TP 13936E

Traffic Monitoring Application of Cellular Positioning Technology: Proof of Concept

Prepared for
Transportation Development Centre
Transport Canada

By

Cell-Loc INC.

June 2002

TP 13936E

Traffic Monitoring Application of Cellular Positioning Technology: Proof of Concept

by

A. Hillson and M. De Santis

Cell-Loc INC.

June 2002

This report reflects the views of Cell-Loc Inc. and the authors and not necessarily those of Transportation Development Centre of Transport Canada or the sponsoring organizations.

The Transportation Development Centre does not endorse products or manufactures. Trade or manufactures' names appear in this report only because they are essential to its objectives.

Project Team

- Andrew Hillson, Cell-Loc Project Leader & Sr. Systems Engineer
- Michael De Santis, Consultant
- Gerry Knopp – Sr. Systems Engineer
- Ron Ramsaran – Sr. Systems Engineer
- Marcia Hofmann – Intermediate Systems Engineer
- John Carpenter – Intermediate Systems Engineer
- Kevin Grover – Technical Support

Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13936E	2. Project No. 5009-10	3. Recipient's Catalogue No.
4. Title and Subtitle Traffic Monitoring Application of Cellular Positioning Technology: Proof of Concept		5. Publication Date June 2002 6. Performing Organization Document No.
7. Author(s) A. Hillson and M. De Santis		8. Transport Canada File No. ZCD2450-D-738
9. Performing Organization Name and Address Cell-Loc Inc. 3015 5th Avenue NE Ste 220 Calgary, Alberta Canada T2A 6T8		10. PWGSC File No. MTB-0-01871 11. PWGSC or Transport Canada Contract No. T8200-0-0545/001/MTB
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final 14. Project Officer B. Marshall

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

Co-sponsored by the Program of Energy Research and Development of Natural Resources Canada

16. Abstract

Obtaining real-time traffic information for monitoring and planning purposes is possible through the use of a variety of field equipment and data processing methods currently employed in Advanced Traffic Management Systems (ATMS). At present, this information is collected with stationary vehicle detection sensors. In view of the need to continually expand the geographical coverage of existing ATMS, a more economical alternative method of collecting traffic data is required.

The objective of this project was to study the technical feasibility of using cellular phone-equipped vehicles as traffic probes for monitoring flow using a wireless location system, the Cellocate System™, developed and operated by Cell-Loc Inc.

Data was collected for the study using two techniques: continuous tracking of registered devices and anonymous tracking. A GPS receiver was used as a position/velocity benchmark while the Cellocate System™ tracked registered and anonymous devices.

Point by point, it was found that GPS accuracies are in the order of 5 to 15 m and Cellocate™ accuracies are in the order of 100 m. For the purpose of monitoring traffic, various simple filtering and averaging techniques can take raw Cellocate™ data and result in a path essentially equivalent to a GPS-generated path. Computing vehicle speeds with the Cellocate™ system also benefited from simple filters and averaging. However, instantaneous velocities were difficult to calculate when vehicles slowed down rapidly at a traffic signal or when their speed fell below a threshold.

17. Key Words Traffic monitoring, intelligent transportation systems, ITS, advanced traffic management system, ATMS, wireless location, cellular telephone	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages xx, 40, apps	23. Price Shipping/ Handling

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 13936E	2. N° de l'étude 5009-10	3. N° de catalogue du destinataire
4. Titre et sous-titre Traffic Monitoring Application of Cellular Positioning Technology: Proof of Concept		5. Date de la publication Juin 2002 6. N° de document de l'organisme exécutant
7. Auteur(s) A. Hillson et M. De Santis		8. N° de dossier - Transports Canada ZCD2450-D-738
9. Nom et adresse de l'organisme exécutant Cell-Loc Inc. 3015 5th Avenue NE Ste 220 Calgary, Alberta Canada T2A 6T8		10. N° de dossier - TPSGC MTB-0-01871 11. N° de contrat - TPSGC ou Transports Canada T8200-0-0545/001/MTB
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final 14. Agent de projet B. Marshall

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

Projet coparrainé par le Programme de recherche et développement énergétiques (PRDE) de Ressources naturelles Canada

16. Résumé

Il est possible d'obtenir des informations en temps réel sur la circulation à des fins de surveillance et de planification grâce à divers dispositifs de terrain et méthodes de traitement de données couramment utilisés dans les systèmes avancés de gestion de la circulation (SAGC). Présentement, ces informations sont recueillies à l'aide de capteurs fixes de détection de véhicules. Afin de continuer à élargir la couverture géographique des SAGC actuels, une autre méthode, plus économique, de collecte de données sur la circulation s'avère nécessaire.

L'objectif de cette recherche était d'étudier la faisabilité technique de suivre l'état de la circulation par pistage de véhicules équipés d'un téléphone cellulaire à l'aide d'un système de positionnement sans fil mis au point et exploité par l'entreprise Cell-Loc Inc.

Les données ont été recueillies au moyen de deux techniques : pistage continu de dispositifs enregistrés et pistage anonyme. On a utilisé un récepteur GPS comme référence de position et de vitesse, et le système Cellocate^MC pour retracer des dispositifs enregistrés et des dispositifs anonymes.

Le GPS affiche une précision de l'ordre de 5 à 15 m et le système Cellocate^MC, une précision de l'ordre de 100 m. Aux fins de la surveillance de la circulation, diverses techniques simples de filtrage et d'établissement de moyennes peuvent traduire des données brutes Cellocate^MC en une trajectoire quasi équivalente à celle générée par le GPS. Ces techniques ont également été exploitées dans le calcul de la vitesse des véhicules à l'aide du système Cellocate^MC. Les vitesses instantanées ont toutefois été difficiles à calculer lorsque les véhicules ralentissaient brusquement à un feu de circulation ou lorsque leur vitesse tombait en deçà d'un seuil.

17. Mots clés Surveillance de la circulation, systèmes de transports intelligents, STI, système avancé de gestion de la circulation, SAGC, positionnement par technologie sans fil, téléphone cellulaire	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	—	xx, 40, ann.	Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

ACKNOWLEDGEMENTS

The support and advice of Brian Marshall, Technology Applications Division, Transportation Development Centre, Transport Canada, is gratefully acknowledged.

EXECUTIVE SUMMARY

Objective

Obtaining real-time traffic information for monitoring and planning purposes is possible through the use of a variety of field equipment and data processing methods currently employed in Advanced Traffic Management Systems (ATMS). At present, this information is collected with stationary vehicle detection sensors. The information is site specific, and coverage is limited because of the costs related to implementing and maintaining the required equipment and communication infrastructure.

In view of the need to continually expand the geographical coverage of existing ATMS, a more economical alternative method of collecting traffic data is required. Consequently, traffic monitoring through the use of wireless technologies and vehicles as probes offers an inexpensive alternative toward data collection over a greater area.

The objective of this research was to study the technical feasibility of using cellular phone-equipped vehicles as traffic probes for monitoring flow using a wireless location system developed and operated by Cell-Loc Inc.

Short-term objectives of this research were twofold:

- Track a test vehicle down a stretch of roadway using both a global positioning system (GPS) and the Cellocate™ System. Compare the positional and velocity outputs of these two methods for similarities and differences.

- Analyze the results of using Cellocate™ technology to anonymously gather velocities of vehicles on a roadway.

Scope

The project represents the initial proof-of-concept phase of a program to develop, demonstrate and evaluate a traffic monitoring application based on cellular positioning technology developed by Cell-Loc Inc.

Work included the design and development of the necessary system architecture, software and algorithms. In addition, the study included a localized field trial in Calgary, Alberta, to determine the preferred data collection and processing methods.

Methodology

Cell-Loc's wireless positioning technology is network-based time difference of arrival (TDOA). TDOA positioning is accomplished by estimating the time of arrival (TOA) of wireless handset signals at a number of fixed sites of known geographical location.

The difference in TOA measurements at two or more cell sites defines a hyperbola on which the handset must lie. This method of positioning is called hyperbolic multilateration. The intersection of the two hyperbolas yields the position estimate of the wireless handset. In the case of two-dimensional (horizontal) positioning, a minimum of three cell sites is required.

Data was collected for the study using two techniques: continuous tracking of registered devices and anonymous tracking. A GPS receiver was used as a position/velocity benchmark while the Cellocate System™ tracked registered and anonymous devices.

The first step of the study involved tracking known cell phones along the target roadway. The intent of this step was to analyze the accuracy of the system in measuring vehicle locations for calculating a vehicle's speed and direction. In addition to a cell phone, probe vehicles were equipped with a GPS receiver that was configured to capture coordinates as the probe vehicle moved through the target roadway.

The second step of the study involved configuring the position determining equipment to monitor a cellular sector to anonymously track vehicles travelling through the target roadway. The intent of this step was to gather a large number of shorter tracking sessions to be used in the computation of average speeds on the target roadway.

Relatively simple techniques were employed to refine raw data and compare it with benchmarks. Among the techniques used were moving averages, fitting collected points to a line and simple filtering.

A number of filters were used in the post-processing of raw data. These filters were used to remove data points and detect certain conditions. The filters removed/modified points based on:

- Sudden changes in direction at slow speeds
- Calculated speeds over a threshold
- Large deviations from the fit line

System Description

The Cellocate™ hardware consists of antennas, filters, power supplies, communication controller units, GPS receivers and radio receivers that encompass a passive system. The method performed for tracking cellular handsets for this study was voice channel positioning. Voice channel positioning is accomplishing by estimating the TOA of signals transmitted by the handset on the reverse voice channel during normal conversation mode. The handset position can be continually updated as long as the call remains active. This allows for "tracking" a moving handset.

Decoded control channel messages are relayed back to the Host subsystem, a software system that both controls the base station hardware and performs the position determination. The Host can determine which calls are to be located based on one or a combination of the following: the calling number, the called number and the sector.

At the Host, the observations made are converted to TOA observations that are differenced between themselves to produce TDOAs.

Results

Data for tracking registered cell phones occurred on March 2, 5, and 6, 2001, during morning, noon and evening rush periods. Anonymous data was collected from early morning until approximately 10 pm on April 27, 28, 30 and May 1, 2, 2001.

Raw data produced by the system/test procedure followed three basic types: benchmark output from the GPS receiver, output from an individual cell phone tracking session and output from a velocity averaging module. All files were created in a comma-delimited format for easy import into Microsoft Excel.

It was found that the Cellocate System™ provides a rougher, yet essentially equivalent view of the vehicle's path along the target roadway. Fitting a line to the Cellocate™-generated points matches the GPS benchmark path. In a subsequent test, the tracking session followed the benchmark with very few deviations. When performing a linear regression, these minor deviations essentially cancelled each other out.

The second part of tracking test vehicles on the target roadway involved calculating both the GPS and Cellocate™ speeds and comparing them. The best results obtained from the Cellocate System™ with respect to velocities were when the test vehicle moved at a relatively constant speed. A heavy moving average filter matched the GPS benchmark quite closely by the second. A light moving average filter was capable of matching the GPS as the vehicle moved at a relatively constant speed.

When traffic lights were introduced, it became more difficult to match the GPS. Filters helped to detect extremely slow or stopped vehicles. Lighter moving average filters had to be used to catch sharper changes in speed. Despite the varying speed of the test vehicle, certain sessions indicated a very successful match on the benchmark. In addition, the use of filters provided a good match to the GPS benchmark, even as the vehicle stopped for a traffic light.

The second step of the study involved the collection of anonymous locations for the purpose of monitoring velocities during the day for the target roadway. Vehicles were tracked for the initial 20 to 30 seconds of their cell phone call and then dropped out of the loop. These shorter tracking sessions were used to gather and calculate as many velocity vectors as possible during the collection period.

The GPS receivers in the probe vehicles performed well as a benchmark with an accuracy of 5 to 20 m, giving a very realistic view of the vehicle's path and velocity. Data provided by the Cellocate System™, on the other hand, was within 100 m 67 percent of the time and within 300 m 95 percent of the time. This level of accuracy gives a very good view of a vehicle's path and velocity when the sample size of raw positions is large enough. The fit line between the Cellocate™ and GPS data was conclusive.

In terms of calculating speeds, averaging produced meaningful results when comparing GPS and Cellocate™.

- With an accuracy of 100 m 67 percent of the time and 300 m 95 percent of the time, Cellocate™ has varying resource requirements to track slow-moving vehicles. The time required to track each probe is a function of the travel speed.

As the minimum speed threshold increases, the network needs less time to track each probe. Traffic data can be represented by speed grouping, such as 0-50, 50-75, 75-90, 90+, with individual probe vehicles tracked for a total of 20 seconds.

Conclusion

Point by point, GPS accuracies are in the order of 5 to 15 m and Cellocate™ accuracies are in the order of 100 m. For the purpose of monitoring traffic, various simple filtering and averaging techniques can take raw Cellocate™ data and end up with a path that is essentially equivalent to a GPS-generated path.

Computing vehicle speeds with the Cellocate™ system benefits from simple filters and averaging. GPS vs. Cellocate™ data compared very favourably when vehicles moved through the target roadway at a relatively constant speed near the speed limit of the road. However, instantaneous velocities were difficult to calculate when vehicles slowed down rapidly at a traffic signal or when their speed fell below a threshold.

In the case of anonymous tracking, data was successfully collected, filtered for relevance to the target roadway, and used to calculate a velocity. The number of points collected for calculating the velocity was restrained. However, the resulting speeds matched known traffic patterns on the target roadway.

Recommendations

Based on the results and the operation of the traffic system, there are numerous recommendations on the next areas to research and develop. In no particular order, they are:

- Increase sample sizes for anonymous probes
- Improve accuracy
- Tighten geographic filter for anonymous collection of data
- Integrate with an existing ATMS
- Improve filtering
- Improve processing

SOMMAIRE

Objectif

Il est possible d'obtenir des informations en temps réel sur la circulation à des fins de surveillance et de planification grâce à divers dispositifs de terrain et méthodes de traitement de données couramment utilisés dans les systèmes avancés de gestion de la circulation (SAGC). Présentement, ces informations sont recueillies à l'aide de capteurs fixes de détection de véhicules. Elles sont propres à un endroit et leur couverture est limitée en raison des coûts associés à la mise en œuvre et à l'entretien du matériel et de l'infrastructure de communications requis.

Afin de continuer à élargir la couverture géographique des SAGC actuels, une autre méthode, plus économique, de collecte de données sur la circulation s'avère nécessaire. La surveillance de la circulation par technologie sans fil et véhicules utilisés comme sondes offre une possibilité peu coûteuse de recueillir des données sur un secteur plus vaste.

L'objectif de cette recherche était d'étudier la faisabilité technique de suivre l'état de la circulation par pistage de véhicules équipés d'un téléphone cellulaire à l'aide d'un système de positionnement sans fil mis au point et exploité par l'entreprise Cell-Loc Inc.

Les objectifs à court terme de la recherche se subdivisaient en deux volets :

- À l'aide d'un système mondial de localisation (GPS) et du système Cellocate^MC, pister un véhicule d'essai sur un tronçon routier. Comparer les données de position et de vitesse obtenues au moyen des deux méthodes afin d'établir les similarités et les différences entre elles.
- Analyser les résultats obtenus à l'aide de la technologie Cellocate^MC pour obtenir de manière anonyme la vitesse de véhicules circulant sur une route.

Portée

Le projet représente la phase initiale de validation de principe d'un programme visant à développer, à démontrer et à évaluer une application de la technologie de positionnement par téléphonie cellulaire, développée par Cell-Loc Inc., à la surveillance de la circulation.

Les travaux portaient sur la conception et le développement de l'architecture, du logiciel et des algorithmes du système. L'étude visait en outre un essai localisé mené en situation réelle, à Calgary, en Alberta, dans le but de dégager les méthodes de collecte et de traitement de données à privilégier.

Méthode

La technologie de positionnement sans fil de Cell-Loc est un système réseau fondé sur la différence de temps d'arrivée (TDOA, pour *time difference of arrival*). Elle permet d'estimer le temps d'arrivée (TOA, pour *time of arrival*) de signaux provenant de combinés sans fil à un certain nombre de sites fixes dont l'emplacement géographique est connu.

La différence dans les mesures de temps d'arrivée (TOA) à deux sites cellulaires ou plus définit une hyperbole sur laquelle le combiné doit se trouver. On désigne cette méthode de positionnement par multilatération hyperbolique. L'intersection des deux hyperboles donne la position estimée du combiné sans fil. Dans le cas d'un positionnement bidimensionnel (horizontal), trois sites cellulaires au moins sont nécessaires.

Les données ont été recueillies au moyen de deux techniques : le pistage continu de dispositifs enregistrés et le pistage anonyme. On a utilisé un récepteur GPS comme référence de position et de vitesse, et le système Cellocate[MC] pour retracer des dispositifs enregistrés et des dispositifs anonymes.

La première étape de l'étude a consisté à suivre des téléphones cellulaires connus sur la route cible. Il s'agissait d'analyser avec quelle précision le système pouvait mesurer la position des véhicules pour calculer leur vitesse et leur direction. Outre un téléphone cellulaire, les véhicules sondes étaient équipés d'un récepteur GPS configuré de manière à saisir leurs coordonnées alors qu'ils se déplaçaient sur la route cible.

Au cours de la deuxième étape, on a configuré le matériel de localisation de manière à surveiller un secteur cellulaire pour le pistage anonyme de véhicules se déplaçant sur le tronçon routier cible. On cherchait ainsi à obtenir un grand nombre de pistages de courte durée devant servir à calculer les vitesses moyennes sur ce tronçon.

Des techniques relativement simples ont été utilisées pour affiner les données brutes et les comparer à des valeurs de référence. Au nombre de ces techniques, il convient de citer celle des moyennes mobiles, de l'ajustement de courbes et du simple filtrage.

Pour le traitement ultérieur des données brutes, on a fait appel à un certain nombre de filtres qui ont servi à éliminer des points de données et à déceler certaines conditions. Les filtres ont éliminé ou modifié des points pour les raisons suivantes :

- changements soudains de direction à faibles vitesses,
- vitesses calculées dépassant un seuil,
- écarts importants par rapport à la courbe d'ajustement.

Description du système

Le matériel Cellocate[MC] comprend des antennes, des filtres, des blocs d'alimentation, des contrôleurs de transmission, des récepteurs GPS et des récepteurs radio qui constituent un système passif. On a eu recours à la méthode de positionnement par voies téléphoniques pour retracer les combinés cellulaires dans cette étude. Cette méthode consiste à évaluer le temps d'arrivée des signaux émis par un combiné sur la voie de retour en mode de conversation normal, et la position du combiné peut être mise à jour continuellement pendant toute la durée de l'appel. La méthode permet donc de «retracer» un combiné mobile.

Les messages décodés de la voie de commande sont relayés au sous-système hôte, un logiciel qui commande le matériel de la station de base et qui sert aussi à la localisation. Ce logiciel peut déterminer les appels à localiser en fonction d'un ou de plusieurs des éléments suivants : le numéro d'appel, le numéro appelé et le secteur.

Le logiciel convertit alors les observations faites en observations TOA qui sont différenciées entre elles pour produire des TDOA.

Résultats

Les données servant à retracer des téléphones cellulaires ont été recueillies les 2, 5 et 6 mars 2001 pendant les périodes de pointe du matin, du midi et du soir. La collecte des données anonymes a été réalisée les 27, 28 et 30 avril ainsi que le 1er mai 2001, depuis tôt le matin jusqu'à environ 22 heures.

Les données brutes produites par le système et les méthodes d'essai étaient de trois types principaux : données de référence du récepteur GPS, données obtenues au cours d'une période de pistage d'un téléphone cellulaire particulier et données fournies par un module de moyenne de vitesse. Tous les fichiers ont été créés dans un format défini par virgules afin de faciliter leur importation dans Microsoft Excel.

