue du coût des équipements, des matériels requis, de la précision autorisée, de la fiabilité, de la facilité de mise en oeuvre et des exigences d'entretien et d'exploitation.

Suite à cette première analyse, les appareils et systèmes reposant sur les technologies laser et hyperfréquences ont été jugés trop coûteux et ont été écartés. La technologie de l'imagerie vidéo paraissait plus prometteuse. La recherche sur cette technologie a donc été approfondie pour la mise au point du système V-DIM.

Deux prototypes expérimentaux ont été construits et essayés en service. La précision des mesures de la largeur et de la vitesse des véhicules en mouvement s'est avérée constante. Par contre, les mesures de la longueur des véhicules n'étaient pas toujours aussi précises. Les algorithmes de mesure de la longueur des véhicules en mouvement doivent donc être affinés.

En somme, le système V-DIM possède les fonctions courantes de détection des véhicules et diverses autres fonctions, dont la mesure de leurs dimensions. Les essais en service ont donné de bons résultats quant à la détection de la présence et la mesure de la largeur et de la vitesse des véhicules en mouvement et ont révélé un potentiel quant à la mesure de la longueur des véhicules. Le système V-DIM offre des possibilités supérieures à celles de tous les autres systèmes existants, à un coût comparable. Il marque un progrès important dans l'application de technologies à la résolution des problèmes de la circulation.

CONTENTS

		Page
Chapter 1	Introduction	1
1.1	Background	1
1.2	Research Objective	3
1.3	Scope of Research	3
1.4	Methodology	4
1.5	Structure of Report	5
Chapter 2	Moving Vehicle Sizing System Technologies	6
2.1	Introduction	6
2.2	Background	6
2.3	Comparison Among Technologies	6
2.4	V-DIM Technology	7
Chapter 3	Development of a Computerized Moving Vehicle Sizing System Using V-DIM Technology	8
3.1	Introduction	8
3.2	Specifications/Requirements	8
3.3	Development Stages	10
3.3.1	Stage 1 - Proof of Concept	10
3.3.2	Stage 2 - Development of Prototypes	11
3.3.3	Stage 3 - Preproduction Design	13
3.4	System Operation	14
3.4.1	Calibration	14
3.4.2	Background Accumulation	14
3.4.3	Vehicle Monitoring	15
3.5	Proof of Concept Testing	17
3.5.1	Test Methodology	17
3.5.2	Truthing	17
3.5.3	Conclusions	20
Chapter 4	Field Testing of the IRD V-DIM System	21
4.1	Introduction	21
4.2	Prototype Field Tests	21
4.3	Summary of Development and Tests	27
4.4	Conclusion	28
Chapter 5	Summary and Conclusions	29
5.1	Project Summary	29
5.2	Future System Research and Development	30

LIST OF TABLES

Table 1 :	Effect of lighting conditions on the accuracy of measurements	18
Table 2 :	Repeatability tests from a stream of free flow traffic (Milton)	22
Table 3 :	Repeatability tests on randomly selected vehicles (Milton)	23
Table 4 :	Repeatability tests on two vehicles of known dimensions (Milton)	24
Table 5 :	Repeatability tests on vehicles of known dimensions	25
Table 6 :	Tests on two passenger vehicles of different dimensions (Mississuaga)	25

LIST OF FIGURES

Figure 1 :	Imaging situation with camera at 90° to road, showing views both across and along the direction of traffic flow	16

LIST OF ACRONYMS

V-DIM	Video Dimension-In-Motion
WIM	Weigh In Motion
AVI	Automatic Vehicle Identification
HELP	Heavy Vehicle Electronic Licence Plate
CVO	Commercial Vehicle Operation
AVC	Automatic Vehicle Classification
CCD	Charged Coupled Device
PCI	Peripheral Component Interface
CRT	Cathode Ray Tube
CMVS	Computerized Moving Vehicle Sizing
ASIC	Application Specific Integrated Circuits
DSP	Digital Signal Processor

Chapter 1 INTRODUCTION

1.1 Background

Following government regulations, laws and Traffic Acts which govern weights and dimensions of heavy vehices in Canada and the US, and also to ensure public safety and enforce permit regulation and dimension adherence, there are definite needs for dimension measurements by government transportation agencies. However, there are presently no commercially available devices/equipment which are inexpensive to install, economical to operate, effective and efficient to perform dimensions and speed measurements of moving vehicles. This has led to a number of innovative approaches to measuring techniques and innovations of measuring devices and systems in this field.

Traditionally, in-pavement sensors are necessary components of traffic control and transport management systems. In-pavement sensors include magnetic inductive loops, weight sensors (weighing pads) and axle sensors. In high traffic areas, the installation and replacement of in-pavement sensors is either very costly or sometimes not practical. Thus, for reasons of economy and practicality, many government traffic and transportation agencies have shown a keen interest in non-intrusive traffic sensing and dimensioning systems.

V-DIM (Video Dimension-In-Motion) is the product name given by International Road Dynamics Inc. (IRD) in the development of the Computerized Moving Vehicle Sizing system under this research project.

The V-DIM's ability to provide unique vehicle profiles including colour pattern makes it a valuable tool for tracking vehicles in critical situations. Bridges and tunnels are areas of high liability for heavy trucks and trucks carrying toxic or dangerous goods. Stalled vehicles and accidents may present dangerous situations in the presence of these trucks. Tunnels present the added possibility of fires, which may reduce visibility and result in fatalities due to smoke. It is important that any accident occurring on a bridge or in a tunnel be detected as quickly as possible, so that traffic management measures can be taken to minimize further incidents and emergency response can occur quickly. To ensure public safety, a series of V-DIM cameras can be used to track the movement of specific vehicles (heavy trucks, etc.) through the tunnel or bridge to safeguard public safety.