Le système Cellocate^MC a fourni une image plus grossière, mais essentiellement équivalente, de la trajectoire des véhicules sur la route cible. La courbe d'ajustement des points générés par le système Cellocate^MC concordait avec la trajectoire de référence GPS. Au cours d'un essai subséquent, la période de pistage a suivi la trajectoire de référence avec très peu d'écarts. À la réalisation d'une régression linéaire, ces écarts mineurs se sont quasi annulés mutuellement.

Au cours de la deuxième partie du pistage des véhicules d'essai, on a calculé les vitesses à l'aide du GPS et du Cellocate^MC et on les a comparées. On a obtenu les meilleurs résultats avec le système Cellocate^MC à cet égard lorsque les véhicules se déplaçaient à vitesse relativement constante. Avec un filtre dense de moyenne mobile, les résultats correspondaient assez bien à la référence GPS à la seconde près. Le recours à un filtre léger de moyenne mobile a permis d'obtenir une correspondance avec la référence GPS lorsque le véhicule se déplaçait à vitesse relativement constante.

Lorsque les feux de circulation ont été introduits, il s'est avéré plus difficile de faire la correspondance avec le GPS. Les filtres ont contribué à détecter des véhicules extrêmement lents ou à l'arrêt. Il a fallu utiliser des filtres de moyenne mobile plus légers pour déceler les changements de vitesse brusques. Malgré la vitesse variable du véhicule d'essai, certaines périodes de pistage se sont soldées par une très bonne correspondance avec la référence GPS. De plus, l'utilisation de filtres a permis d'obtenir aussi une bonne concordance avec la référence GPS, même lorsque le véhicule était arrêté à un feu de circulation.

La deuxième étape de l'étude visait la collecte anonyme de données pour surveiller les vitesses sur la route cible au cours de la journée. Des véhicules ont été suivis pendant les 20 à 30 premières secondes d'un appel effectué sur leur téléphone cellulaire, après quoi le pistage était abandonné. Ces pistages de courte durée ont servi à recueillir et à calculer le plus de vecteurs vitesse possible au cours de la période de collecte de données.

Les récepteurs GPS installés dans les véhicules sondes ont affiché une bonne performance à titre de référence, avec une précision de 5 à 20 m, donnant ainsi une image très réaliste de la trajectoire et de la vitesse du véhicule. Les données fournies par le système Cellocate^MC quant à elles avaient une précision de l'ordre de moins de 100 m, 67 p. 100 du temps, et de moins de 300 m, 95 p. 100 du temps. Ce niveau de précision illustre très bien la trajectoire et la vitesse d'un véhicule lorsque la taille d'échantillon des positions brutes est assez grande. La courbe d'ajustement entre les données du système Cellocate^MC et du GPS s'est avérée concluante.

En ce qui concerne le calcul des vitesses, l'établissement de moyennes a donné de bons résultats lorsqu'on a comparé le GPS et le système Cellocate^{MC}.

- Avec une précision de 100 m, 67 p. 100 du temps, et de 300 m, 95 p. 100 du temps, le système Cellocate^{MC} a des besoins variés en ressources pour pister des véhicules lents. Le temps requis pour suivre chaque sonde est fonction de la vitesse de déplacement.

Plus le seuil de vitesse minimale augmente, plus le temps nécessaire au réseau pour pister chaque sonde diminue. Les données de circulation peuvent être représentées par des groupes de vitesse, tels que 0-50, 50-75, 75-90, 90+, le pistage de chaque véhicule sonde se faisant pendant un total de 20 secondes.

Conclusion

Le GPS affiche une précision de l'ordre de 5 à 15 m et le système Cellocate^{MC}, une précision de l'ordre de 100 m. Aux fins de la surveillance de la circulation, diverses techniques simples de filtrage et d'établissement de moyennes peuvent traduire des données brutes Cellocate^{MC} en une trajectoire quasi équivalente à celle générée par le GPS.

Le calcul de la vitesse des véhicules à l'aide du système Cellocate^{MC} fait appel à des techniques simples de filtrage et d'établissement de moyennes. Ce système se compare très favorablement au GPS lorsque les véhicules se déplacent sur le tronçon cible à une vitesse constante proche de la limite de vitesse de la route. Les vitesses instantanées ont toutefois été difficiles à calculer lorsque les véhicules ralentissaient brusquement à un feu de circulation ou lorsque leur vitesse tombait en deçà d'un seuil.

Dans le cas du pistage anonyme, on a pu recueillir des données, les filtrer pour assurer leur pertinence par rapport au tronçon routier cible et les utiliser pour calculer la vitesse. Même si le nombre de points recueillis était restreint, les vitesses obtenues concordaient avec les profils de circulation connus sur ce tronçon.

Recommandations

D'après les résultats obtenus, on peut formuler plusieurs recommandations quant aux secteurs à étudier et à développer. Les voici, sans ordre de priorité particulier :

- augmenter la taille d'échantillon dans le cas des sondes anonymes,
- améliorer la précision,
- resserrer le filtre géographique pour la collecte anonyme de données,
- assurer l'intégration à un SAGC,
- améliorer le filtrage,
- améliorer le traitement.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOGRAPHS

GLOSSARY

AMPS	Advanced Mobile Phone Service
API	Application Programmatic Interface
ATMS	Advanced Traffic Management Systems
CLQ	Cellocate System
COP	Canadian Olympic Park
CORBA	Common Object Request Broker Architecture
ESN	Electronic Serial Number
FCC	Federal Communications Commission (United States regulatory body)
FOCC	Forward Control Channel Control transmissions from a tower to a cell phone
FOVC	Forward Voice Channel Voice transmissions from a tower to a cell phone
GPS	Global Positioning System
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
IDE	Integrated Development Environment
ITS	Intelligent Transportation Systems
LBS	Location Based Services
MPC	Mobile Positioning Centre
MS	Mobile Station
PCDS	Position Collection and Distribution System
PDE	Position Determining Equipment
PSAP	Public Safety Answering Point (call centre responsible for receiving emergency calls)
PSTN	Public Switched Telephone Network
SMS	Short Message System
SOAP	Simple Object Access Protocol
TDOA	Time Difference of Arrival
TOA	Time of Arrival
WAP	Wireless Application Protocol
WLIA	Wireless Location Industry Association
XML	Extensible Markup Language

1 INTRODUCTION

Obtaining real-time traffic information for traffic management purposes is possible through the use of a variety of field equipment and data processing methods currently employed in Advanced Traffic Management Systems (ATMS). At present, traffic data collection is achieved primarily with the aid of stationary vehicle detection sensors. The information so acquired is site specific, and coverage is limited because of the costs related to wire line communications infrastructure, and equipment procurement, installation and maintenance.

In view of the need to continually expand the geographical coverage of existing ATMS, a more economical alternative method of collecting traffic data is required. Traffic monitoring with the aid of wireless technologies and vehicles as probes offers such an alternative, which could provide traffic monitoring capabilities over a much greater area than is economically possible through conventional means.

Although the wireless location industry is relatively young, it has a defined product architecture into which players can participate. Figure 1 shows how mobile stations (MS) (i.e. wireless devices such as cellular telephones) are located by position determining equipment (PDE) that in turn feeds positions into a mobile positioning centre (MPC). Once delivered into an MPC, location data is then enhanced or used to enhance/create other information. The MPC then serves as the platform on top of which location-based services (LBS) are delivered.

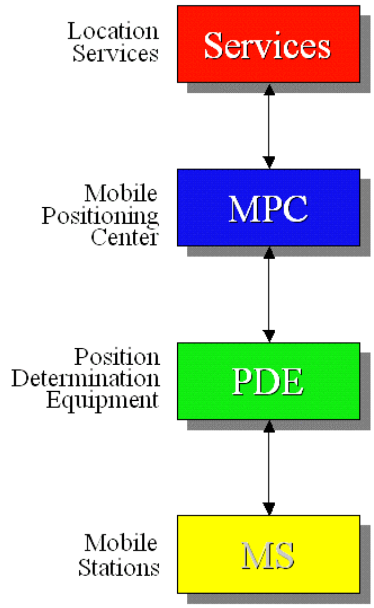

Figure 1 - Wireless location components

1.1 Objective

The objective of this research is to establish the technical feasibility of using cellular phone-equipped vehicles as traffic probes for monitoring flow using a wireless location system created and operated by Cell-Loc Inc.

Long-term potential benefits derived from this concept include the following:

- Extension of geographical coverage of existing ATMS with minimal capital expenditure.
- Elimination of fixed vehicle detector stations and communications infrastructure.
- Functional platform toward the implementation of real-time traffic-related applications such as incident detection, travel time prediction, and origin-destination data collection.
- Deployment of traffic monitoring strategies in a timely and cost-effective manner.

The short-term objectives of this research are twofold:

1. Track a test vehicle down a stretch of roadway using both a global positioning system (GPS) and the Cellocate System™. Compare the positional and velocity outputs of these two methods for similarities and differences.

2. Analyze the results of using Cellocate™ technology to anonymously gather velocities of vehicles on a roadway.

1.2 Scope

The project represents the initial proof-of-concept phase of a program to develop, demonstrate and evaluate a traffic monitoring application based on cellular positioning technology developed by Cell-Loc Inc.

Two methods for collecting and processing traffic data will be considered:

1. continuous voice channel scanning to locate cellular phones and determine vehicle velocity, and

2. intermittent tracking of selected phones to determine average traffic speed with a reduced processing load.

Work included the design and development of the necessary system architecture, software and algorithms. A localized field trial in Calgary, Alberta, was conducted from March to May 2001 to determine the preferred data collection and processing methods.

Upon successful completion of the proof-of-concept phase, a follow-on project may be considered. This would involve a field trial, on a segment of highway within a major metropolitan area, of sufficient scale and duration to provide a comprehensive evaluation of the traffic monitoring application within an existing ATMS.

2 METHODOLOGY

2.1 TDOA Estimation Techniques

Cell-Loc's wireless positioning technology is network-based time difference of arrival (TDOA). Network-based refers to the fact that a series of terrestrially deployed "listening posts" collect data and send it to a centralized server that then calculates locations, versus a handset-based solution in which the handset or wireless device does the calculation using GPS positioning. TDOA positioning is accomplished by estimating the time of arrival (TOA) of wireless handset signals at a number of fixed sites of known geographical location.

The difference in TOA measurements at two cell sites defines a hyperbola on which the handset must lie. A measured TOA at a third cell site may be differenced with one of the first two TOAs to produce a second hyperbola. The intersection of the two hyperbolas then yields the position estimate of the wireless handset. This method of positioning is called hyperbolic multilateration.

In the case of two-dimensional (horizontal) positioning, a minimum of three cell sites is required (i.e. for the three unknown values of longitude, latitude, and time of transmission). Estimation of a three-dimensional position necessitates TOA estimates from a minimum of four cell sites. Figure 2 illustrates the concept of hyperbolic multilateration positioning.

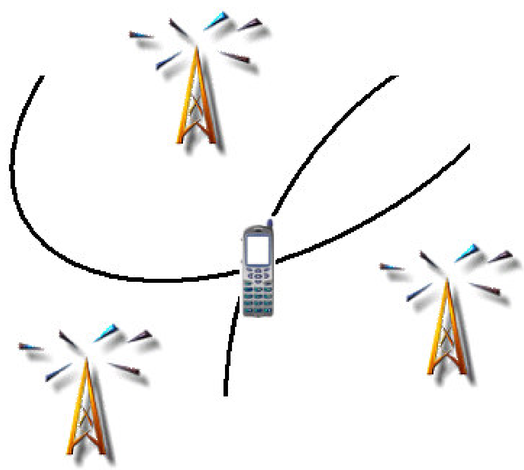

Figure 2 - Positioning via hyperbolic multilateration

2.2 Data Collection

Data was collected for the study using two techniques: continuous tracking of registered devices and anonymous tracking. A GPS receiver was used as a position/velocity benchmark while the Cellocate System™ tracked registered and anonymous devices.

2.2.1 Continuous Tracking of Registered Devices

The first step of the study involved tracking known cell phones along the target roadway. The Cellocate™ PDE was configured to watch for any transmissions from a specific cell phone and to launch a continuous tracking session when such transmissions were detected. This set-up involves using the Cellocate™ registered mobile identification number (MIN) filter.

During the study, drivers in probe vehicles made calls from the target roadway on cell phones registered with the system. Calls tracked using this technique were commonly two to five minutes in duration, which was typically a function of how long it took the probe vehicle to move through the target roadway. The intent of this step of the study was to analyze the accuracy of the system in measuring vehicle locations for calculating a vehicle's speed and direction.

In addition to a cell phone, probe vehicles were equipped with a GPS receiver that was configured to capture coordinates as the probe vehicle moved through the target roadway. GPS-based coordinates were time stamped and used as a benchmark for location and velocity analysis.

2.2.2 Anonymous Tracking

The second step of the study involved configuring the PDE to monitor a cellular sector in an attempt to anonymously track vehicles travelling through the target roadway. Tracking of these calls lasted from 20 to 30 seconds. The intent of this step of the study was to gather a large number of shorter tracking sessions to be used in the computation of average speeds on the target roadway.

2.3 Processing Data

This study did not focus on data processing techniques or algorithms, but rather on the suitability of collected raw data for future processing and integration with external traffic systems. Relatively simple techniques were employed to refine raw data and compare it with benchmarks. Among the techniques used were moving averages, fitting collected points to a line and simple filtering.

2.3.1 Averaging

Averaging is used in many components of the Cellocate™ PDE and the LocationBroker™ mobile positioning centre (MPC). With the PDE, the number of raw observations of received transmissions is a direct contributor to position accuracy. As with any measurement, random errors can be notably reduced by averaging over a large sample size. However, care must be taken when using averaging to position a moving vehicle. Over-averaging can misrepresent a vehicle's movement, especially at higher speeds.

2.3.2 Linear Regression

When comparing vehicle paths through the target roadway, linear regression was used to fit Cellocate™ (CLQ)-gathered points to a line representing the essentially straight road as shown in Figure 3.

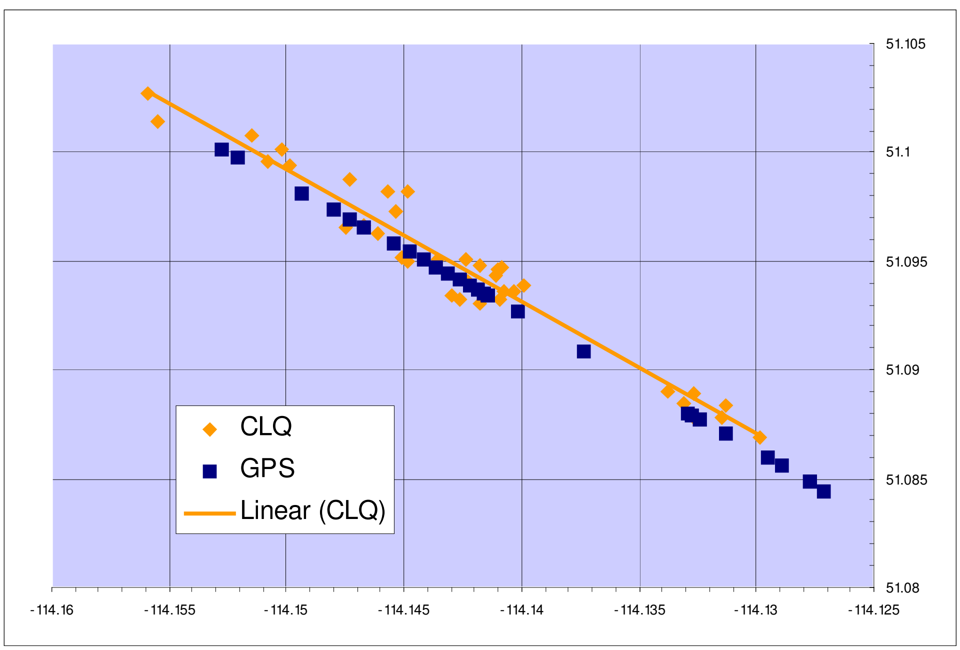

Figure 3 - Comparing GPS and CLQ vehicle paths

2.3.3 Filters

A number of filters were used in the post-processing of raw data from the PDE. These filters were used to remove data points and detect certain conditions. The filters removed/modified points based on:

- Sudden changes in direction at slow speeds. Based on the ~100 m accuracy of the system, sudden direction shifts are indicative of the vehicle slowing down below a certain threshold
- Calculated speeds over a threshold. Positions that lead to the generation of speeds over a realistic limit were rejected.
- Large deviations from the fit line. Positions that deviated from the linear fit line by a certain level were rejected.

The number of positions removed by the filters was not significant. They could theoretically have been left in and their effects handled via averaging.

3 SYSTEM DESCRIPTION

The system is composed of two major subsystems: the Cellocate™ PDE and the LocationBroker™ MPC indicated in Figure 4. As described in section 1, these subsystems are standard components in any wireless location system.

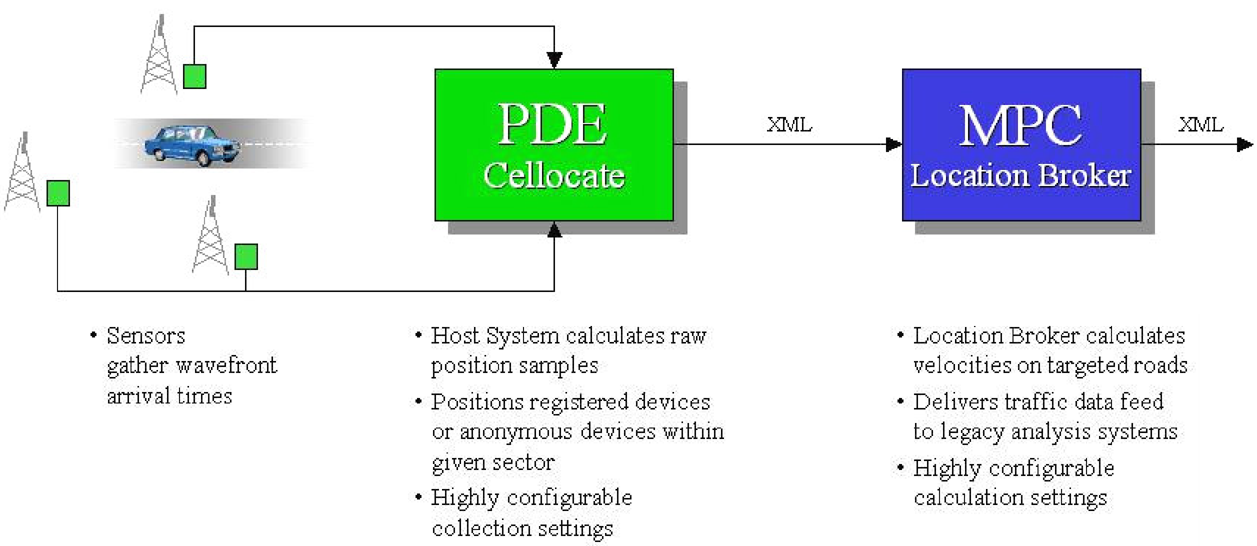

Figure 4 - Gathering traffic information using Cellocate™

3.1.1 Hardware

The Cellocate™ hardware consists of antennas, filters, power supplies, communication controller units, GPS receivers (for time synchronization purposes) and radio receivers. Note that the Cellocate System™ is passive – it does not transmit, it only receives. There are two types of radio receivers: control channel and voice channel. The control receivers are permanently tuned to control channels. Their purpose is to decode all control messages transmitted on the forward and reverse control channels. Voice channel receivers are tuned in real time to the channel of active calls to be positioned.

3.1.2 Monitored Channels

The method performed for tracking cellular handsets for this study was voice channel positioning. Voice channel positioning is accomplishing by estimating the TOA of signals transmitted by the handset on the reverse voice channel during normal conversation mode. As long as the call remains active (i.e. in conversation mode), the handset position can be continually updated. This allows for "tracking" a moving handset, or averaging or obtaining a better position estimate in the case of a stationary handset.