The operating efficiency of a weigh station can be improved with automation. Weigh station automation generally includes the installation of a Weigh In Motion (WIM) system and sometimes an Automatic Vehicle Identification (AVI) system. A WIM system provides compliance check of a vehicle's weights according to its classification. An AVI system provides compliance check of a vehicle's credentials according to its registration information. When both WIM and AVI systems are installed in a weigh station a complete compliance check of a vehicle's weights, configuration, and credentials can be made in real time and a decision is made as to whether the vehicle should report to the weigh station for static weighing and credential checking. However, one important element of this compliance check is missing from these existing systems. The only vehicle dimensions being accurately monitored are the axle spacing and whether the vehicle is over a certain height limit. The V-DIM system can complete the compliance check by providing a full vehicle profile, including width and length, and potentially the height measurements.

The development of a low-cost, non-intrusive, consistent dimensioning system could greatly increase the efficiency of weigh station automation and hence the effectiveness of weights and dimensions monitoring activities. Weigh stations are essential to a weight and measures program. An effective weight and measures program reduces pavement damage due to overloading and ensures compliance by motor carriers with regulations, permits and licensing requirements. Compliance instills fairness to competition and promotes efficiency by competitors.

The economy of a nation is affected by the state of its road infrastructure. An effective weight and measures program contributes beneficially to both users and providers of the infrastructure, and thus the economy of a nation. Weigh station automation contributes to the operating efficiency of the trucking industry in that compliant vehicles do not have to stop in weigh stations en route, thus resulting in savings in transportation costs which may be passed onto the consumers for the transported goods. Weight and measures compliance by the motor carriers contributes to the operating efficiency of the infrastructure in that less overloading conditions are present to cause pavement damage, thus reducing the amount of public funds required to sustain the serviceability of the infrastructure.

IRD has been actively involved in the implementation of weight and measures programs for many nations including Canada and the US for the last 16 years. With its qualifications, expertise and experiences in the transportation systems, IRD was contracted by the Transportation Development Centre of Transport Canada to develop a low-cost, non-intrusive, video image based system for moving vehicle dimensioning application as set out in the objective of the project. The system is to have the capability to successfully operate in all regions and conditions typically experienced in Canada.

1.2 Research Objective

The objective of this proposal was to complete the development of a computerized imaging system for dimensions measurement of moving vehicles. The system was to be non-intrusive, consistent, and economical. It was to be targeted to achieve an overall accuracy of ±150 mm for width and length measurements. It should be possible to deploy the developed system for field installation as an enhancement to the roadside Heavy Vehicle Enforcemnt {Heavy Vehicle Electronic License Plate (HELP)} program.

1.3 Scope of Research

The scope of the proposed work included the following:

- Transformation and extension of the original design and algorithms, both hardware and software, into a system suitable for field installation.
- Evaluation of the potential for commercialization of the proposed system and its viability for custom manufacturing.
- Development of the system into a stand-alone, field installable and serviceable device with minimum procedures.
- Designing the system to measure all types of vehicles at all normal travel speeds.
- Designing the system to operate consistently in severe environmental conditions and under normal ambient and lighting conditions.
- Development of the system using non-intrusive sensing technology.
- Development of the system to be economical, cost effective, and with minimum requirements for maintenance and service.

1.4 Methodology

In accordance with the objective and scope of this research, the following methodology was employed:

- Based on results from previous design work done on demonstrating the concept and feasibility of the product, the functional and performance requirements of the proposed video imaging system were revised.

- Based on the revised functional and performance requirements, hardware and software for the proposed video imaging system were developed. The product was designed as a stand-alone computer-based field installable device.

- The developed hardware and software were integrated into a single package prototype which was then tested in-house to verify functional performance.

- The developed prototypes were installed at field locations for operational trials. Field trial results were compiled and analyzed. A preliminary market research study was conducted to assess the potential for commercialization.

- Results from the field trials and investigations for sales potential and market size were evaluated, summarized and documented.

1.5 Structure of Report

Chapter 1 provides an introduction and summary of background information for the development of a moving vehicle sizing system. Included is a summary of the research objective, scope, methodology and performance specifications that were followed for the development of the V-DIM system.

Chapter 2 presents a comprehensive summary of available technologies for the development of a moving vehicle sizing system. The benefits and drawbacks associated with each technology are examined. The preferred technology and components of the V-DIM system are documented.

Chapter 3 presents requirements of the system and describes the phases in the development of the computerized moving vehicle sizing system based on the preferred technology.

Chapter 4 summarizes and presents the results obtained from detailed field tests of the moving vehicle sizing system developed and employed at different locations in North America.

Chapter 5 summarizes and presents the conclusions obtained from field tests performed on the moving vehicle sizing system prototype developed in the research. Areas of future research and development for the improved performance of the system are identified.

Chapter 2 MOVING VEHICLE SIZING SYSTEM TECHNOLOGIES

2.1 Introduction

Technologies most widely employed for the CVO application include WIM (Weigh-In-Motion), AVI (Automatic Vehicle Identification) and AVC (Automatic Vehicle Classification). All these technologies are dedicated to perform some type of measurement or identification functions on moving vehicles. But none of the technologies can be used effectively to measure dimensions of moving vehicles. Specifically, these measurements cannot be made with consistently accurate results.

2.2 Background

At the present time, moving vehicles are measured for length and classified for type using a combination of magnetic loop detectors and axle sensors. Depending on the mass, shape, chassis construction and chassis height, it is difficult to make consistently accurate length measurements of a moving truck. Loops and axles sensors are installed in the pavement, and in high traffic areas their installation and replacement costs are quite high and sometimes not practical. For reasons of economy and practicality, many government and transportation agencies have been looking for non-intrusive means to perform dimension measurements and traffic monitoring. Such non-intrusive means typically include systems or devices operating on laser, microwave or imaging technologies.

2.3 Comparison Among Technologies

Non-intrusive measurements usually need to perform profiling processes on objects. Laser technology can be applied for dimension measurements and classification of vehicles. However, profiling of moving 3-dimensional objects with laser technology requires complex scanning processes and electronics. The equipment cost for a laser system is expensive and its general use for traffic/vehicle monitoring application is at least economically questionable. Microwave technology can be employed quite effectively for traffic monitoring applications, but it would not be cost effective for applications requiring accurate dimension measurements and classification of vehicles.

Significant advances in optics and digital processors have meant the evolution of imaging technology into a stable and sophisticated technology that presents promising potential for non-intrusive measurement applications.

Imaging technology is preferred for dimensions measurements because it is less complicated and less costly than laser technology, and it offers more precise dimension information than microwave technology. The low lighting level requirement by advanced optics also enhances the suitability of imaging technology for most vision-based applications.

2.4 V-DIM Technology

Image processing technology is employed in the development of the V-DIM. A Charged Coupled Device (CCD) video camera is used to capture the images of moving vehicles on a roadway. The acquired images are then digitally processed frame-by-frame in a computer.

The V-DIM is a vision-based system and hence a non-intrusive type of vehicle detection system. It "watches" the roadway for "a change of scenery" to determine the presence of a vehicle, and employs mathematical computations to continuously monitor and adapt to the background image of the roadway. It "learns" what the roadway should look like at any time when there is no vehicle present. The V-DIM does not require distinctive lane markings to mark the zone of detection.

Similar in some aspects to many currently available video systems for vehicle detection, the V-DIM system employs the principle of edge detection to locate the object of interest in an imaged frame. However, the V-DIM system is quite different from other currently available video systems in both application and processing techniques. In addition to detecting vehicle presence and speed, the V-DIM system is intended for measuring dimensions and in future application tracking moving vehicles. Rather than isolating individual pixels of an image for processing, the V-DIM system processes edge points by sampling these points into multiple subsets and comparing the alignment of these subsets to a best fit edge shape.

A V-DIM system consists of two separate units: a video camera and a controller. The video camera unit is a miniature 12.7 mm. CCD with auto iris and CS mounted wide angle lens. The controller is a self-contained, PCI bus, industrial single board computer with flash semiconductor disk, RS-232 serial interface, keyboard and monitor interfaces, and a passive backplane. The video output from the camera is connected to the controller unit via a co-axial cable. The processed information is stored locally in the controller and is retrievable either locally with the attachment of a CRT terminal, or remotely with another computer via the RS-232 interface. Operating parameters of the controller can be set either locally or remotely by similar arrangements.

Chapter 3 DEVELOPMENT OF A COMPUTERIZED MOVING VEHICLE SIZING SYSTEM USING V-DIM TECHNOLOGY

3.1 Introduction

The Computerized Moving Vehicle Sizing (CMVS) device was developed for measuring the width and length of trucks traveling at highway speeds under normal ambient and lighting conditions.

Development was carried out in three stages:

Stage 1 - Proof of Concept

Stage 2 - Development of Protoypes

Stage 3 - Preproduction Design

3.2 Specifications/Requirements

Common to all three stages of product development, the CMVS device was to be capable of:

- measuring the width and length of any vehicle traveling at speeds up to 160 km/hr (100 mph) to within 150 mm (6 inches) accuracy of actual values in overall dimension measurements.
- using single camera (image sensor) for capturing images.
- measuring the speed of any approaching vehicle using two consecutive images.
- measuring the speed of any departing vehicle using two consecutive images.

- processing the images of a vehicle and determine its length based on the average speed of the vehicle entering and leaving the field-of-view location.

- measuring the speed of a vehicle to within 2 km/hr (1.2 mph) accuracy of actual value in speed measurement.

- performing accurate dimensions (width and length) and speed measurements under prevailing ambient lighting conditions except during heavy rain and snow storms.

- performing accurate measurements of platooning vehicles.

3.3 Development Stages

3.3.1 Stage 1 - Proof of Concept

The following functional requirements were used in this stage of product development:

- Apply proof of concept to at least three vehicles of each type, including 2-axle, 3-axle, 4-axle, 5-axle, 6-axle and 7-axle vehicles.
- Capture images at different times of the day to represent different lighting conditions.
- Capture images for analysis on video tapes from a truss bridge at a weigh station or from an overpass bridge.
- Digitize segments of the video tape for a vehicle into an image file which will be processed.
- Develop application programs to be to automatically process images of a vehicle to produce dimensions and speed measurements.
- Verify accuracy of the measurements.
- Demonstrate functions of the application programs and the operation of the CMVS device.
- Finally, evaluate the success of the concept, and assess performance and other requirements.

3.3.2 Stage 2 - Development of Prototypes

The following activities were performed in this stage of product development:

- Two prototypes were developed which were assembled from off-the-shelf hardware without the need for expensive and extensive custom components. Each prototype consisted of two separate units; a camera unit and a controller unit.

- The camera unit and the controller unit of the prototype were individually designed to be self-contained, stand-alone devices complete with all components, accessories, power supplies and electronics.

- The prototype was designed with minimally sized, commercially available circuit boards, modules and components and packaged into commercially available housings suitable for outdoor installation.

- The operating temperature range of the prototype was tested from -30°C to 50°C.

- The prototype was designed to be portable for installation at different demonstration/evaluation sites throughout North America.

- The prototype was designed for displaying measurement outputs on a remote PC through RS-232/422 interface and modem/direct connection. Tests were done using radio modems and directional antennas for communications between the prototype and a remote PC.

- The prototype was designed with parameter setting features to accept user inputs to set or adjust operating parameters to suit individual site-specific conditions. These parameters included mounting angles (down to road and across lane) height and position (offset from lane centre) of the camera unit relative to the pavement surface, the latitude and hemisphere of the test site, time and date of data collection, and measurement units for speed, width and length.