3.1.3 Host Subsystem

Decoded control channel messages are relayed back to the Host subsystem, a software system that both controls the base station hardware and performs the position determination. The Host can determine which calls are to be located based on one or a combination of the following: the calling number, the called number and the sector.

If a call is to be located, the Host, knowing the voice channel assignment from the forward control channel message, commands a certain group of voice receivers to tune to the voice channel of interest. The radio receivers make observations on the voice channel at exactly the same time, using GPS to synchronize them. These phase observations are communicated back to the Host that processes them and produces a position for the handset. While the call is in progress, numerous observations can be made resulting in numerous position estimates. This allows one to average over time or to track the handset as it moves. Since the forward voice channel is monitored, handoffs are detected allowing the system to continue positioning the handset on the new voice channel.

At the Host, the observations made are converted to TOA observations that are differenced between themselves to produce TDOAs. A specialized hyperbolic multilateration model is used by least squares to estimate the position of the handset. Filtering is performed on the measurements prior to the least squares process to remove those of poor quality. Following the least squares estimation process, statistical testing is performed on the observation residuals to identify further questionable observations. If identified by this testing, an observation is discarded and the position estimation process is repeated. Once a position estimate is produced, it is transmitted to a waiting MPC.

3.1.4 System Accuracy

Cell-Loc has demonstrated in field tests that the Cellocate™ Advanced Mobile Phone System (AMPS) PDE meets phase 2 requirements of the Federal Communications Commission's (FCC) E911 mandate. The following is a summary of phase 2 requirements for positioning wireless emergency 911 calls:

- Deliver best position estimate within first 30 seconds of placing the 911 call
- Location error thresholds for network-based solutions:
    - 67% of measurements within sample set < 100 m
    - 95% of measurements within sample set < 300 m
- Confidence interval threshold for FCC accuracy standard is based on a 90 percent confidence level and the # of samples.

3.2 LocationBroker Mobile Positioning Centre (MPC)

Cell-Loc's MPC product, LocationBroker™, formerly known by a working name of PCDS™ (Position Collection and Distribution System), is a distributed message-oriented middleware product with a Common Object Request Broker Architecture (CORBA) backbone and Java, C++ and C# components.

LocationBroker™ is capable of connecting to a wide variety of Position Determining Equipment (PDE). Figure 5 shows the basic architecture of LocationBroker™ with position sources coming in from the left, merging with inline content and processing, and the resulting services emerging to the right. Figure 6 shows specific examples of position sources, content, inline position processing and location services.

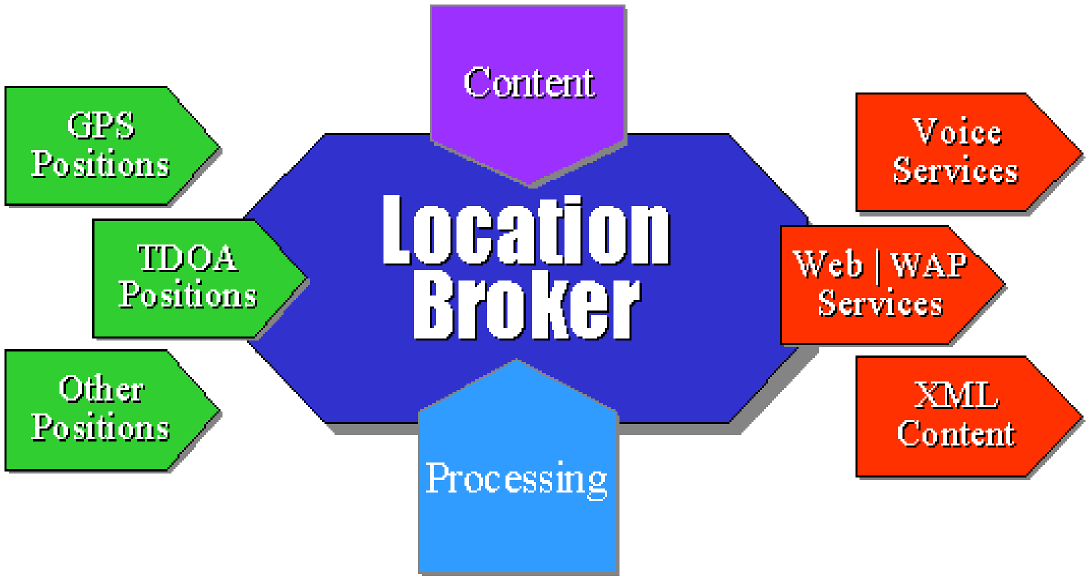

Figure 5 - Basic functional components of LocationBroker™

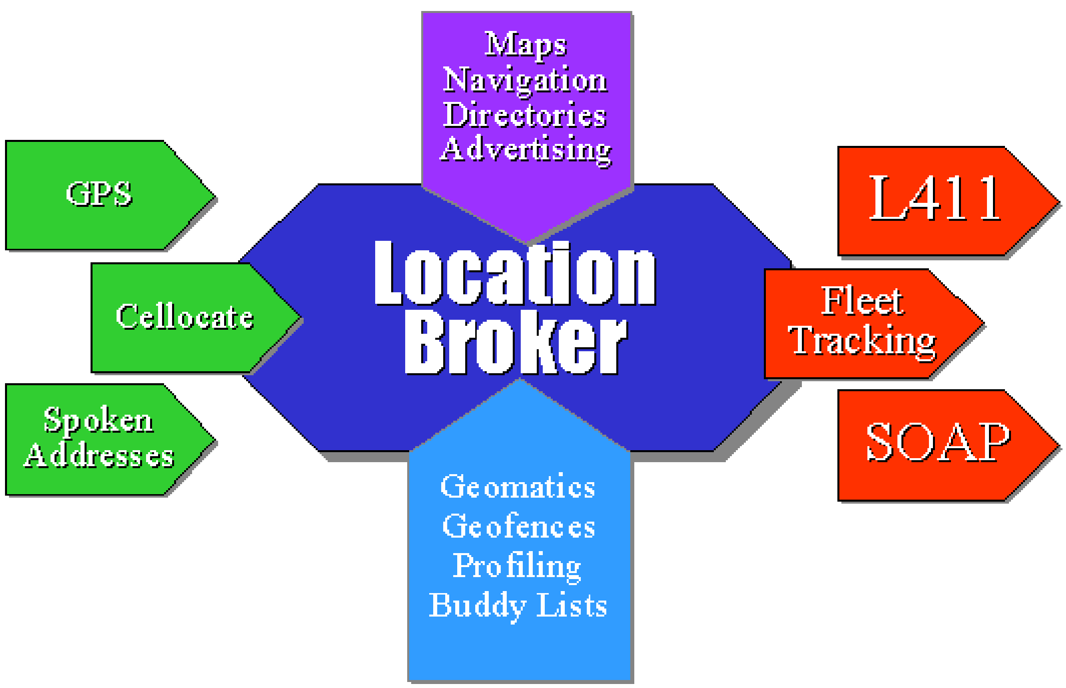

Figure 6 - Example location sources and service destinations

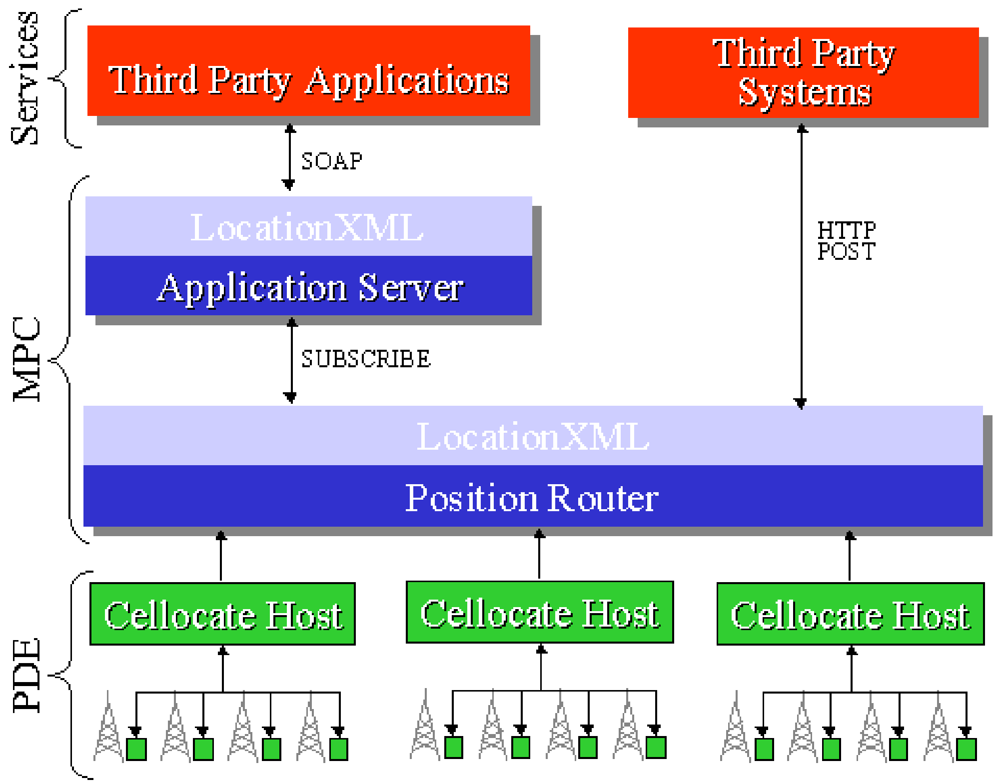

Figure 7 - Exposing location XML to third parties

3.2.1 Location Service Platform

Cell-Loc has defined the first version of Location Extensible Markup Language (XML), a standard way to represent data associated with the wireless device location industry. This effort is aimed at encouraging interoperability so that location-based information can easily be formatted and exchanged between systems.

Figure 7 depicts the layered architecture of the system and how the framework exposes the application server and content within the position router to external access.

3.2.2 Location XML and SOAP

Interfaces into the Cell-Loc positioning network are based on XML documents transmitted to and from the LocationExchange™ via private or public networks. The purpose of this section is to describe the XML components and the protocol that defines interactions with the LocationExchange™. For ease of integration with the widest variety of integrated development environments (IDE), Cell-Loc has elected to incorporate Simple Object Access Protocol (SOAP) as a way of easily packaging these XML documents and transmitting them over Hyper Text Transfer Protocol (HTTP).

SOAP is rapidly being accepted within the developer community as a standard way to communicate with XML over HTTP and has been embraced by such IDE vendors as Microsoft and IBM.

4 FIELD TRIAL SITE DESCRIPTION

Calgary is the headquarters for Cell-Loc and home to its “living lab.” Within the city there are numerous deployed Cellocate™ networks used for both research and development, and in the future, for commercial purposes. In terms of Cellocate™ AMPS, there are three networks: an engineering test bed, a co-located (with carrier) network, and a network deployed on independent towers known internally at Cell-Loc as “super-sites.” Currently tuned to listen to AMPS B-side, all three networks can be switched to A-side with limited configuration. Listening to both A and B is possible with limited capital investment.

4.1 Site Selection Process

Figure 8 shows a section of northwest Calgary and the roadway, Crow Child Trail, chosen to conduct the research. The test site boundaries are 53rd St. NW and 32nd Ave. NW.

Figure 8 - Field trial location

This section of roadway was chosen for three reasons:

1. The speed limit is relatively high, 80 km/h.
2. The roadway is well covered by the location network.
3. Simultaneous testing was being carried out by Cell-Loc in the area.

It is worth noting the presence of traffic lights on the target roadway. The effect these lights had on the testing will be covered in section 6. Also indicated on the map are the locations of the Cell-Loc sites providing coverage in the area.

4.2 Configuration

Once PDE and MPC have been deployed, there is a limited amount of required configuration to enable the collection of traffic information. In step one of the research, the phone numbers of the cell phones within probe vehicles must be provisioned on the system. This ensures that all calls made from the phones will result in a tracking session. In step two, anonymous tracking was set up to run within a specific sector to track any intercepted call for approximately 20 seconds.

Common to both steps was the definition of the target roadway. Figure 9 shows the web-based tool available for defining the boundaries and parameters associated with monitoring a section of roadway.

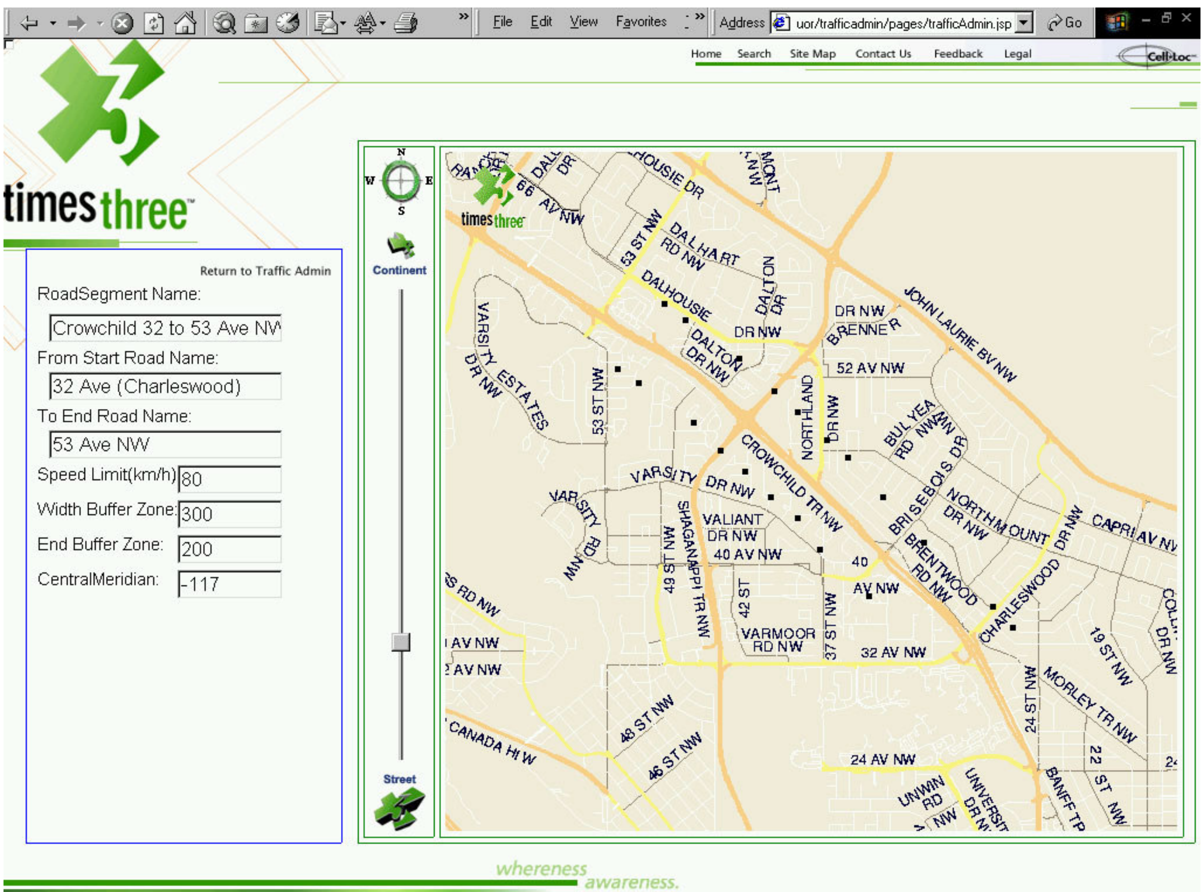

Figure 9 - Setting up a section of road to monitor

As shown in Figure 9, a zone around the roadway was defined to capture all relevant positions generated by the system. Values such as the speed limit on the road contribute toward filters that establish thresholds for computed speeds.

4.3 Test Site Installation Images

Photographs 1 through 8 show actual tower set-ups from Cell-Loc's Calgary wireless location network.

Photograph 1 - Canada Olympic Park (COP) site

Photograph 2 - Antenna configuration on COP

Photograph 3 - Equipment rack

Photograph 4 - Fortress site (apartment building rooftop)

Photograph 5 - Equipment rack in Fortress site

Photograph 6 - Mounted antenna

Photograph 7 - Tower-mounted antennas

Photograph 8 - Equipment rack in tower shack

5 DATA COLLECTION

5.1 Dates

Step one data for tracking registered phones occurred on March 2, 5, and 6, 2001, during morning, noon and evening rush periods. Anonymous data was collected from early morning until approximately 10 pm on April 27, 28, 30 and May 1, 2, 2001.

5.2 Raw Data Format Produced

5.2.1 Format

Raw data produced by the system / test procedure followed three basic types: benchmark output from the GPS receiver, output from an individual cell phone tracking session and output from a velocity averaging module. All files were created in a comma-delimited format for easy import into Microsoft Excel.

Latitude WGS-84 format	Longitude WGS-84 format	Speed km/h	Time of Day Mountain Time

Table 1 - GPS Format

Individual tracking sessions produced groups of the following records:

Latitude WGS-84 format	Longitude WGS-84 format	Time of Day Mountain Time

Table 2 - Cellocate

Output from the averaging module produced the following records:

Average Speed km/h	Lane North or South	Time of Day Mountain Time

Table 3 - Averaging Module

5.2.2 Examples

Latitude	Longitude	Speed	Time
51.10309	-114.160422	74.6767	11:52:01
51.102837	-114.15964	73.320477	11:52:05
51.102043	-114.157337	74.247916	11:52:14
51.101743	-114.156589	74.701707	11:52:16
51.101089	-114.15512	76.640434	11:52:23
51.099038	-114.151473	86.134983	11:52:38

Table 4 - GPS Output

Latitude	Longitude	Time
51.101928	-114.155894	11:52:01
51.101424	-114.155841	11:52:05
51.100004	-114.153828	11:52:14
51.100697	-114.151349	11:52:16
51.099611	-114.150859	11:52:23
51.09962	-114.148485	11:52:29

Table 5 - Raw Tracking Session Output

Speed	Direction	Time
57.6	N	13:54:38
82.8	N	14:11:47
75.6	N	14:16:51
79.2	N	14:42:43

Table 6 - Output from Averaging Modules

6 RESULTS

6.1 Continuous Tracking of Registered Devices

Figure 10 shows GPS positions (blue circles) mapped against Cellocate™ (CLQ) positions (red squares). GPS coordinates were captured from a GPS receiver inside the probe vehicle. Cellocate™ positions were generated at the same time by tracking a cell phone in the probe vehicle using the Cell-Loc network.