- The prototype was designed to accept programming changes to preset reference parameters which were used in measurement calculations. Programming changes to these reference parameters were secured by password.

- Except for the initial efforts by a user to set/adjust operating parameters, the prototypes were designed to operate automatically upon power-on. During the tests, however, image processing and dimension calculations were initiated manually by starting the measurement program and setting the duration of data collection and processing.

- For each vehicle passing through the camera detection zone, a single line display was presented. The displayed line showed time, speed, width and length of the passing vehicle.

- The prototype was designed with sufficient flexibility in the software design to allow for future changes and growth, such as switching to or adding different applications like vehicle classification, left/right turn speed, placard location, placard content recognition, and chassis vertical travel distance.

- The prototype was developed with sufficient processing power and flexibility in the hardware design to support multiple lane operation and/or to switch to different applications.

- The prototypes were tested at different sites, at different times and for different traffic and lighting conditions.

Independent of the technical development work, IRD has endeavoured to pursue a Market assessment effort. This was not covered by the Research project even though it was done by IRD.

Marketing efforts were initiated to commercialize the CMVS device. The marketing plan included the designation of the CMVS device as an IRD product under the name of V-DIM, the making of sales brochure for the V-DIM system, and the acceptance of inquiries on the product by prospective customers.

A number of inquiries were received for applying the V-DIM system to different applications. These applications centred on the adaptation of the imaging technology and the extension of the operating features of the V-DIM system. Although these applications had been identified in the plan for future development of the V-DIM system, they were not immediately available at the time.

3.3.3 Stage 3 - Preproduction Design

Based on the result of the market assessment and prototype tests, a preliminary engineering plan was prepared for preproduction of the CMVS device, or in IRD designation the V-DIM system. This engineering plan examined different options for hardware and software and for different applications. To assess these options, a checklist was drafted to identify the functional requirements of hardware and software for various applications. Preliminary cost/benefit analysis was performed on the merits of, or need for, customizations of hardware and software components of the V-DIM system.

Hardware customizations included:

- Transformation of the prototype into a DSP-based controller with ASIC (Application Specific Integrated Circuits) and DSP (Digital Signal Processor).

- Transformation of the camera unit of the prototype into a digital camera unit with on-board integrated DSP (Digital Signal Processor).

- Miniaturization of circuit boards and modules of the prototype through custom design and engineering.

Software customizations included:

- Creation of a custom kernel for the Operating System of the prototype.

- Porting of application programs into custom hardware devices.

3.4 System Operation

The CMVS system operates in three basic modes; calibration, background accumulation, and vehicle monitoring.

3.4.1 Calibration

The calibration is performed only when the system is initially set up and perhaps infrequently during the continuous operation of the system. During calibration, the camera and imaging parameters are entered into the system and a set of calculation reference parameters may also be entered. Calibration parameters include the following:

Parameters that must be set on-site:

- camera height
- camera orientation with respect to traffic
- background images of the road surface required
- verification of the field of view

Parameters that can be set on-site or off-site:

- system time
- lens distortion map
- compass orientation (only for certain situations)
- system location (approximate latitude/longitude, only for certain situations)

3.4.2 Background Accumulation

This is the default mode for the system. The CMVS will continuously acquire images and accumulate the background. Accumulation of the background images is simply a time-weighted average of the most recently acquired "non-vehicle" images. If, during background accumulation, an image is acquired that is sufficiently different from the background and that may represent the presence of a vehicle, the system switches to vehicle monitoring mode.

3.4.3 Vehicle Monitoring

When the system first detects the possible presence of a front edge of a vehicle, it seeks the exact location of the front edge in the first frame of monitoring, then checks subsequent frames to ensure that the image information is consistent with the presence of a vehicle. A vehicle should have a detectable front edge, two side edges, and should be moving in an appropriate direction.

Once the front edge has been detected and located, it is tracked in the subsequent frame(s). Vehicle speed is calculated from the front edge positions in consecutive frames and from the known time between frames and intra-frame exposure time. The side edges are detected in the first few images of the vehicle being tracked while monitoring the vehicle. The angle of each line segment and the distance between them are used to determine vehicle width, given vehicle speed. The width of the vehicle is taken as the maximum width detected over a portion of the length of the vehicle. The assumption was made that small protrusions such as side mirrors are not of interest.

Once presence of the back edge of the vehicle is detected, along with a discontinuance of the side edges, the back edge position is determined. The vehicle length is calculated from the relative positions of the front and back edges in their respective images and from the number of intervening images. Vehicle speed is again calculated, this time from the back edge position information. This serves as a validation of the front-edge speed calculation.

An illustration of the imaging environment is shown is Figure 1 for the case of a camera mounted at 90° to the road and viewing directly along the direction of traffic.