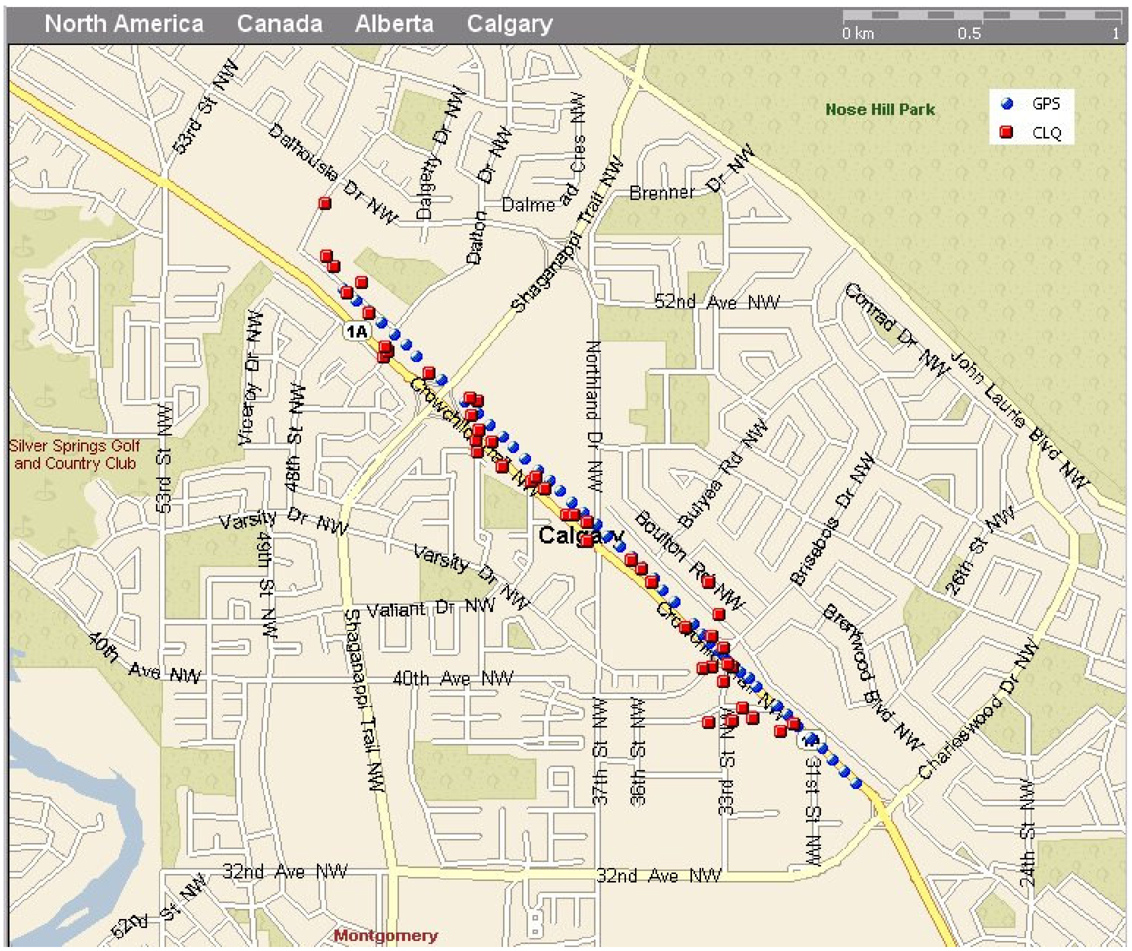

Figure 10 - Mapped GPS vs. CLQ positions, March 5/01, 07:35

Plotting the two data sets on a grid and overlaying a line that represents a linear regression performed on the Cellocate™ data results in Figure 11.

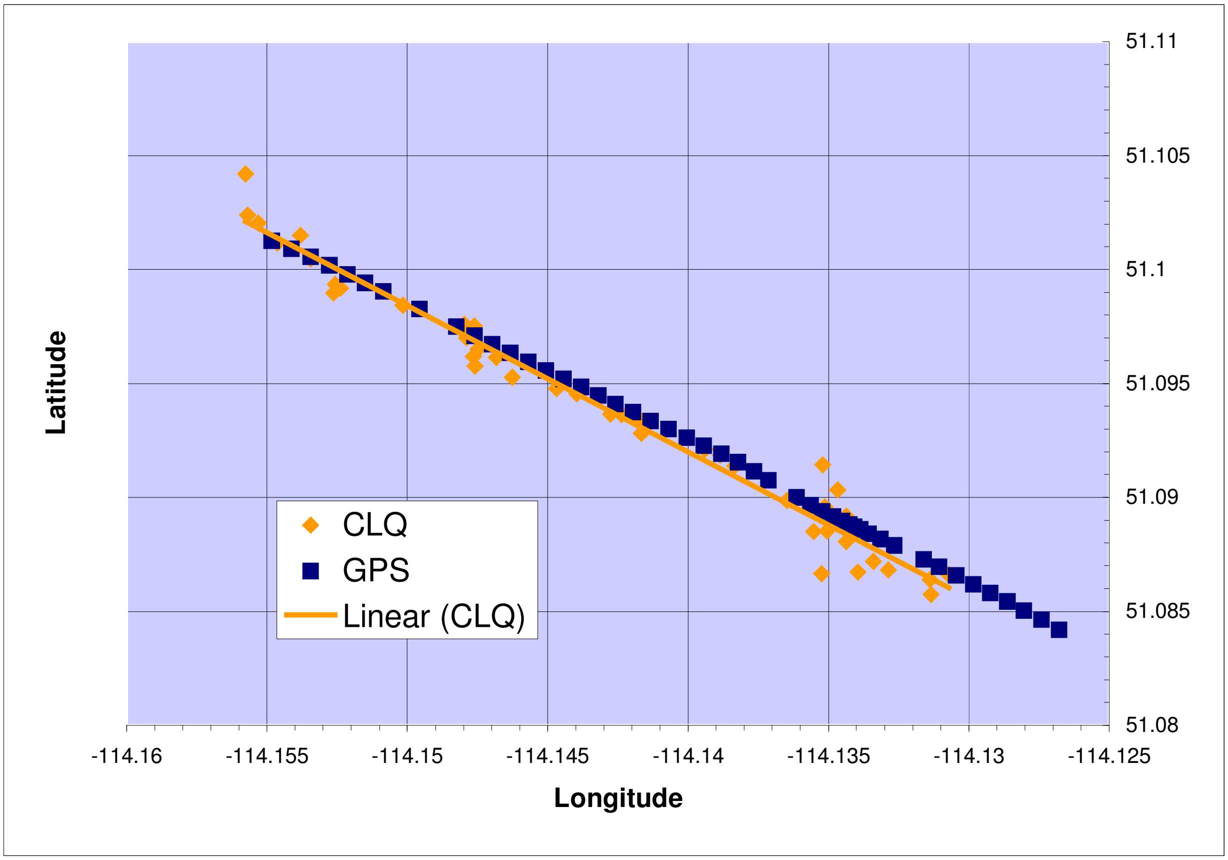

Figure 11 - Plotted GPS vs. CLQ positions vs. CLQ fit line, March 5/01, 07:35

In addition to comparing the actual position trails, the resulting computed speeds were also compared. Figure 12 shows GPS-computed speeds compared to Cellocate™-computed speeds and a corresponding moving average of the Cellocate™ speeds.

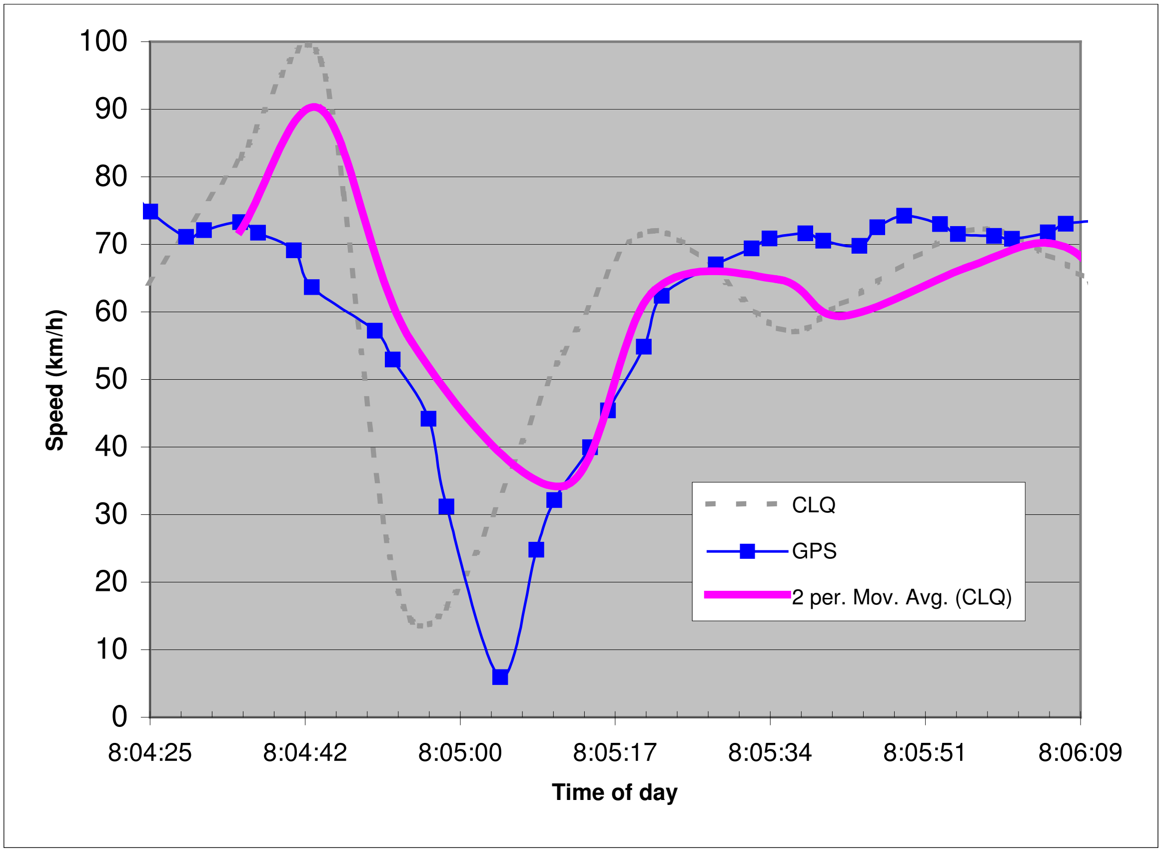

Figure 12 - Plotted GPS vs. CLQ speeds, March 5/01, 07:35

6.2 Anonymous Tracking

With respect to anonymous tracking of cell phones, histograms were compiled based on observed speeds during various periods during the day. A scatter diagram of data retrieved for a whole day is shown in Figure 13.

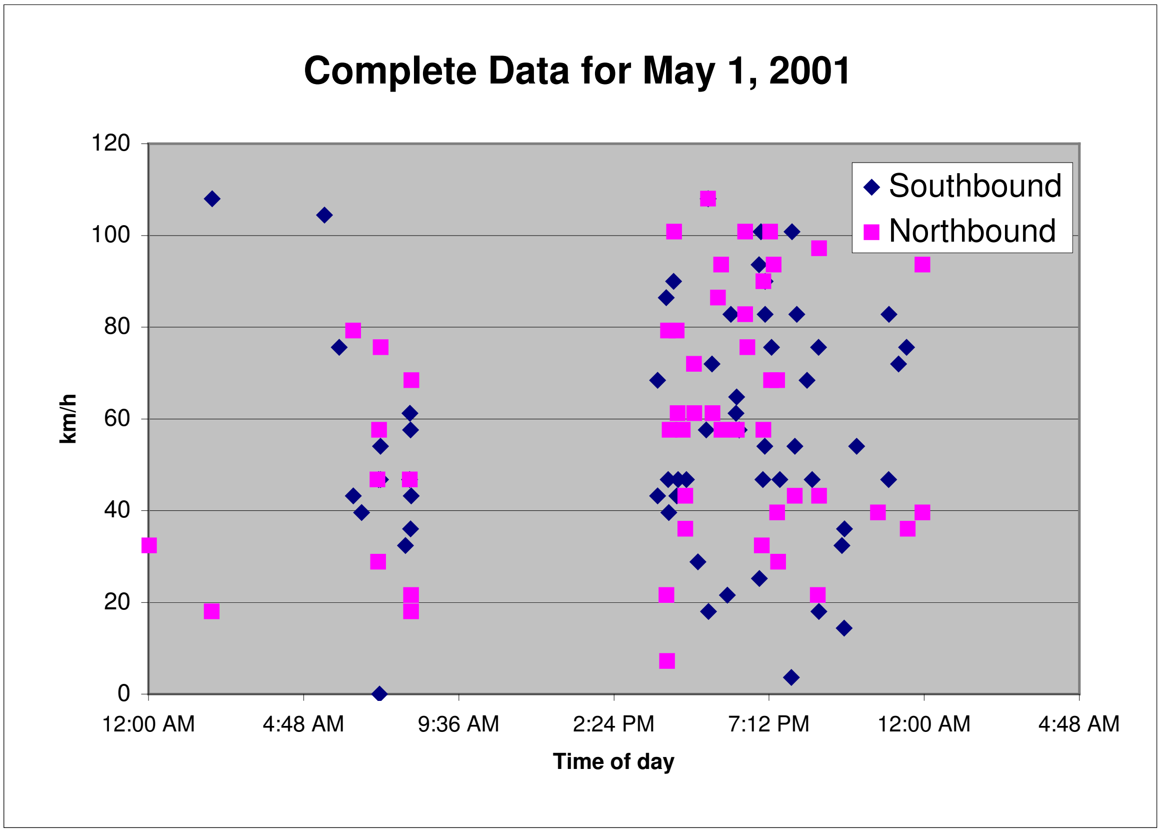

Figure 13 - Speed values gathered anonymously on May 1/01

Extracting data from a specific time and lane (e.g. southbound evening rush), histograms were also constructed to analyze computed speeds. An example is shown in Figure 14.

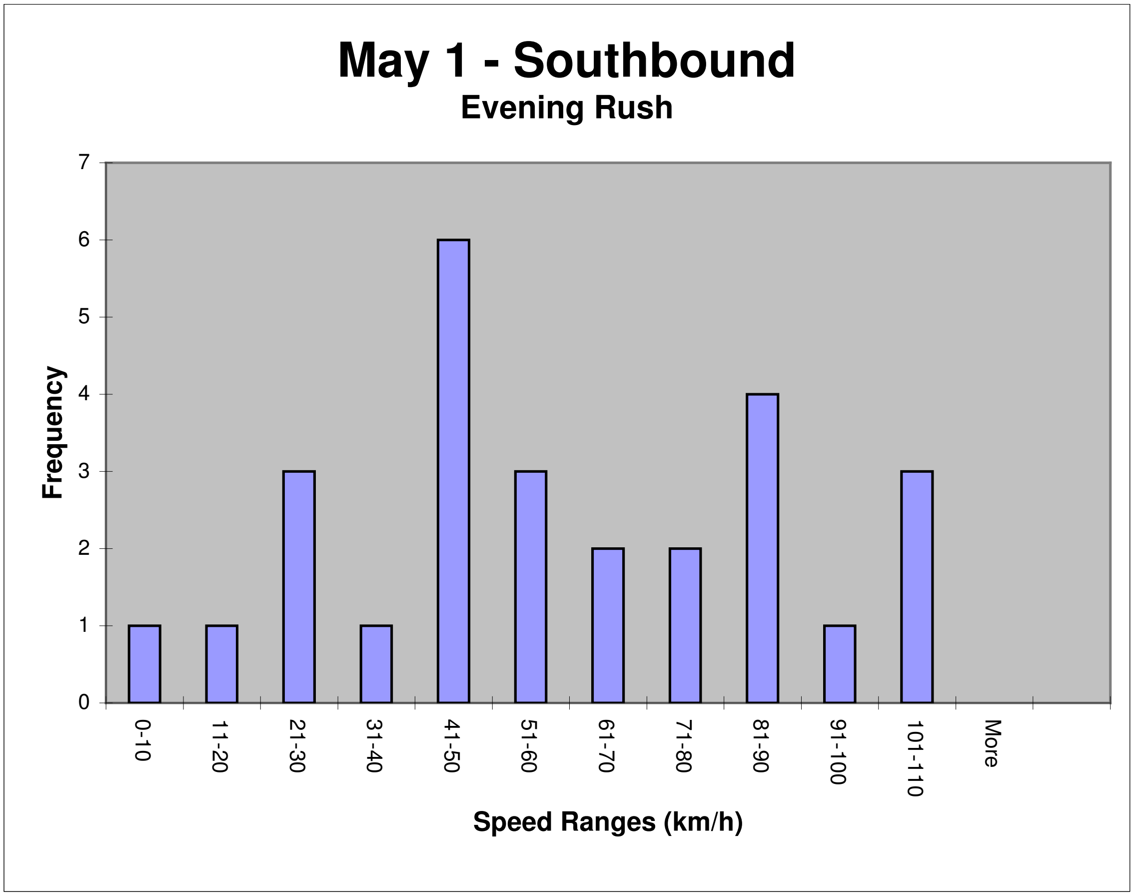

Figure 14 - Histogram showing vehicle speeds during the May 1/01 evening rush hour

6.3 Summarized Results

In accordance with the objectives of this study, the results from 1) simultaneously tracking test vehicles with GPS and Cellocate™, and 2) anonymous collection of velocities are summarized in this section.

6.3.1 Continuous Tracking of Registered Devices – Location

Throughout testing, the Cellocate™ network performed at FCC phase 2 levels (see section 3.1.4 for specifications).

Viewing the map in Figure 15, it is evident that Cellocate™ provides a rougher, yet essentially equivalent view of the vehicle's path along the target roadway.

With the test vehicle travelling at a relatively fixed speed, this is one of the best tracking sessions produced.

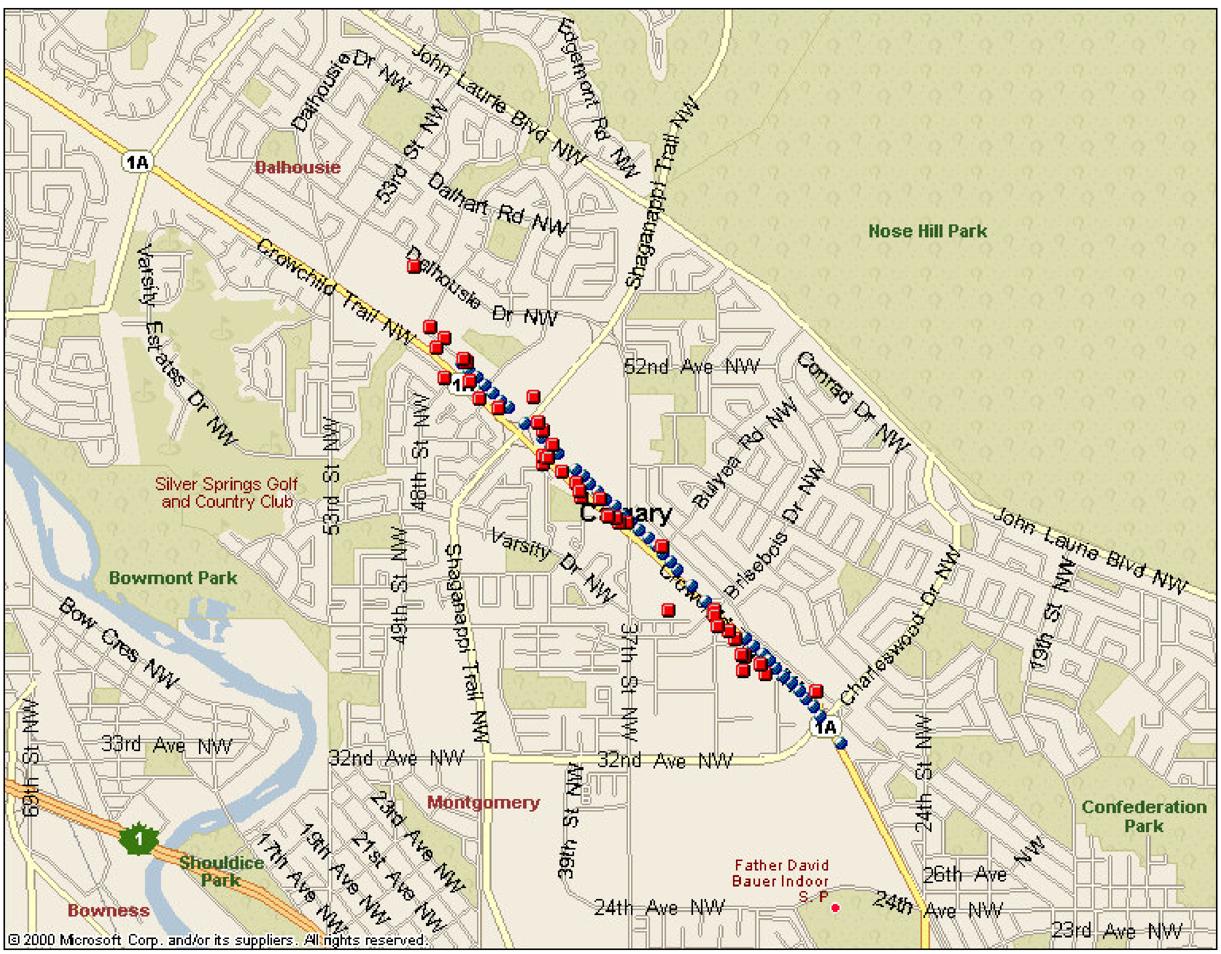

Figure 15 - GPS vs. CLQ, March 5/01, 07:35

Fitting a line to Cellocate™-generated points matches the GPS benchmark path (see Figure 16).