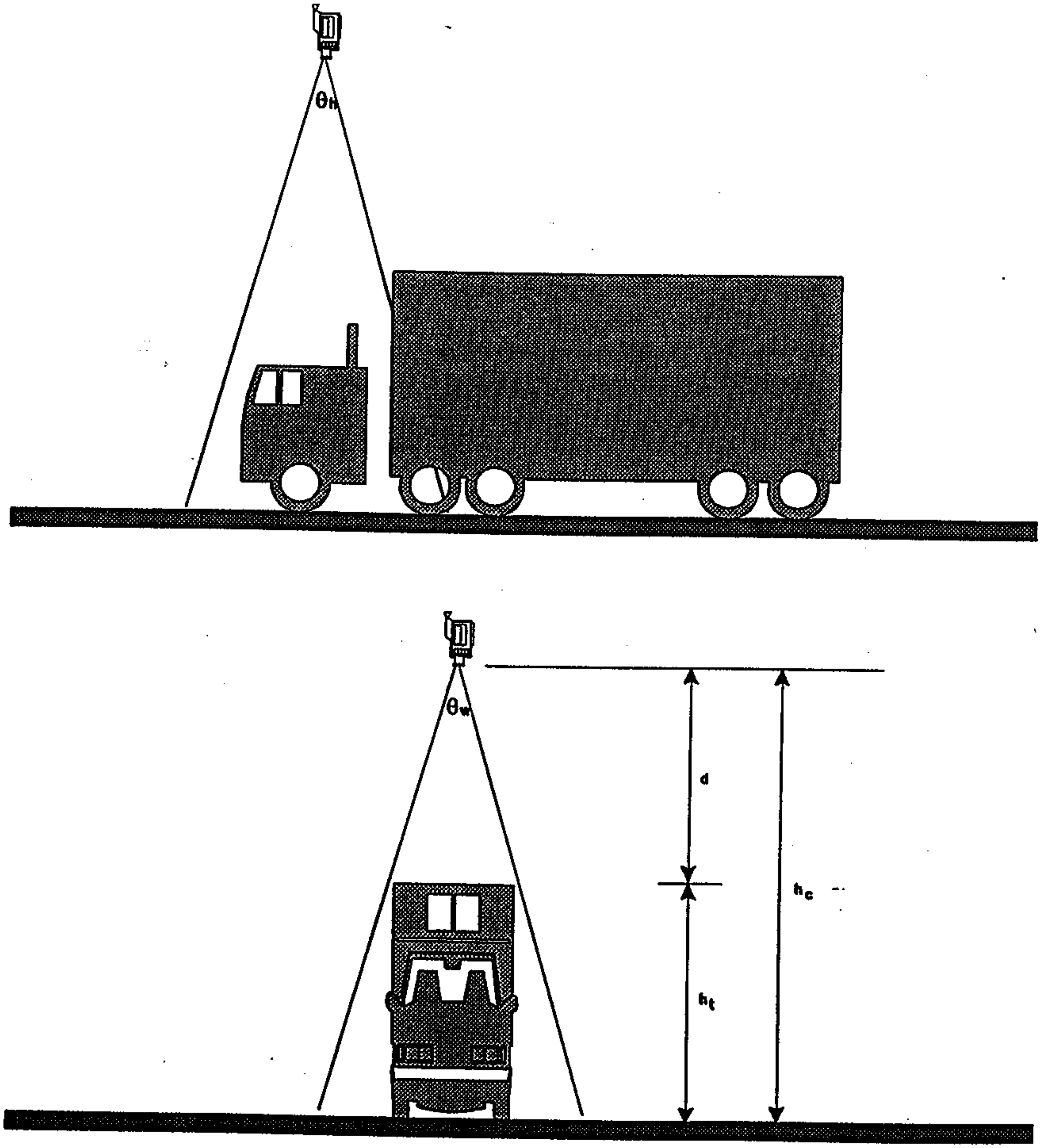

Figure 1. Imaging situation with camera at 90° to road, showing views both across and along the direction of traffic flow.

3.5 Proof of Concept Testing

3.5.1 Test Methodology

The algorithms developed for automated extraction of vehicle width, length, and speed were applied to the images of a variety of truck types under a set of four different lighting conditions. The large majority of tests were run with the camera at an angle of 54° to the road (from horizontal), with the center of the field of view aligned directly with arriving or departing traffic. A few tests were also run with the camera at 90° to the road. Preliminary "side-view" tests were run with the camera placed perpendicular to traffic flow. The camera field of view was generally set at about 42° horizontal by 32° vertical.

The lighting conditions for the test were chosen to provide a range of difficulties for the edge extraction part of the algorithm. Noon lighting was selected to test effects of glare. Afternoon and early morning lighting were used to generate side-shadow and back-shadow conditions, respectively. Imaging at dusk offered a test of edge extraction under low-contrast conditions.

The vehicles imaged ranged from extended-length passenger vans to 2- or 3-axle local delivery trucks to long tractor-trailer rigs. A couple of double-trailer rigs were also tested. Regular and flat-cab trucks, both those lighter and those darker than the road surface, were imaged. Trailers of white, silver, and dirtied road colour were all tested, as were flatbeds and car haulers with more complex loads.

Images were acquired at 30 frames/second with a resolution of 320×240 pixels on a PC computer with an Intel 486 processor.

3.5.2 Truthing

True values for the speed of target vehicles were determined by having a chase car driven alongside or behind a target vehicle and recording the speed of the chase car. Because this method would be impractical for all 140 of the vehicles processed at 54° to the road, we targeted vehicles traveling in platoons and assumed each of the vehicles in the platoon was traveling at approximately the same speed. The chase car approach was applied directly to 10 vehicles in 10 platoons. Those platoons contained a total of 32 vehicles. For the remainder of the imaged vehicles, truth was determined by manual frame-to-frame scoring of front-edge displacement.

True values for vehicle length and width were found by imaging known vehicles, trucks whose source depot was readily identifiable. We directly measured 18 types of trucks, from large vans to medium-sized local delivery to large UPS semis. These truck types accounted for some 37 of the vehicles imaged. For the remainder of imaged vehicles, truth was determined by manually scoring target images.

Other camera mounting positions and arrangements were also tested. For the side-mounting camera, the side-view images were assigned truth in a way similar to that for the overhead, 54° to road images: 2 vehicles in 2 platoons having 5 total vehicles, were accompanied by a chase car. The remaining vehicles were truthed manually. For top-mounting camera directly on top of traffic flow, images acquired at 90° to the road all had truth set from manual scoring.