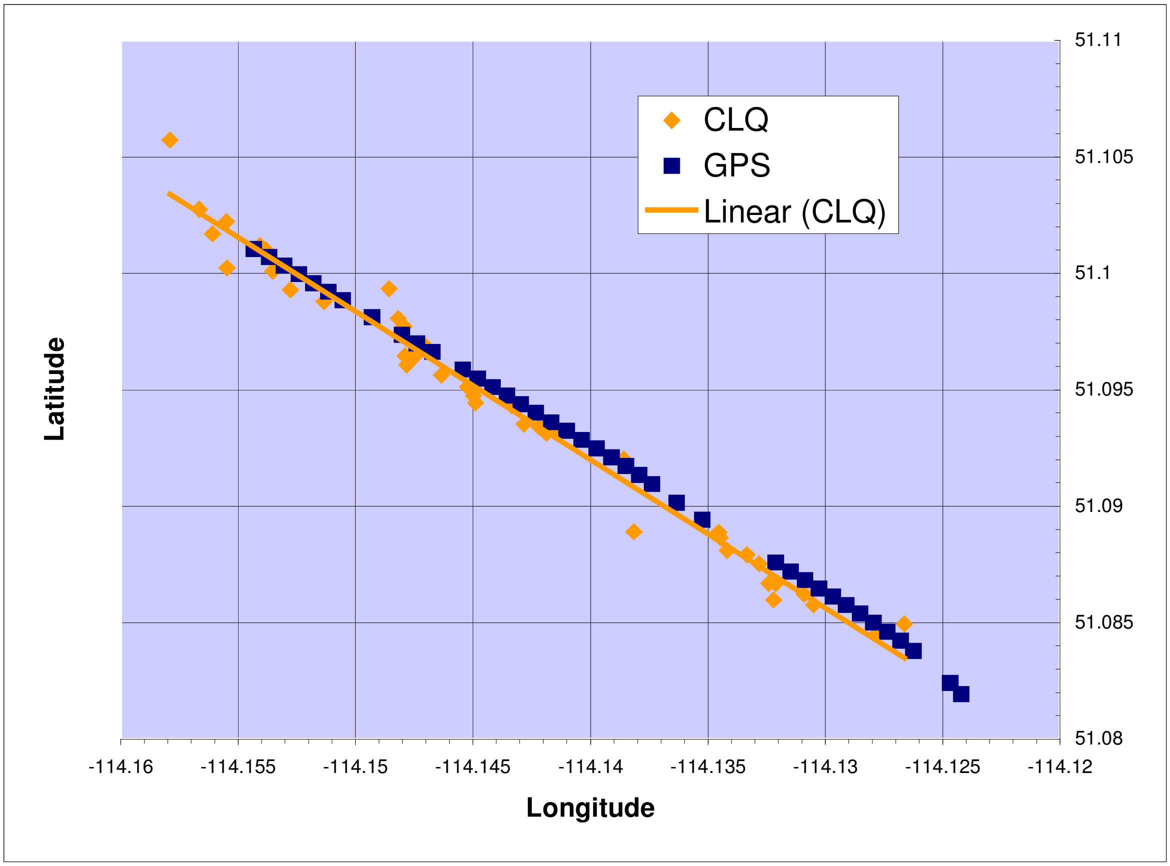

Figure 16 - GPS vs. CLQ positions vs. CLQ fit line, March 5/01, 07:35

In a subsequent test (Figure 17), the tracking session follows the benchmark with very few deviations

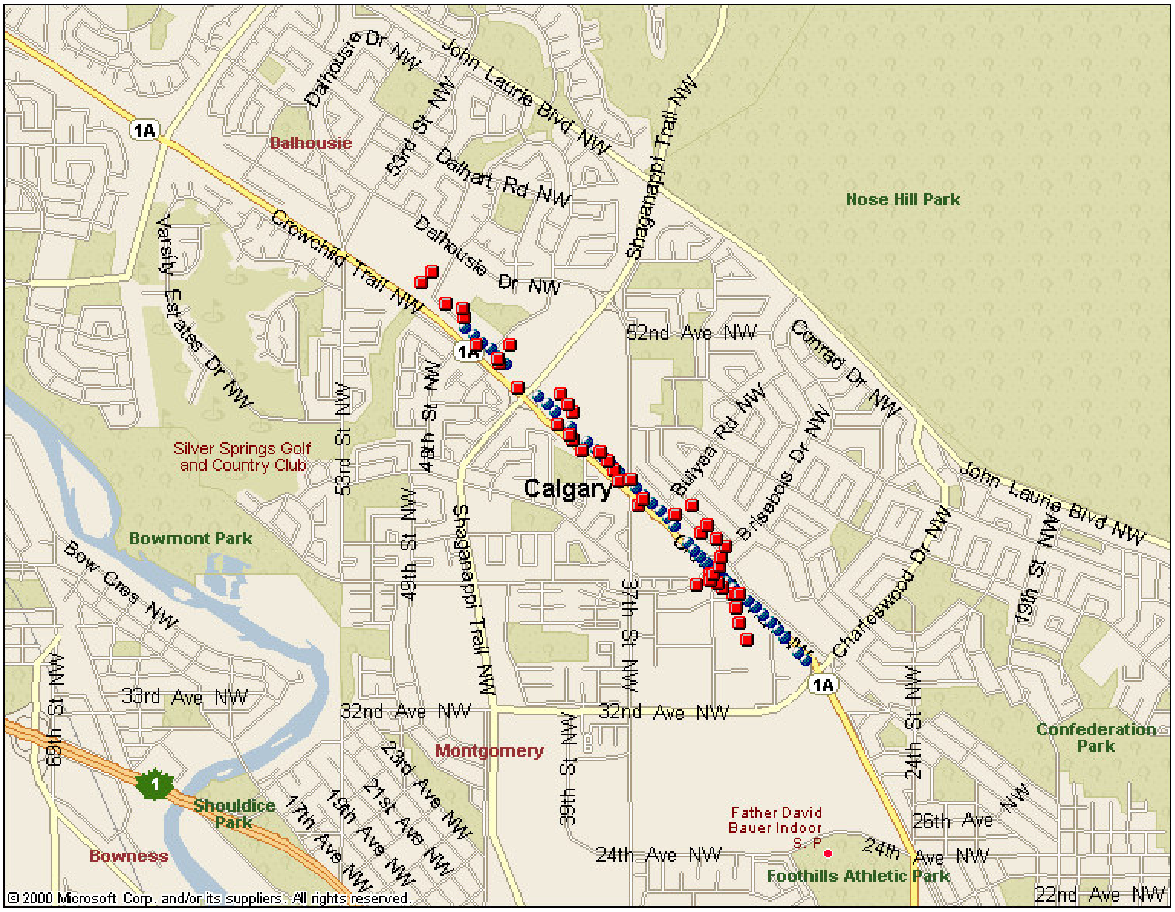

Figure 17 - GPS vs. CLQ, March 6/01, 07:37

When performing a linear regression (Figure 18), these minor deviations essentially cancel each other out.

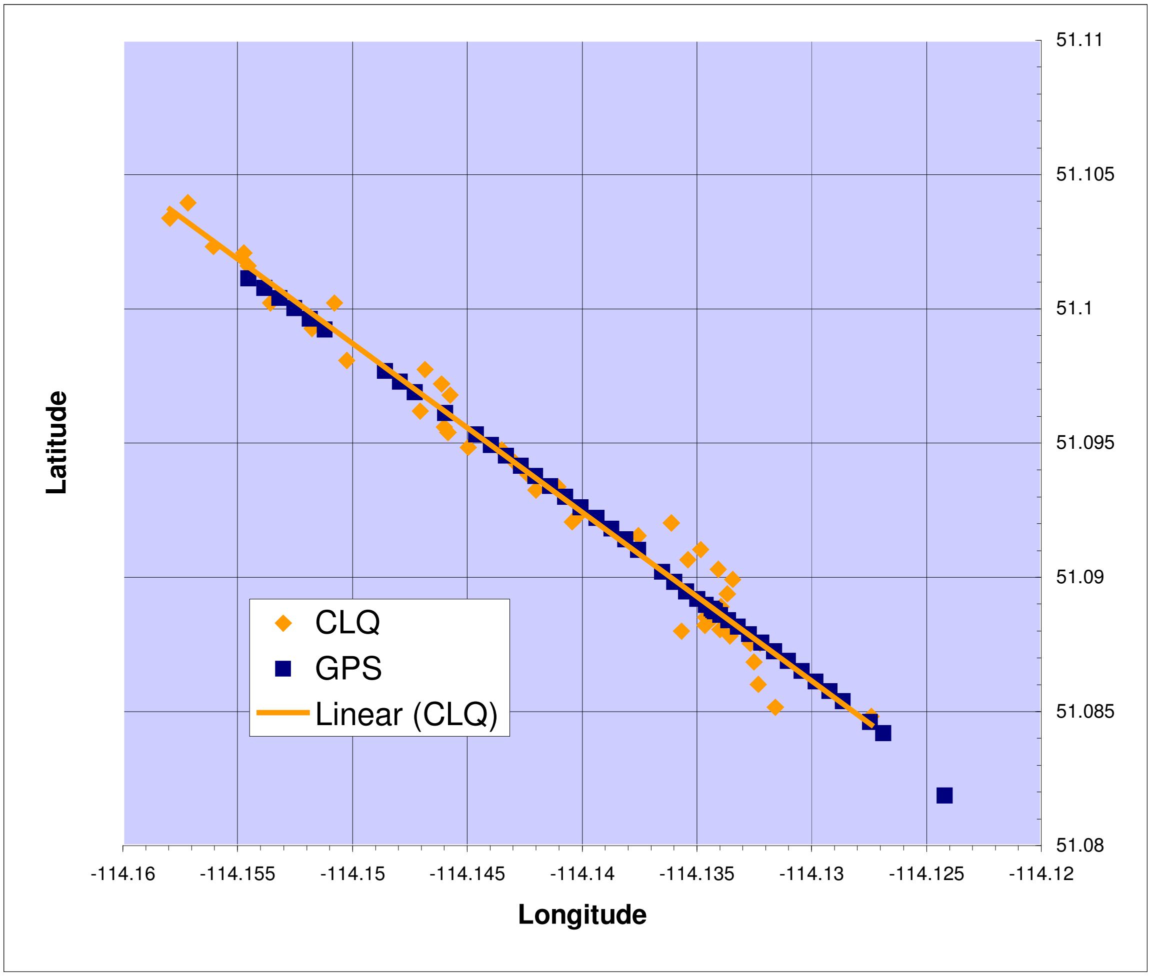

Figure 18 - GPS vs. CLQ positions vs. CLQ fit line, March 6/01, 07:37

In the case shown in Figure 19, the test vehicle moved to the northwest rapidly and stopped at the second of two possible traffic signals. After stopping at this signal, it gradually accelerated out of the target roadway section.

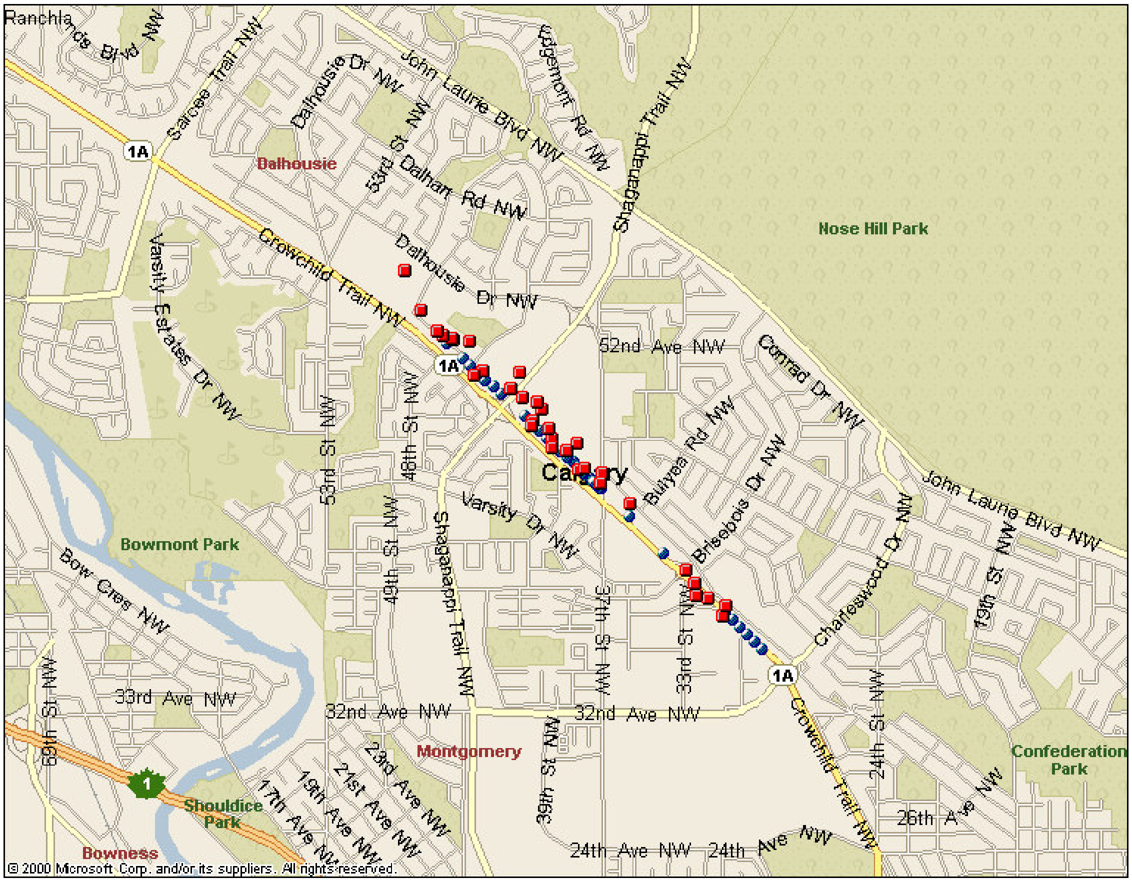

Figure 19 - GPS vs. CLQ, March 6/01, 12:44

A minimal number of points (both GPS and Cellocate™) is indicative of a rapid moving vehicle. As the vehicle moves to the northwest (see Figure 20) the spacing between the points grows slowly wider, indicating a gradual acceleration.

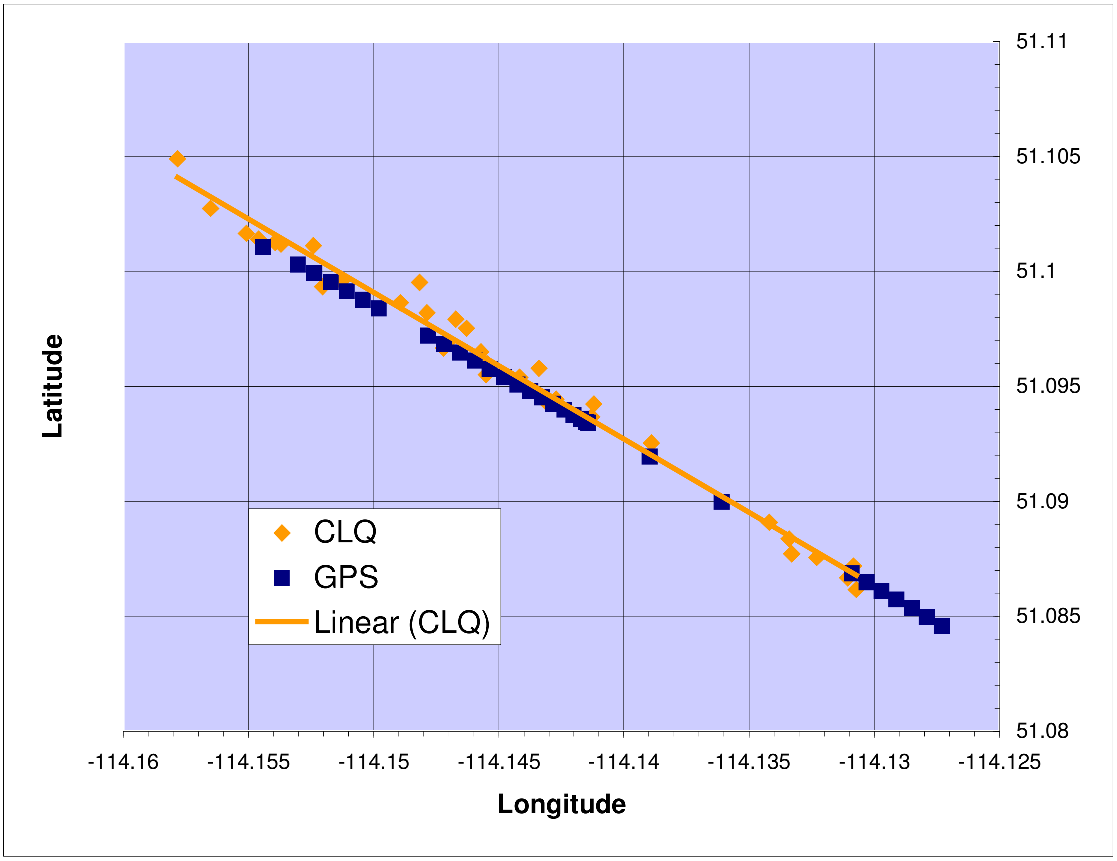

Figure 20 - GPS vs. CLQ positions vs. CLQ fit line, March 6/01, 12:44

6.3.2 Continuous Tracking of Registered Devices – Velocities

The second part of tracking test vehicles on the target roadway involved calculating both the GPS and Cellocate™ speeds and comparing them. Figures 21 through 26 show the results.

The best results obtained from the Cellocate System™ with respect to velocities were when the test vehicle moved at a relatively constant speed (i.e. did not stop at a light). A heavy moving average filter matches the GPS benchmark quite closely by the second (see Figure 21).

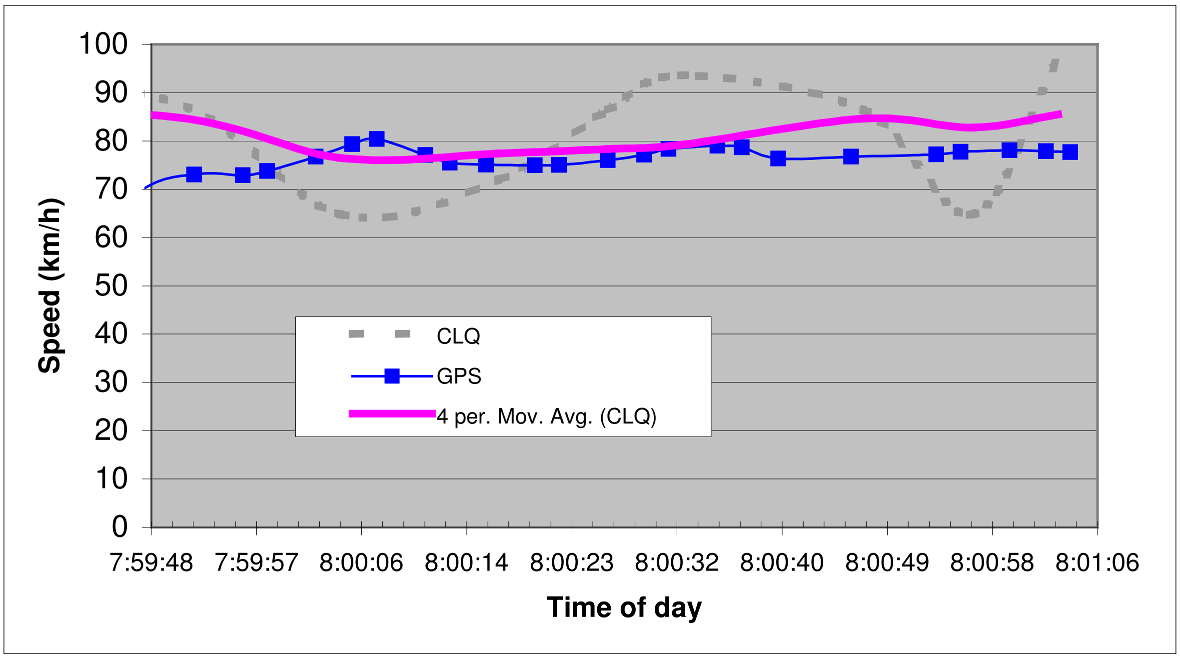

Figure 21 - Velocity comparison, March 2/01, 07:58

In the case shown in Figure 22, the test vehicle accelerated from a stop and gradually picked up speed. Once again, the heavy filter matches the GPS well yet misses the slight acceleration in the centre of the graph.

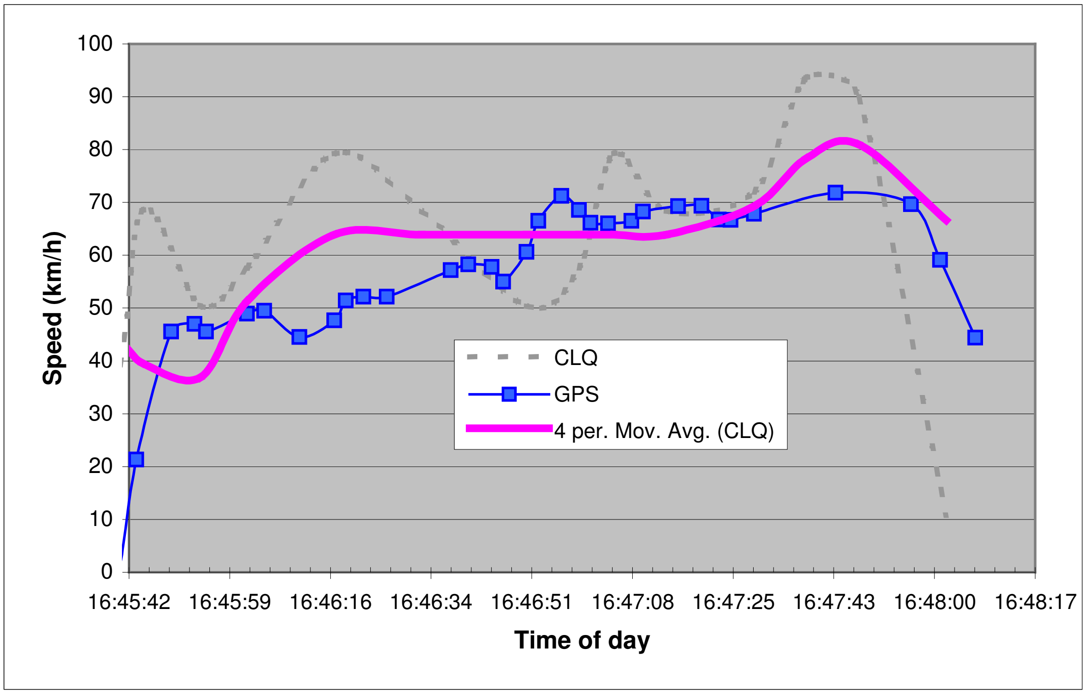

Figure 22 - Velocity comparison, March 5/01, 16:29

A light moving average filter is capable of matching the GPS as the vehicle moved at a relatively constant speed (see Figure 23).

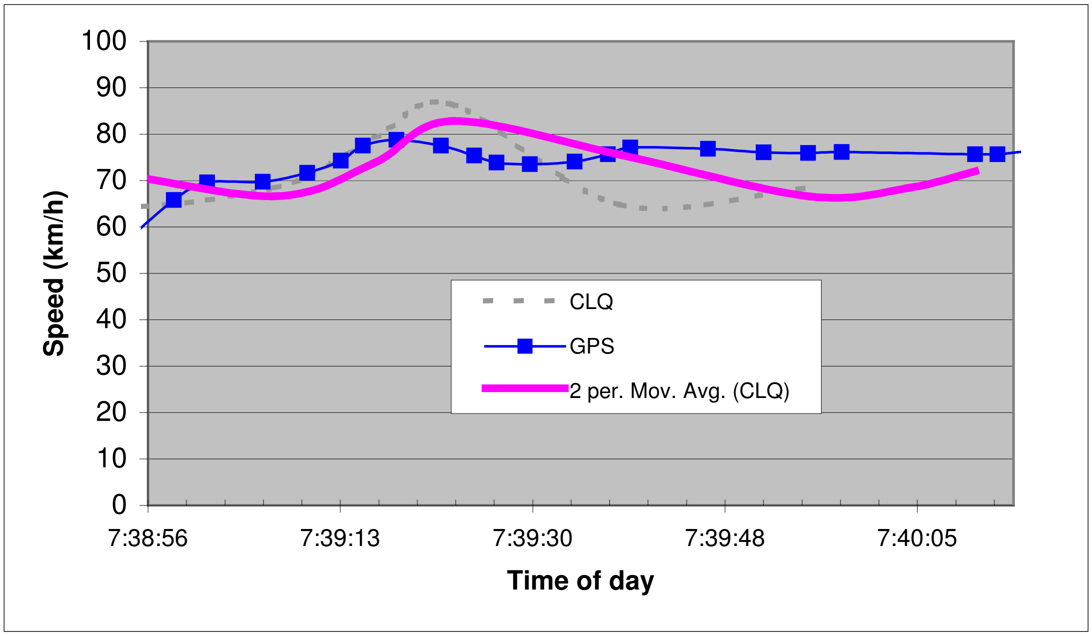

Figure 23 - Velocity comparison, March 6/01, 07:38

When traffic lights are introduced (Figure 24), it becomes more difficult to match the GPS. Filters helped to detect extremely slow or stopped vehicles. Lighter moving average filters must be used to catch sharper changes in speed.

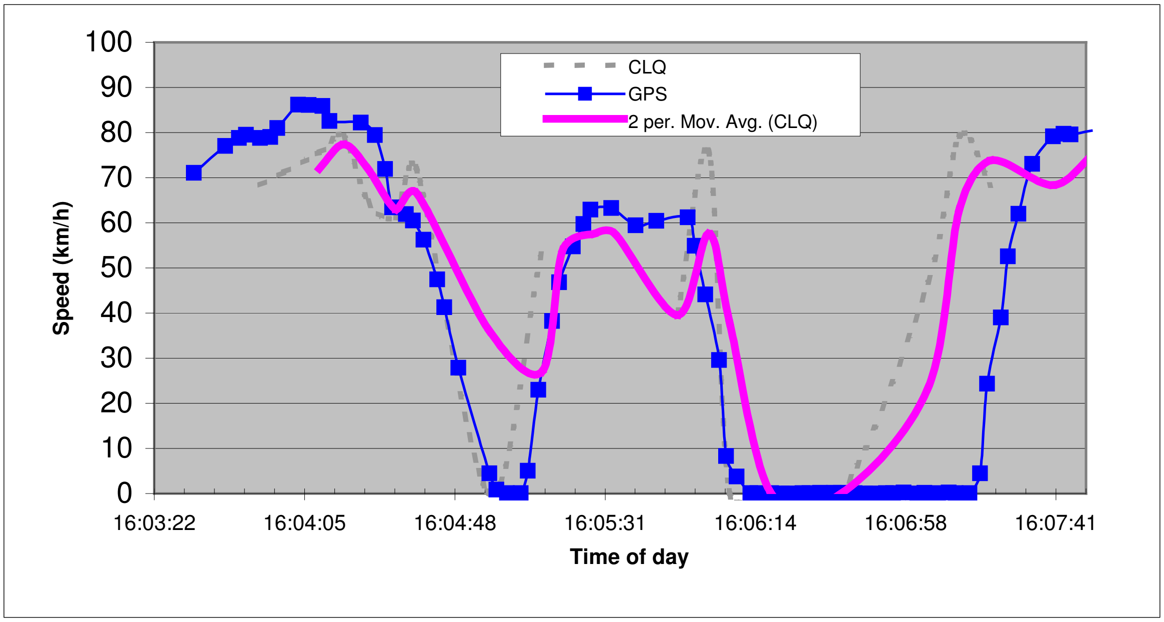

Figure 24 - Velocity comparison, March 2/01, 16:03

Despite the varying speed of the test vehicle (Figure 25), this session shows a very successful match on the benchmark.

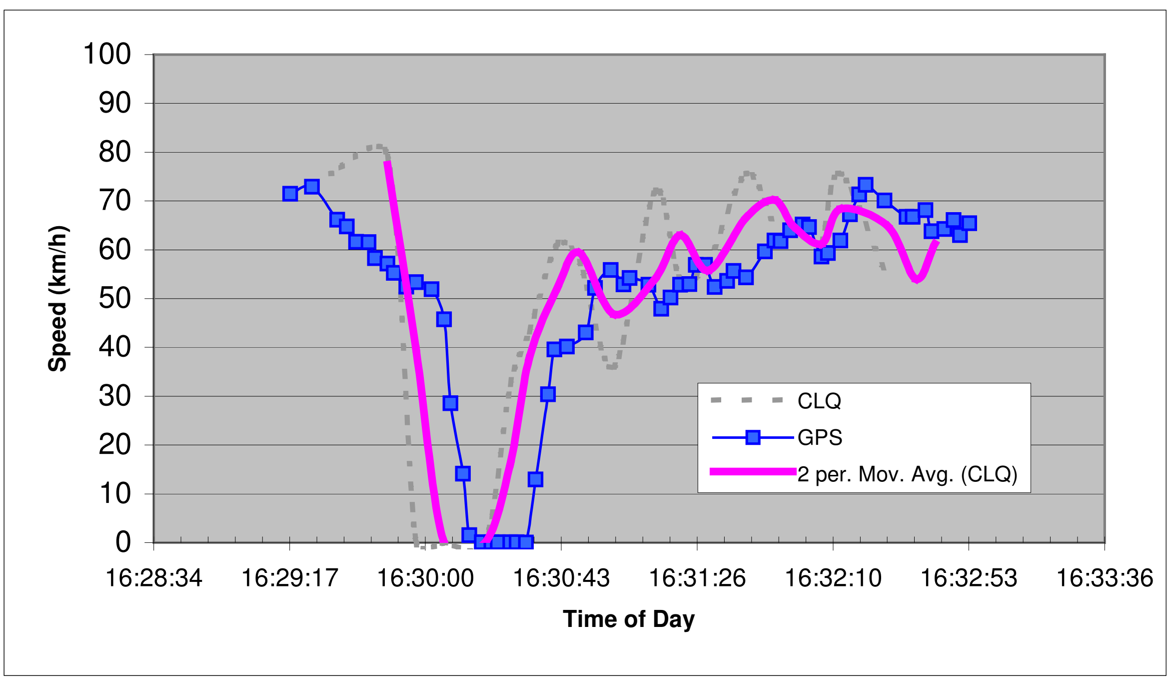

Figure 25 - Velocity comparison, March 5/01, 16:29

The use of filters provides a good match to the GPS benchmark, even as the vehicle stops for a traffic light (see Figure 26).

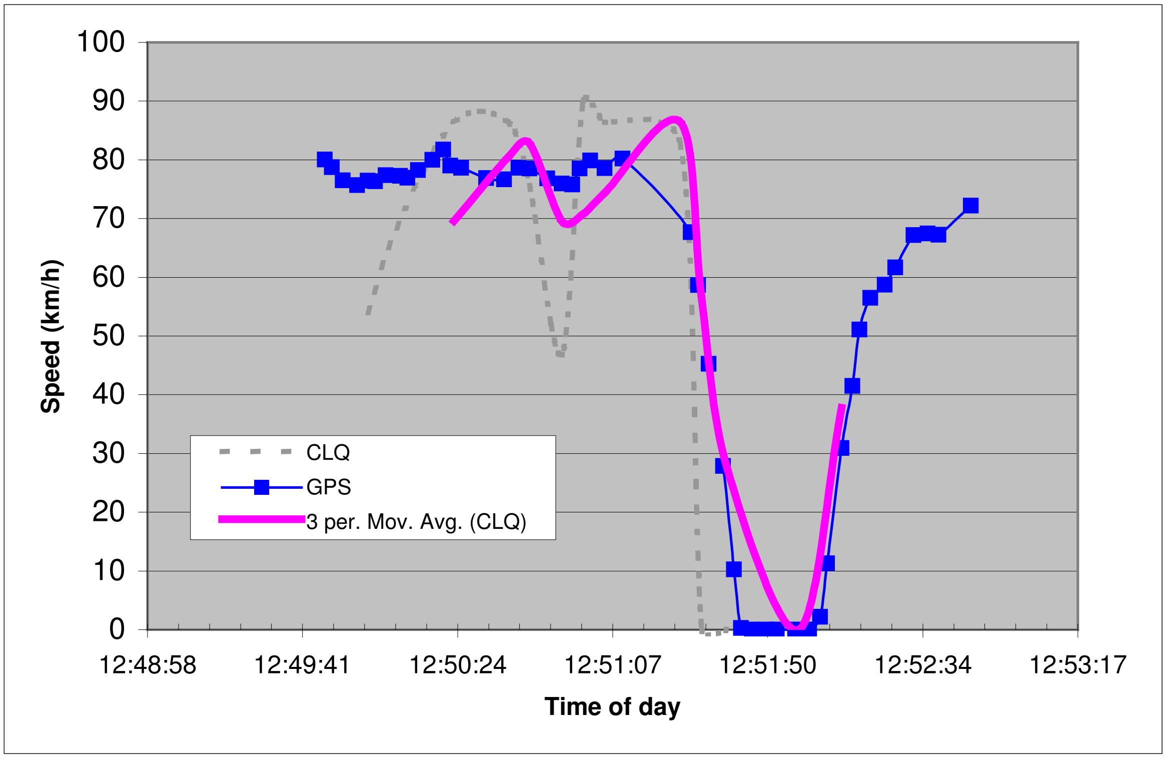

Figure 26 - Velocity comparison, March 6/01, 12:50

6.3.3 Anonymous Tracking - Velocities

The second step of the study involved collection of anonymous locations for the purpose of monitoring velocities during the day for the target roadway. Instead of tracking a vehicle for a number of minutes, as was the case in step one, this step tracked vehicles for the initial twenty to thirty seconds of their cell phone call and then dropped out of the loop. Figure 27 shows five of the shorter tracking sessions gathered.

These shorter tracking sessions were used to gather and calculate as many velocity vectors as possible during the collection period.

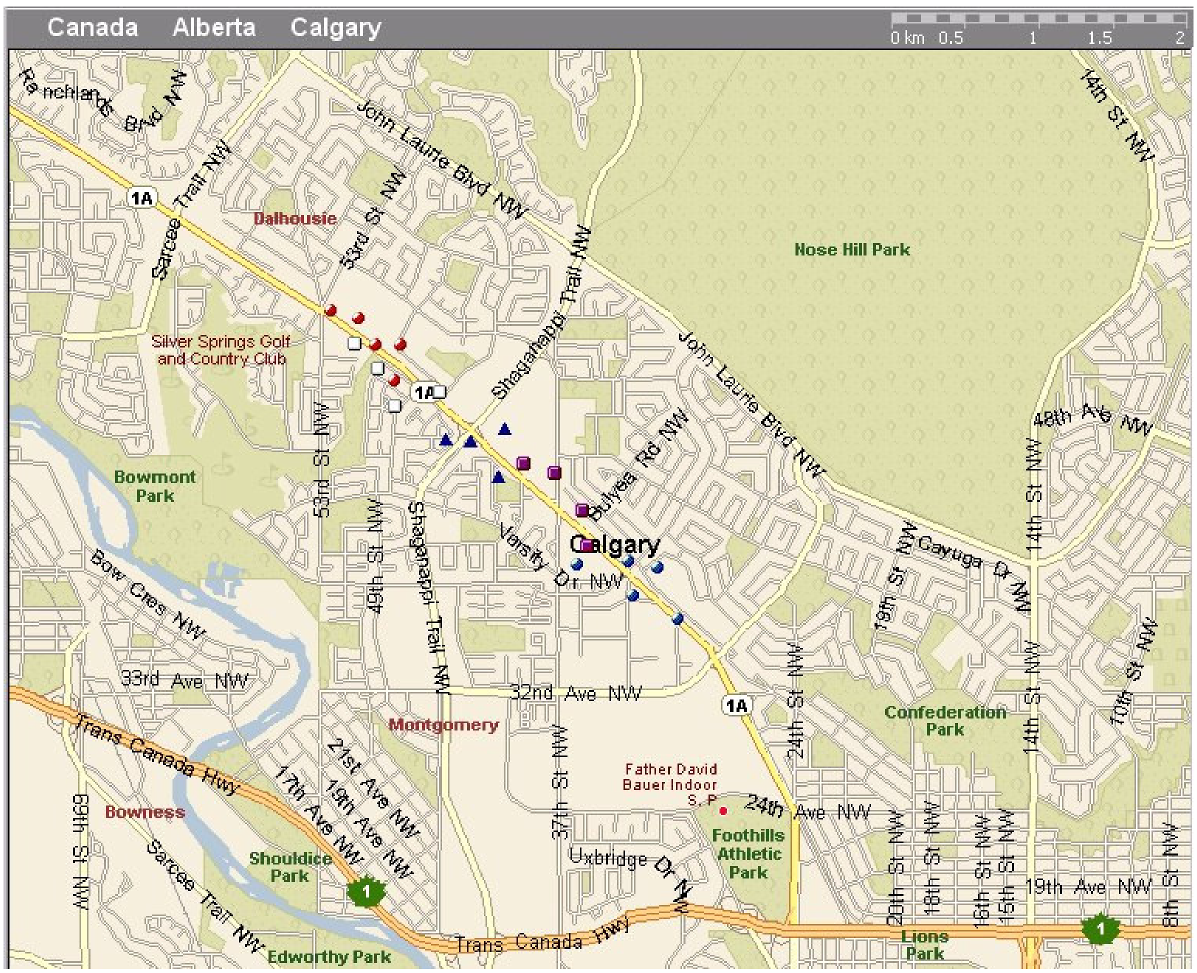

Figure 27 - Examples of anonymously collected positions

Shorter periods were chosen for a number of reasons:

- Reducing the tracking session time increases the number of sessions that can be collected in a given time.
- The larger the size of samples collected, the more statistically significant the result is.
- Anonymous collection of data using Cellocate System™ monitors an entire cell sector at a time. This is overkill when simply monitoring a section of a specific roadway. Because much of the collected data is discarded, the more sessions captured the better.
- In preliminary testing, five or six positions produced a relatively accurate velocity vector.

Figure 28 shows the collection of speeds retrieved from all lanes of the target roadway during an evening rush hour. The number of analog calls made from this roadway during the time span was 83. The most common travel speed was between 40 and 50 km/h, about half the posted speed limit.