Results at 54° to Road

Edge Extraction Performance:
Camera angle: 54° to road
Field of View: 42° (h) × 32° (v)
Entries represent the number of vehicles with all edges detected/total number of vehicles

Table 1 Effect of lighting conditions on the accuracy of measurements

lighting/vehicle	**Double**	**Large**	**Medium**	**Small**
noon		6/6	6/6	6/6
side shadow	2/2	13/15	14/15	15/15
back shadow		14/15	15/15	15/15
dim light		11/11	11/11	6/8

Accuracy of Measurements:

Front/Back Edge:	8 cm	± 2.7 cm
Length:	12 cm	± 3.4 cm
Speed:	2.4 km/h	± 0.4 km/h
Width:	11 cm	± 3.2 cm

Results at 90° to Road

Edge Extraction Performance:
Camera angle: 90° to road
Camera height: 5.8 metres
Focal Plane: road surface
Estimated Field of view: 42° (h) × 32° (v)
Entries represent # vehicles with back and front edge detected / # vehicles

lighting/vehicle	**Large**	**Medium**	**Small**
back shadow	25/25	6/6	1/1

Accuracy of Measurements:
Front/Back Edge: 3 cm ± 2.1 cm

Note: For the 90° tests, no absolute truth was available, so accuracy is with respect to manual scoring of the video.

Results for Side View

Edge Extraction Performance:
Camera angle: Side view, 30° to road
Entries represent # vehicles with back and front edges detected / # vehicles

lighting/vehicle	**Large**	**Medium**	**Small**
back shadow	4/4	3/3	1/1

Entries represent # vehicles with both side edges detected / # vehicles

lighting/vehicle	**Large**	**Medium**	**Small**
back shadow	3/4	3/3	0/1

Mean Error of Measurements:
Front/Back Edge: 9 cm
Length: 12 cm
Speed: 2 km/h
Width: 12 cm

Note: The side view tests are considered preliminary. For these tests, we simply applied the algorithms developed for the along-traffic direction trails. With some modifications, we expect the performance of the algorithm in picking out side edges to improve sharply. In addition, though we set the camera angle to be similar to that for imaging vehicles from a camera mounted on a light pole off the side of highway, our viewing distance for the trials was much longer. A closer viewing distance would give much better accuracy for all measurements.

3.5.3 Conclusions

A single-camera imaging system can be implemented to automatically detect highway vehicles and measure their width, length, and speed. Imaging along the direction of traffic or straight down towards the vehicles allows reliable and accurate measurement of vehicle dimensions and speed. Initial trials using a view perpendicular to traffic indicate good accuracy, though more such trials are required to develop side-edge identification and test the imaging robustness over a wider variety of vehicles.

Chapter 4 FIELD TESTING OF THE IRD V-DIM SYSTEM

4.1 Introduction

Tests were conducted at three locations: in Boston from a highway overpass; in a weigh station in Milton near Toronto, Ontario; and at the parking lot of IRD office in Mississauga, Ontario. These tests were intended to investigate the accuracy and repeatability of the dimension measurements processed by the V-DIM system under different ambient and traffic conditions. The Boston and Mississauga tests were controlled tests of selected vehicles whereas the Milton tests were free flow traffic tests.

4.2 Prototype Field Tests

<u>Boston Tests</u>

The tests were conducted primarily to verify the results previously recorded in the Proof of Concept Testing. Other tests and simulated tests were conducted in Boston to duplicate performance deficiencies as experienced with the prototype while on field tests in Ontario.

<u>Milton Tests</u>

The Milton weigh station is large with a race-track design, three traffic lanes in the station proper, and automation systems for traffic control, permit/licence verification, and weight enforcement. Tests were conducted at two locations in the Milton weigh station; one location at the station entrance area, and the other location downstream from the station control building.

At the station entrance area, after trucks enter the station from the Hwy 401, they are split into two lanes. The inside lane is intended for trucks carrying loads to be sorted by a high-speed WIM (Weigh-in-Motion) system to enter into one of two lanes. The camera was mounted on a changeable message sign truss which is 50 m downstream from the traffic split. The tests were run with the camera mounted at 5.6 m above the road and set at an angle of 90° from horizontal, with the center of the field of view aligned directly with arriving or departing traffic. The traffic of loaded trucks was recorded on a videotape.

The images recorded on the videotape were fed into the V-DIM system for measurement analyses. The tape contained recorded images of two hours of noon-time traffic, two hours of late afternoon traffic, and 45 minutes of traffic from dusk to evening darkness. The ambient condition was sunny during the day. Traffic was moving from west to east.

Three sixty-minute segments of the tape were processed three times by the V-DIM system. Table 2 illustrates test results of repeatability of measurements from a stream of free flow traffic under various lighting conditions.

Table 2 Repeatability tests from a stream of free flow traffic (Milton)

Ambient/ Lighting Condition	Number of Vehicles Processed	Standard Deviation of Speed Measurements	Standard Deviation of Length Measurements	Standard Deviation of Width Measurements
Sunny, noon hours, no shadows	115	2.0 km/h	250.8 cm	11.9 cm
Sun setting, long shadows almost 50% length of vehicle	115	5.2 km/h	512.8 cm	21.1 cm
Dusk, glare on pavement from oncoming headlights	115	3.1 km/h	229.1 cm	10.6 cm

Vehicles were randomly selected from two of these three sixty-minute segments of the tape and processed repeatedly by the V-DIM system. Table 3 illustrates test results of repeatability of measurements of randomly selected vehicles from a stream of free flow traffic:

Table 3 Repeatability tests on randomly selected vehicles (Milton)