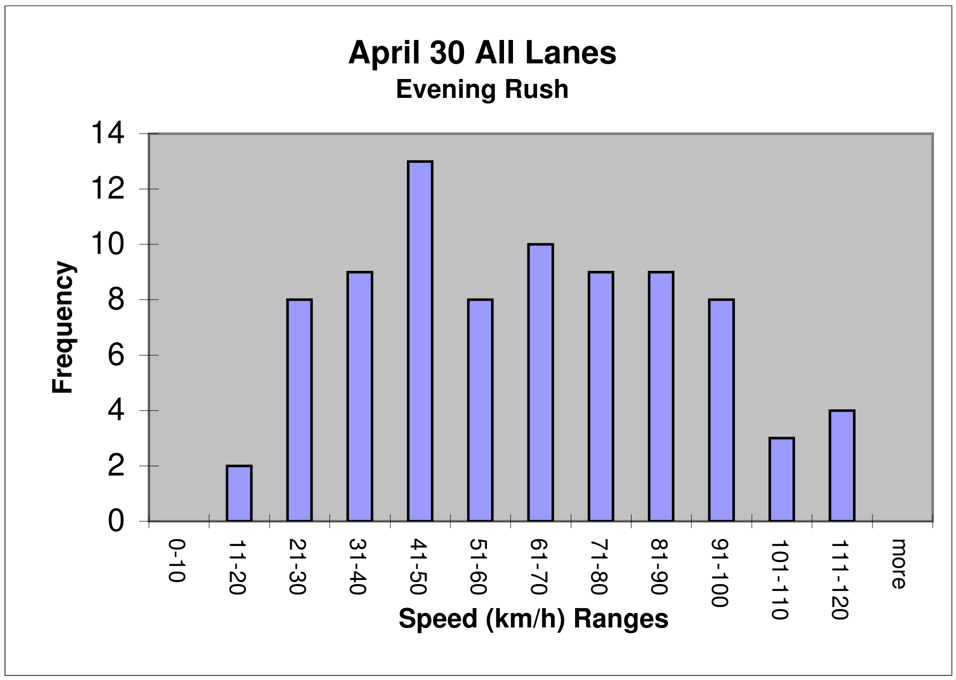

Figure 28 - Histogram of speeds during April 30/01 evening rush

In comparison, Figure 29, shows afternoon traffic speeds, which are skewed to the right and probably more limited by the speed limit of the road rather than traffic volume.

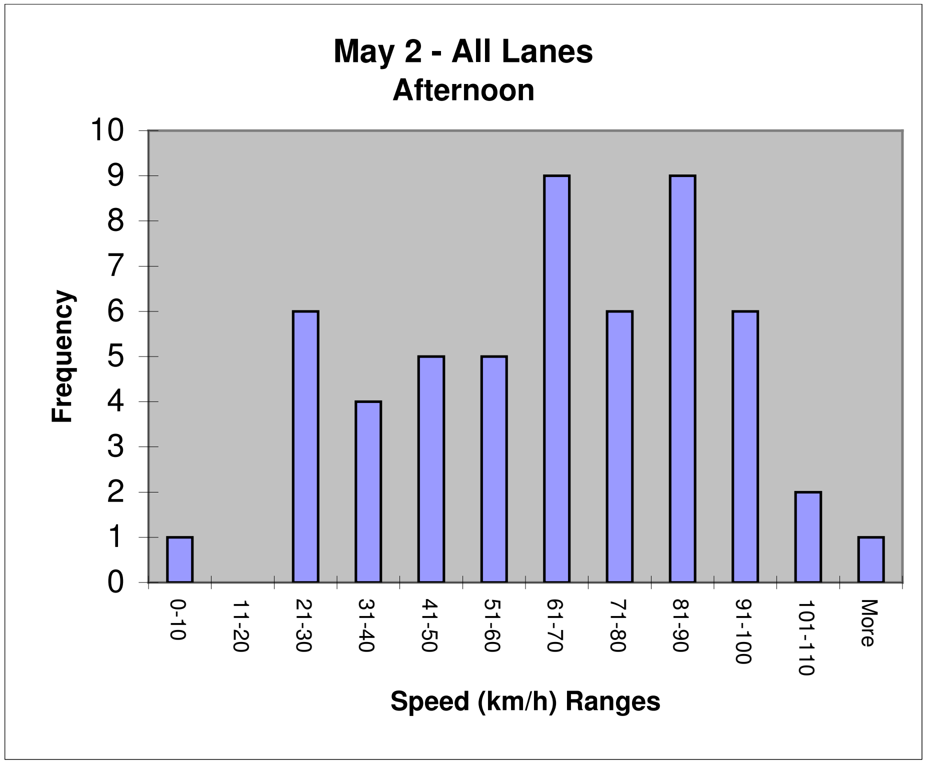

Figure 29 - Histogram of speeds during May 2/01 afternoon

It is possible to see in Figure 30 the speed shifting back to the left (slower) as volumes build toward peak level and the speed limit is no longer the limiting factor on speed.

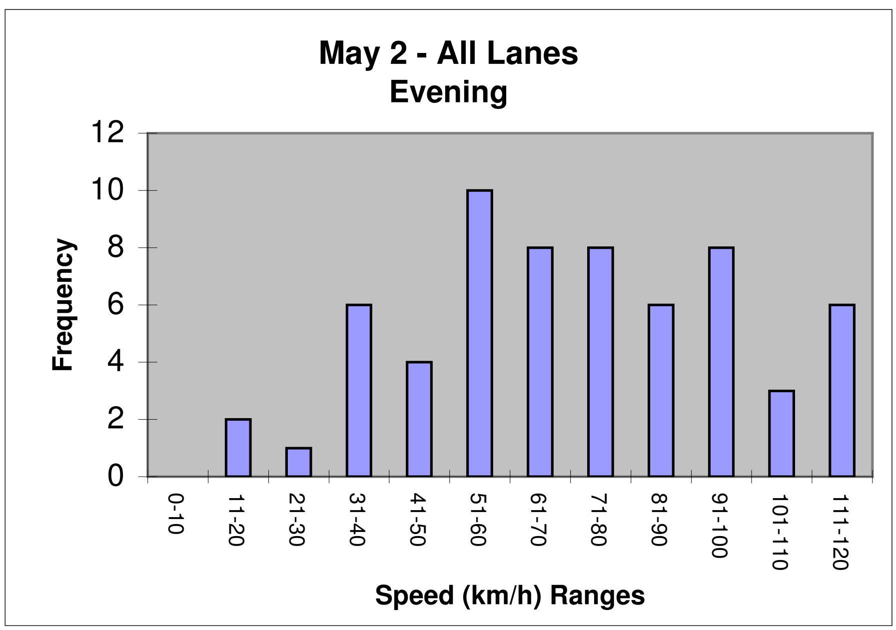

Figure 30 - Histogram of speeds during May 2/01 evening

7 ANALYSIS OF RESULTS

7.1 Data Precision in Comparison with Benchmark (GPS)

As expected, the GPS receivers in the probe vehicles performed well as a benchmark with an accuracy of 5 to 20 m, giving a very realistic view of the vehicle's path and velocity. Throughout testing, the Cellocate System™ performed at FCC phase 2 levels (within 100 m 67 percent of the time and within 300 m 95 percent of the time). This level of accuracy gives a very good view of a vehicle's path and velocity when the sample size of raw positions is large enough.

Figure 31 shows a vehicle tracked for a period of about four minutes with approximately 60 positions gathered. The fit line for the entire tracking Cellocate™ session matches the GPS path well. Reducing the number of samples (19 positions), and still getting a good fit is possible as shown in Figure 32.

Figure 31 - GPS vs. CLQ positions, March 6/01, 07:38

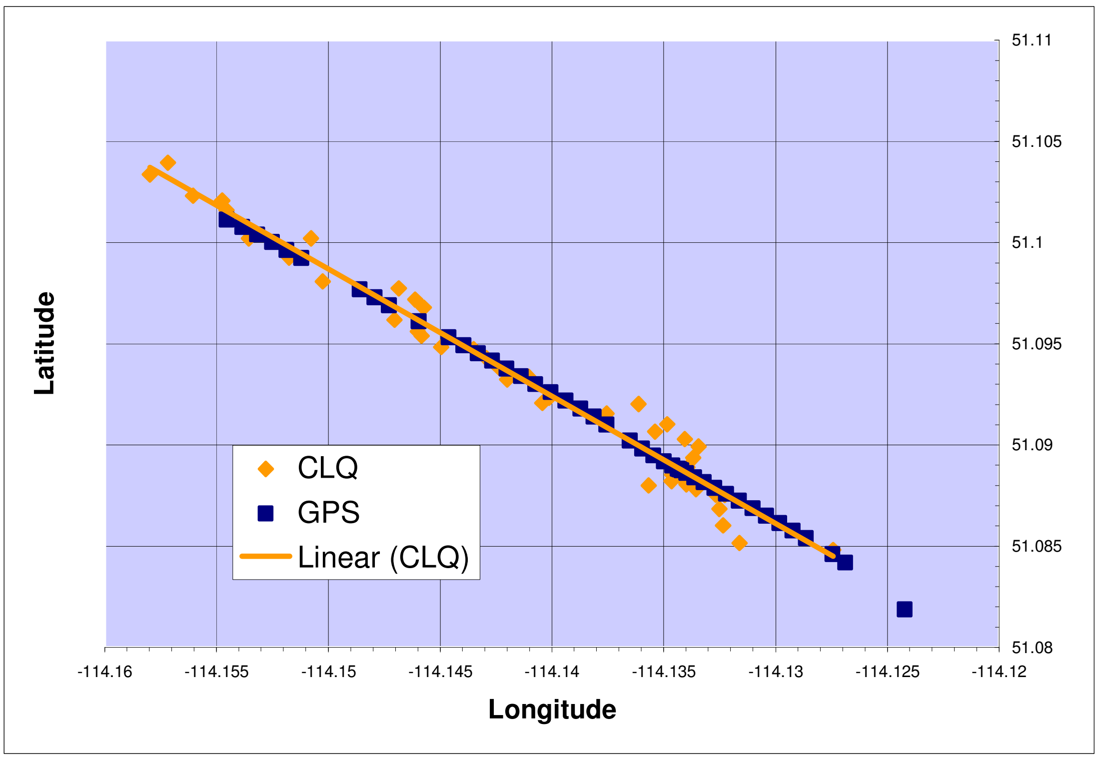

Figure 32 - GPS vs. CLQ positions, March 5/01, 11:53

The number of positions was further reduced to 5 to 7 positions when collecting anonymous data. This meant the collection period was only about 15 to 20 seconds. Moving toward the measurement of an instantaneous velocity is discussed in section 8.2

In terms of calculating speeds, Figures 33 and 34 shows the corresponding graphs (time vs. speed in km/h) for GPS vs. Cellocate™. In both cases, averaging produces a meaningful result.

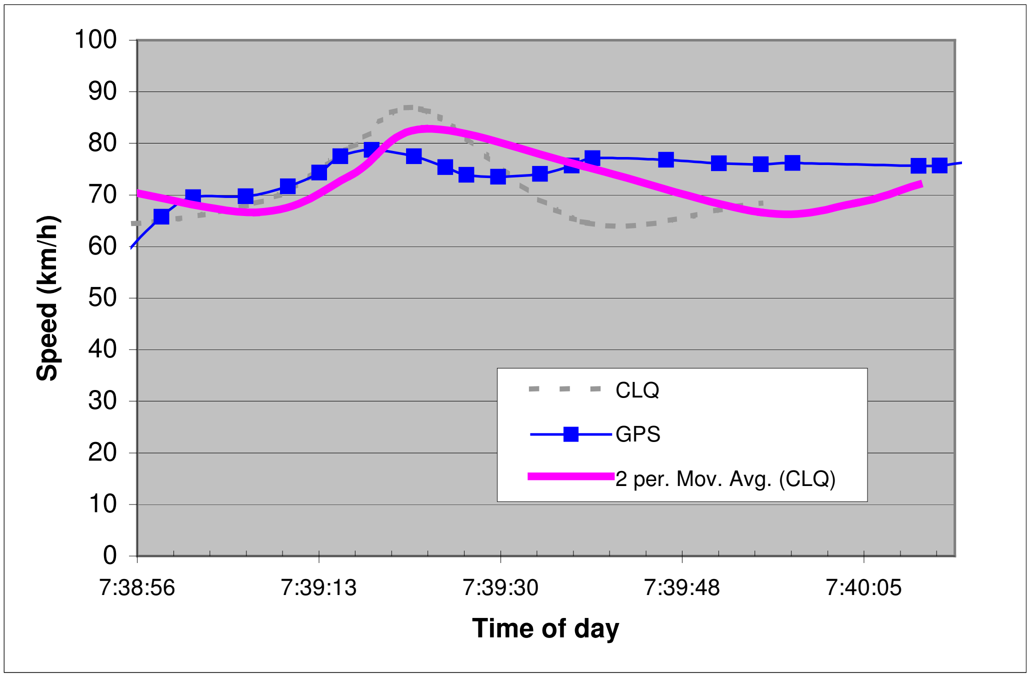

Figure 33 - GPS vs. CLQ speeds, March 6/01, 07:38

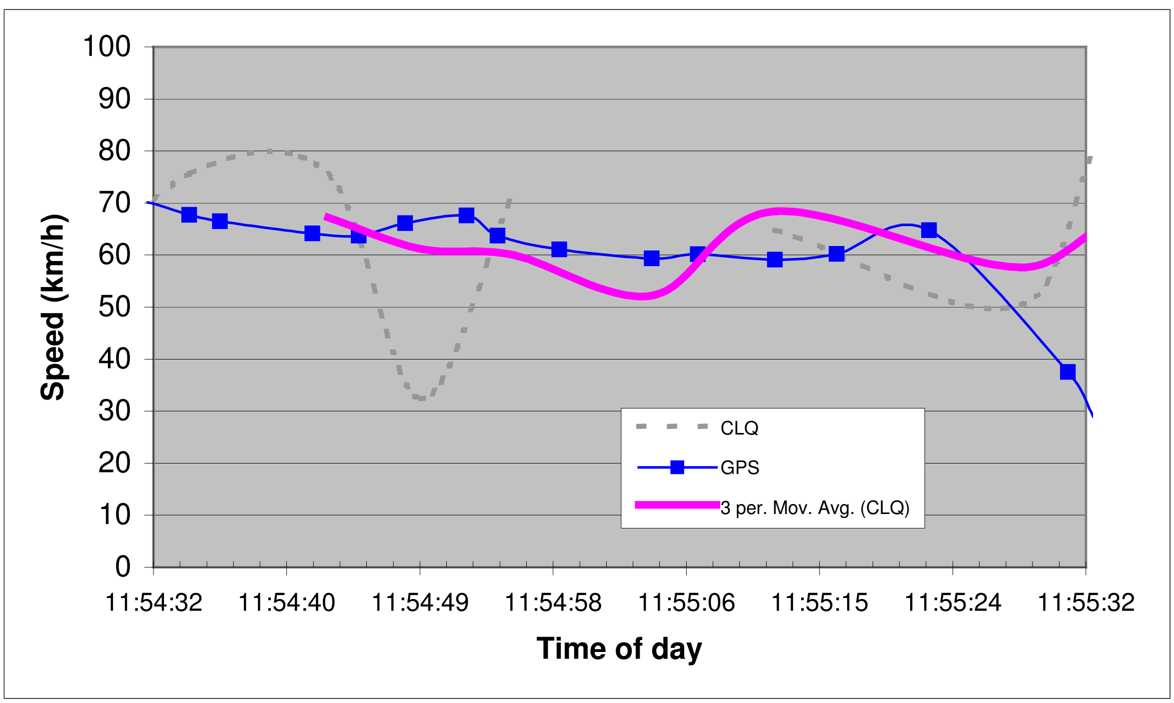

Figure 34 - GPS vs. CLQ speeds, March 6/01, 11:54

7.2 Monitoring Slow Moving Traffic

With an accuracy of 100 m 67 percent of the time and 300 m 95 percent of the time, Cellocate™ has varying requirements with regard to the radio receiver resources required to track slow moving vehicles. As with any tracking system, available accuracy determines the minimum distance an object must move before it can be detected as moving. Some rough calculations confirmed through observation are as follows:

- With an upper end error of 300 m, a vehicle must travel in excess of 300 m before the system can safely say it has actually moved.
- A vehicle travelling at 100 km/h travels at 27 m/sec or 300 m in 10.8 seconds. This represents the amount of time the location network must track the vehicle to produce an accurate velocity.
- Reducing the speed to 80 km/h, approximately 15 seconds is needed to get a good fix on the velocity.
- Reducing further to 50 km/h, the tracking time increases to 21 seconds. Finally, 30 km/h takes 36 seconds.

Obviously, the longer a probe must be tracked, the more resources are expended and the more expensive it is to operate the service. For the example of wanting to accurately monitor speeds 30 km/h and up, each probe vehicle must be tracked for approximately 30 seconds. This should not be considered negatively; as the minimum speed threshold increases, the network needs less time to track each probe. If a consumer of traffic data is satisfied with grouping speeds such as 0 - 50, 50 - 75, 75 - 90, 90+, individual probe vehicles could be tracked for a total of 20 seconds. Speeds below the 50 km/h threshold can be detected by software filters that key off of such behaviour as sudden changes in direction. Hence, these speeds can be grouped under a category labelled “slow” or “slow to stopped.”

7.3 Effects of Traffic Signals on Trail Route

The effect of having two traffic signals on the target roadway meant that probe vehicles often slowed down or even stopped while being tracked. Figure 35 shows the probe vehicle stopping at both signals.

As described in section 6, vehicles travelling slowly must be tracked longer to accurately read their speed. If a vehicle slows down or stops for a short period of time, raw data from the Cellocate System™ does not clearly reflect this. To remedy this situation, software filters can be invoked to detect behaviour associated with a slow moving vehicle (described in section 7.2). Filters applied to the data in Figure 35 zeroed out the speed because of the detection of sudden, unexpected direction changes.

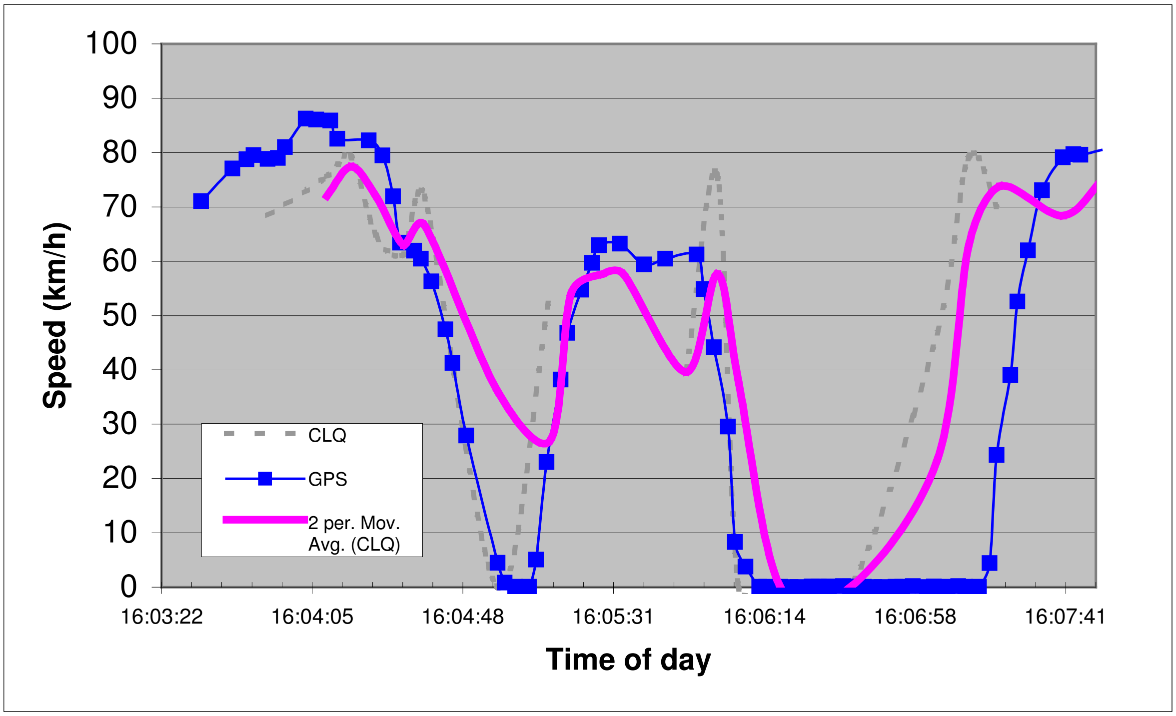

Figure 35 - GPS vs. CLQ speeds, March 2/01, 16:03

7.4 Sample Sizes Using AMPS Cell Phones as Probes

With declining usage of analog cell phones in most markets, sample sizes using AMPS cell phones as probes for traffic monitoring will most likely decline as well. During the anonymous monitoring of a Calgary cell sector, there was still sufficient air traffic to produce expected velocity results. There is no doubt that the use of analog cell phones as probes has a limited window of opportunity; how long the window is open is unclear.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Reiterated, the objectives of this study were as follows:

1. Simultaneously track a test vehicle down a stretch of roadway using GPS and the Cellocate System™. Compare the positional and velocity outputs of these two methods for similarities and differences.
2. Analyze the results of using Cellocate™ to anonymously gather velocities of vehicles on a roadway.