Ambient/ Lighting Condition	Randomly Selected Vehicle Number; (Number of Times Processed)	Standard Deviation of Speed Measurements	Standard Deviation of Length Measurements	Standard Deviation of Width Measurements
Sunny, noon hours, no shadows	#1 ; (50) #2 ; (22)	0.6 km/h 0.5 km/h	42.5 cm 35.8 cm	3.9 cm 4.1 cm
Sunny, early afternoon, some shadows	#3 ; (20) #4 ; (20) #5 ; (20) #6 ; (20)	0.9 km/h 0.6 km/h 1.3 km/h 1.9 km/h	100.6 cm 69.9 cm 97.7 cm 179.2 cm	4.0 cm 4.1 cm 3.7 cm 4.0 cm
Sunny, mid afternoon, sun starting to set, long shadows	#7 ; (20) #8 ; (20)	0.7 km/h 1.6 km/h	51.1 cm 117.9 cm	3.9 cm 4.2 cm
Late afternoon, sun setting, long shadows of 50% of vehicle length	#9 ; (20) #10 ; (20)	0.8 km/h 1.0 km/h	65.2 cm 90.2 cm	3.1 cm 4.0 cm

At the location downstream from the station control building, traffic moves in three lanes; the outside lane for trucks not carrying any load, the centre lane for trucks carrying loads but directed by the WIM system to bypass, and the inside lane for trucks carrying loads but directed by the WIM system to enter the static scale lane for further investigation. There is a truss bridge 15 m downstream from the station control building and spanning the three lanes. For tests conducted at this location, the camera was mounted on this truss bridge centering to the inside lane and directly above it. The camera height was 5.4 m above the road and set at an angle of 90° from horizontal, with the center of the field of view aligned directly with arriving or departing traffic. Video images of traffic on this lane were transmitted in real time to the controller unit of the V-DIM system via coaxial cable.

Speed measurement accuracy and repeatability tests were not performed since from previous tests they have been established as satisfactory. Length and width tests were conducted with two vehicles of known dimensions, a passenger vehicle (vehicle #1) and a pickup truck (vehicle #2). Table 4 illustrates test results of repeatability of these two vehicles:

Table 4 Repeatability tests on two vehicles of known dimensions (Milton)

Ambient/ Lighting Condition	Vehicle #;Run # (Number of Passes)	Average Vehicle Speed	Standard Deviation of Length Measurements	Standard Deviation of Width Measurements
Sunny, no wind, late afternoon, long shadows	#1;1 (5) #1;2 (6) #1;3 (7)	55 km/h 51 km/h 54 km/h	66.1 cm 31.6 cm 12.7 cm	10.2 cm 6.9 cm 2.0 cm
Sunny, occasional clouds, early afternoon, some shadows	#1;4 (6) #1;5 (6) #1;6 (6) #1;7 (7)	58 km/h 57 km/h 55 km/h 43 km/h	18.5 cm 32.9 cm 25.0 cm 45.0 cm	3.2 cm 11.3 cm 8.8 cm 2.1 cm
Sunny, cloudy periods, mid afternoon, mid length shadows	#1;8 (5) #1;9 (3) #1;10 (2) #1;11 (3)	43 km/h 54 km/h 39 km/h 45 km/h	46.5 cm 157.5 cm 72.2 cm 6.1 cm	3.3 cm 11.9 cm 0.0 cm 2.5 cm
Bright, windy, late afternoon, long shadows	#1;12 (6) #1,13 (3) #1,14 (6) #1,15 (6) #2,16 (5) #2,17 (6)	52 km/h 43 km/hr 36 km/h 54 km/h 54 km/h 55 km/h	19.4 cm 14.6 cm 12.3 cm 17.0 cm 57.7 cm 31.1 cm	10.9 cm 8.7 cm 10.9 cm 9.3 cm 10.0 cm 6.2 cm

Mississauga Tests

A temporary cantilever structure was used to mount the camera which was placed outside of the Mississauga office. The camera height was set to 3.39 m above the road surface of the parking lot. The camera angle was set to 90° to the road from horizontal, with the center of the field of view aligned directly with arriving or departing traffic. Vehicles of known lengths and widths were used for test runs. These runs were conducted to evaluate the repeatability of measurements by the V-DIM system. Since speed measurement accuracy and repeatability had been established as satisfactory from previous tests in Boston and Milton, speed measurement accuracies were not analyzed in the Mississauga runs.

Table 5 illustrates test results of repeatability of measurements from vehicles of known dimensions:

Table 5 Repeatability tests on vehicles of known dimensions

Ambient/ Lighting Condition	Vehicle#;Run# (Number of Passes)	Average Vehicle Speed	Standard Deviation of Length Measurements	Standard Deviation of Width Measurements
Daylight, overcast	#1;1 (7) #1;2 (7) #1;3 (7)	29 km/h 28 km/h 29 km/h	34.6 cm 57.6 cm 50.2 cm	9.2 cm 10.3 cm 8.8 cm
Daylight, overcast, slight wind	#1;4 (9)	27 km/h	15.6 cm	8.7 cm
Daylight, light rain, slight wind	#1;5 (3) #1;6 (3)	20 km/h 22 km/h	21.9 cm 9.5 cm	3.1 cm 3.6 cm
Daylight, rain, windy	#1;7 (6)	26 km/h	65.8 cm	3.7 cm

The construction of the original cantilever was not rigid enough. A new and more rigid cantilever was constructed. More tests were conducted with the camera height set at 3.6 m above road surface. Two passenger vehicles were used in the tests; vehicle #1 and vehicle #2. Table 6 illustrates test results of these two vehicles:

Table 6 Tests on two passenger vehicles of different dimensions (Mississuaga)

Ambient/ Lighting Condition	Vehicle#;Run# (Number of Passes)	Average Vehicle Speed	Standard Deviation of Length Measurements	Standard Deviation of Width Measurements
Overcast, no wind, mid afternoon, no shadows	#1;1 (6) #2;2 (9) #2;3 (10) #2;4 (10) #2;5 (7) #2;6 (8) #2;7 (8) #2;8 (7)	23 km/h 19 km/h 18 km/h 16 km/h 18 km/h 18 km/h 15 km/h 22 km/h	82.5 cm 77.3 cm 25.6 cm 38.4 cm 103.9 cm 128.8 cm 142.3 cm 59.1 cm	7.7 cm 2.4 cm 2.2 cm 2.2 cm 2.7 cm 9.3 cm 8.1 cm 2.3 cm
Cloudy, no wind, late afternoon, no shadows	#2;9 (7) #2;10 (6) #2;11 (9)	23 km/h 15 km/h 14 km/h	41.4 cm 33.1 cm 15.4 cm	1.8 cm 2.5 cm 2.5 cm

Sunny, slight wind 10-20 kph mid afternoon, some shadows	#2;12 (5) #2;13 (9) #2;14 (7) #1;15 (6) #1;16 (15) #1;17 (14)	10 km/h 14 km/h 12 km/h 11 km/hr 14 km/h 14 km/h	59.3 cm 55.4 cm 27.1 cm 48.7 cm 35.9 cm 45.8 cm	2.1 cm 2.6 cm 2.8 cm 2.2 cm 2.2 cm 2.6 cm
Overcast, drizzle, mid morning, no shadows	#1;18 (3)	14 km/h	9.5 cm	4.5 cm
Rainy, windy, early afternoon, no shadows	#1;19 (6) #1;20 (8) #1;21 (12)	10 km/h 12 km/h 12 km/h	30.8 cm 111.8 cm 123.4 cm	2.0 cm 9.7 cm 8.4 cm

4.3 Summary of Development and Tests

The tests showed consistency in speed and width measurements. This is expected since both types of measurements are not subject to influences by a lot of variables. Length measurement presents quite a challenge to the design and development of the V-DIM system. The tests showed inconsistency in length measurements, although on an individual vehicle basis the accuracy of length measurement was significantly better, and in many tests they were found close to the actual length of the selected vehicle.

Based on the tests and their set-ups, several factors were observed to have significant negative impact on the accuracy and repeatability of length measurements. These factors were:

- The long shadow casting on a vehicle at sunset artificially lengthened the vehicle as seen by the V-DIM system. The V-DIM system could not consistently separate the shadow from the vehicle, particularly in a platoon of vehicles.

- The camera mount and its mounting structure (a truss bridge in Milton and a cantilever arm in Mississauga) would sway very slightly due to gusts of wind. This altered the length measurement of a vehicle by the V-DIM system.

- Due to low mounting height of the camera, an extra wide angle lens was used in the camera. This occasionally made it difficult for the V-DIM system to separate lane-straddling vehicles appearing at the traffic split location in Milton.

4.4 Conclusion

The V-DIM system provides basic vehicle detection information similar to that obtainable from commercially available vehicle detectors. The V-DIM system also provides a number of additional features including length and width measurements which are not currently available with inexpensive vehicle detection systems. Test results of the V-DIM system have indicated good performance in the areas of speed detection and width measurement, and potential for effective length measurement. The V-DIM technology appears capable of providing additional functionality other than vehicle detection. The V-DIM technology is a more economical approach to non-intrusive vehicle detection than other technologies. The V-DIM system is an important step in applying technology to develop new solutions for traffic management problems.

Chapter 5 SUMMARY AND CONCLUSIONS

5.1 Project Summary

The objective of this project was to develop a non-intrusive computerized system for measuring speeds and dimensions of moving vehicles. The system was to be economical, cost-effective, consistent and suitable for both normal ambient and lighting conditions.

A number of technologies such as video imaging, laser and microwave were considered suitable for or adaptable to this non-intrusive detection application. Each technology shared advantages and disadvantages. There are commercially available devices and systems for non-intrusive detection applications which are based on laser and microwave technologies. To provide dimension measurements, additional development work was deemed necessary on these devices and systems. However, it was determined that these devices and systems are either too complex or not economical for general deployment.

The V-DIM technology is based on video imaging technology. Investigative work done prior to and after this research project, showed that the V-DIM technology is the most applicable for development into a computerized moving vehicle sizing system. Subsequently, development of the V-DIM system commenced under this project. Two prototypes were produced for field trials. Test results indicated that the V-DIM system has the potential of being developed into an accurate, reliable, low cost, multi-purpose system which could be used in traffic engineering and planning applications.

However, much more work will have to be done to produce a commercially viable system.

5.2 Future System Research and Development

The video imaging technology employed to develop a non-intrusive computerized moving vehicle sizing system resulted in a seemingly viable and operational vehicle dimensioning (V-DIM) system. However, field trials with the prototypes indicated that further development work on the product would be necessary to achieve consistent length measurement results. Recommended further development and future refinement on the V-DIM system include the following:

- More research is required to develop the system for faster response to background changes which affect edge identification of image from pavement. This should help to establish consistent, accurate length dimensioning.

- More research is required to develop the system to reduce the effect of vehicle speed changes on the accuracy of length dimensioning.

- Further refinement needs to be done to develop the system to consistently separate a vehicle's image from its shadow, particularly in a platoon of vehicles. This would result in better and more accurate length dimensioning.

- Further refinement needs to be done to develop the system to perform better separation of lane-straddling vehicles appearing at traffic split locations.

- Future research is recommended to develop the system to capture vehicle images from side mount positions. These installation arrangements would make the system more suitable for freeway traffic vehicle detection and dimensioning applications.

- Future research is recommended to develop the system into a vehicle classification system based either on profile dimensions or on axle spacing. This would make use of the system platform for multi-purpose application.

- Future research is recommended to develop the system for vehicle matching and tracking application. This would make use of the system platform for multi-purpose application.

- Future research is recommended to develop the system for vehicle height measurement application. This would complete the system functionality as a dimensioning system.

Although the research performed in this project to develop a computerized moving vehicle dimensioning system did yield very promising results, more research and further refinement are necessary before the system’s functionality and multi-purpose intent can be fully exploited.