8.1.1 Continuous Tracking of Registered Devices / Test Vehicles

Point by point, GPS accuracies are in the order of 5 to 15 m and Cellocate™ accuracies are in the order of 100 m. Using GPS as a benchmark, the locations that comprise a Cellocate™ tracking session can provide a very accurate view of a vehicle's path down a roadway. For the purpose of monitoring traffic, various simple filtering and averaging techniques can take raw Cellocate™ data and end up with a path that is essentially equivalent to a GPS-generated path.

Similar to tracking with Cellocate™, computing vehicle velocities with Cellocate™ benefits from simple filters and averaging. GPS vs. Cellocate™ data compared very favourably when vehicles moved through the target roadway at a relatively constant speed near the speed limit of the road. Instantaneous velocities were difficult to calculate when vehicles slowed down rapidly at a traffic signal or their speed fell below a threshold. At slower speeds, errors within the 100 m accurate Cellocate System™ dominate output. Extending the length of tracking sessions and allowing data to accumulate for a time in the order of 30 seconds removed this problem. For example, tracking a vehicle for 21 seconds at 50 km/h will return an accurate result. Delays in collecting such velocities are not anticipated to be a problem for consumers of the data.

8.1.2 Anonymous Tracking / Data Collection

Anonymous collection of location data from the Cellocate System™ was a very expensive operation to perform, given that this collection cannot be focused on a particular roadway (see section 8.2, point 3). However, data was successfully collected, filtered for relevance to the target roadway, and used to calculate a velocity. The number of points collected for calculating the velocity turned out to be a little on the low side (5 to 7 positions over a 15 to 20 second period) and the number of samples was not as high as hoped (see section 8.2, point 1). However, the resulting speeds matched known traffic patterns on the target roadway.

8.2 Recommendations

Based on the results and the operation of the traffic system, there are numerous recommendations on the next areas to research and develop. In no particular order, they are:

1. Increase Sample Sizes for Anonymous Probes

Supporting a digital interface will greatly increase the number of data gathered during anonymous monitoring. Also an instantaneous velocity per position should be computed instead of using multiple positions to compute a single velocity vector. Calculations based on Doppler effects are highly possible.

2. Improve Accuracy

Any improvements to accuracy will directly improve the quality of velocity measurements. Because cell phone transmissions have not been designed to be located, there are theoretical limits on accuracy.

Recommendations on improving accuracy:

a) Design a small radio frequency (RF) transmitter with a custom highly locatable waveform that could be embedded in the battery, belt clip or circuitry of a cell phone. The device could even be directly installed in vehicles specifically for traffic-related services.

b) Work with the wireless industry to improve the locatability of cell phone transmissions.

3. Tighten Geographic Filter for Anonymous Collection of Data

Collection of anonymous data needs to be focused on targeted roadways. Monitoring a sector is a large resource drain with most of the computed locations discarded because they are not on the target roadway.

4. Integrate with an Existing ATMS

Move toward commercialization of the service by connecting to an existing ATMS. Traffic velocity data can be published from the system as it is created via a secure Internet connection.

5. Improve Filtering

The filters used for this study were relatively simplistic in nature. The intelligence of the system can be greatly improved via enhancements in this area. Addition of existing filters owned by Cell-Loc that snap positions to roadways is an obvious enhancement to make. Enhancements to handle slow moving traffic are possible as well.

6. Improve Processing

When sample sizes increase, velocities can be grouped into bins over shorter periods of time and shorter sections of roadway. This will give a very accurate and up-to-date view of traffic conditions.

REFERENCES

- Cellocate™ Beacon Network white paper
- Web sites
    - www.cell-loc.com
    - www.nearmagazine.com
    - www.wliaonline.org

APPENDICES

A. TRAFFIC TEST PLAN

Traffic Test Plan

Date: Mar 23/2001

Prepared By:
Marcia Hofmann

A1. INTRODUCTION

The Traffic Study project's objective is to determine the technical feasibility of monitoring the flow of traffic using the Cellocate™ technology.

A1.1 Purpose

The purpose of this document is to define the test plan and procedures for the Traffic Study project.

A1.2 Scope

The objective of this test is to gather data from the Cellocate™ Host System and to use the Cellocate™ Traffic Monitoring System (CTMS) to calculate velocities of positions generated by a specific cell phone in a pilot vehicle. A second set of tests will be run using anonymous tracking and a pilot vehicle. The field trial will be performed on a segment of Crowchild Trail NW within Calgary.

A1.3 Acronyms and Abbreviations

Acronym/Abbreviation	Description
AMPS	Advanced Mobile Phone System
CTMS	Cellocate Traffic Monitoring System
GPS	Global Positioning System
PCDS	Position Collection and Distribution System
Phase 1	The predefined centroid of the cell sector
Phase 2	A location that the Cellocate™ System has calculated using TDOA
TDOA	Time Difference of Arrival

A2. REQUIREMENTS

A2.1 Equipment Used

The following equipment will be used during testing:

1. Nokia Dual Mode Cellular Phone, Model 6185. Cell phone number (403) 863-9137 in AMPS mode, used for CTMS data gathering.
2. Headset for the Nokia Model 6185.
3. Nokia Dual Mode Cellular Phone, Model 6185. Phone Number (403) 807-8202 used for communicating with the office and set to Digital mode.
4. Magellan GPS receiver.

A2.2 System State

The following provides the state of the system at the time of testing.

Product Releases:

Base Station AMPS Firmware version: Build 38
Host Software version: Build 2.0.8 SP02
PCDS Build 5a - SP14

A2.3 Road Segment

The requirements of the Traffic Study road segment are:

- Minimum 2 KM
- Highway

Based on our current coverage area, we have chosen Crowchild Trail North - between 32nd Avenue and 53 Street NW. The speed limit on this segment of road is 80 km/h and consists of two potential stoplights: one at Brisebois Drive and the other at Northland Drive. Figure A-1 shows this segment of Crowchild Trail.

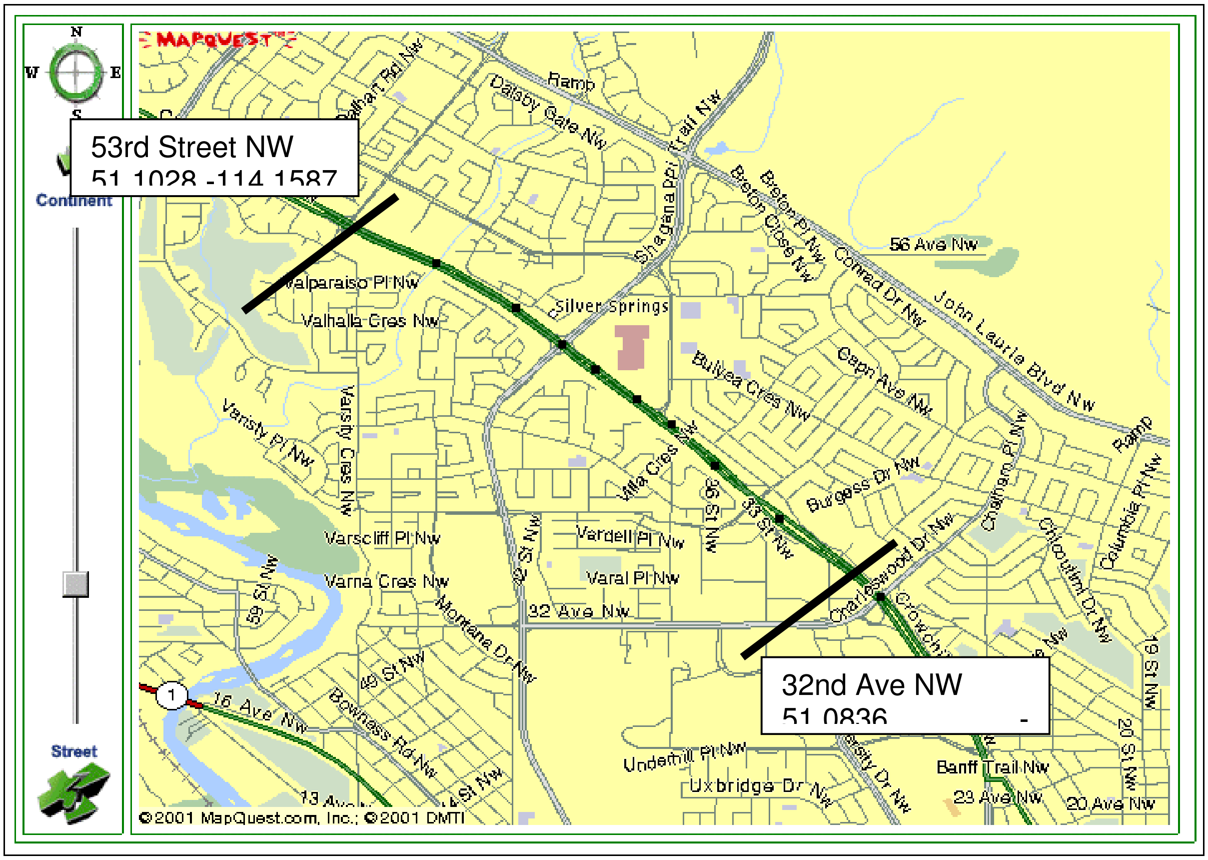

Figure A-1 Crowchild Trail road segment

A2.4 Location Confidence

For the Traffic Study to be successful, the Cellocate™ Host System must be generating positions that are Phase 2. Phase 1 locates are not used by CTMS.

A3. TEST PREPARATION - PILOT VEHICLE ONLY

Configuration parameters in the Host and PCDS Systems will be set prior to testing. These parameters may change during the course of the testing cycle. All parameters changed within a test cycle will be documented in the Call Sheet provided as Appendix 1.

A3.1 GPS Receiver Configuration

The sampling rate will be set to 1/second.

A3.2 Host Configuration Parameters

Host will be configured to perform continuous tracking on device (403) 863-9137; and will generate a location every 3 seconds.

A3.3 PCDS Configuration Parameters

PCDS will be set up to collect the raw data from the host in the format of the location information message, which can then be 'replayed' through a host simulator program into the CTMS as required. The parameter exportData in the positionrouter.xml file needs to be set to 'true' for the host location information messages to be saved to a data file. Additionally, the CTMS consists of three configuration files that are used to set up the application:

1. Master.Properties
2. CalgaryRoad.xml
3. TrafficCityList.xml

Master.Properties file has the following parameters:

Parameter	Value	Description
TrafficDataChannelName	Calgary-MIN	Channel used for collecting positions
TrafficWatchChannelName	Calgary-Traffic-Processed	Channel name used CTMS
RawPositionChannelName	Calgary-Traffic-Raw	Channel name used potential 3rd party partners
MemUsageThresholdMB	30	Amount of memory set aside for this PCDS instance
SamplingPeriodInSec	30	How often to generate a velocity calculation
PositionAgeThresholdInSec	60	If position is older than this value, this new position becomes point 1
CalculationCodeUsed	1	Manual velocity calculation
DirectionFilterBuffer	80	In degrees from road segment to generated position
SpeedLimitBufferInKMPerH	• 30	If velocity is > 110 (80 KM + 30) then it is not included in

		the calculations
PositionGarbageCollectorTimerInMin	5	Remove data older than 5 minutes from the buffer
CoordinatesToPolygon	TRUE	Include points that fall within the defined polygon only
FirstToLastPtCalculation	TRUE	Calculate point 1-2, 2-3 and 1-3 (based on the Number Of PositionsThreshold)
ComputeOneTwoPosition	TRUE	Calculate point 1-2, 2-3
NumberOfPositionsThreshold	3	Once this value is reached, perform a velocity calculation
CentralMeridian	-117.0	
TrafficCityListFile	./cfg/trial/trafficCityList.xml	Configuration file
• TrafficSetupFile	./cfg/trial/calgaryRoads.xml	Configuration file
UpdateTrafficSetToFile	TRUE	All configuration changes made through the Administration section of CTMS will be saved to the Traffic configuration files
Context	/ContentConsumers/Trial/	System configuration parameter
LogFileName	Traffic	Name of file to log system information
RolloverHours	24	When to roll the system log file
DebugDisplayLevel	1	Debug information
DebugFileLevel	Screen	Debug information
TrafficDataLogging	TRUE	Whether to log the data to a file or not
TrafficRawLogFileName	TrafficRawPosition	Name of the raw data file
TrafficVelocityLogFileName	TrafficVelocity	Name of the velocity calculated file
DataLogRolloverHours	240	When to roll the data files - don't want it to reset during a test
Delimiter	44	Comma delimited
LogMin	TRUE	Should the cell phone number be captured as part of the file
LogAverageVelocity	FALSE	As part of the TrafficVelocityLogFile include the average velocity calculation
UsePCDSTimeStamp	FALSE	Flag to determine which timestamp value to use.

The CalgaryRoad.xml file is created using the Traffic Monitoring administration application.

This file contains the co-ordinates of the road segment selected as well as the polygon created. Figure A-2 shows the polygon around Crowchild Trail NW. The parameters used to draw this polygon are on the left-hand side; the values are represented in metres.

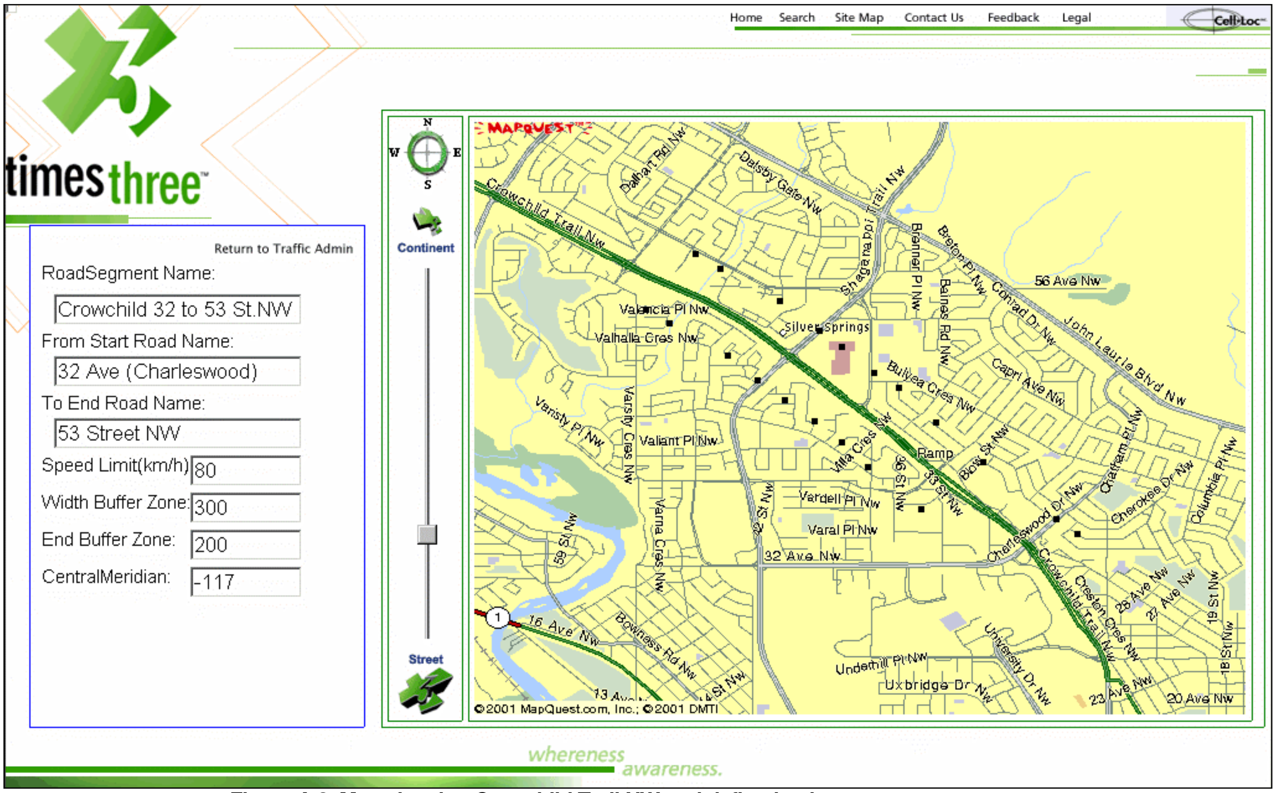

Figure A-2 Map showing Crowchild Trail NW and defined polygon

The TrafficCityList.xml file contains a listing of cities and their central GPS co-ordinates. Here is how it is set up for the test:

<TrafficCityCoverage>
<cityCentreCoordinate>
<name>**Calgary**</name>
<WGS84Coordinate>
<latitude>51.0</latitude>
<longitude>-114.0</longitude>
</WGS84Coordinate>
</cityCentreCoordinate>
</TrafficCityCoverage>

A3.4 Cell Phone Configuration

The cell phone will be registered and enabled within the Fleet Tracking service, with 24 x 7 positioning. Ensure that the cell phone has been configured for continuous tracking in the Host System.

A4. TEST PROCEDURE - PILOT VEHICLE ONLY

The requirement of the Traffic Study is to perform several tests. We will perform tests at three different times of the day for a period of 4 days. For each day, we will perform three test cycles:

1. Morning rush hour (between 07:30 and 09:00)
2. Noon hour (between 11:45 and 13:15)
3. Evening rush hour (between 16:00 and 18:00).

This test procedure requires two people, one in the car with the cell phone and GPS unit and a second in the office to receive and document the calls.

It is the responsibility of the person documenting the calls to ensure that all the system configuration parameters are captured at the beginning of each test cycle within the Call Sheets.

The actual test procedure for one test cycle is as follows:

1. Have the driver go to Crowchild and 24th Street NW
2. The driver turns on the GPS receiver and leaves it on
3. The driver calls the office (using the Digital mode cell phone) to notify the beginning of the test cycle
4. The driver begins driving West on Crowchild. When he passes under the 32nd Avenue overpass, he presses 'Send' to call the office - beginning the call
5. The driver proceeds along Crowchild until 53rd Street NW. The call is ended. During the call, the driver tells the person at the office information about the drive, i.e. stoplights encountered, traffic accident, etc.
6. The driver turns around to head East on Crowchild.
7. When the driver passes the overpass near the Dalhousie Gate Shopping Centre entrance, he presses 'Send' to call the office - beginning the call.
8. The driver proceeds along Crowchild until 24th Street. The call is ended. During the call, the driver tells the person at the office information about the drive, i.e. stoplights encountered, traffic accident, etc.
9. Repeat the above test - perform two passes for each test cycle.

If the call is dropped by the Cellocate™ Host System during a pass, this pass must be repeated. The sequential order of the passes does not matter. The information gathered during the dropped call will be ignored.

A5. DATA COLLECTION - PILOT VEHICLE ONLY

Data is collected in the GPS unit, the Cellocate™ Host System and the PCDS System. Each day the data will be gathered from the GPS receiver and PCDS and placed into an Excel spreadsheet. Each day, a separate Excel workbook will be created. The layout of this workbook can be found in Appendix A2.

A5.1 GPS Data

The information gathered from the GPS receiver will be used as a base line for the CTMS. Differential corrections will be applied to the GPS data, using data purchased from a local Base Station. This will produce accuracy levels of approximately ± 2M.

The Geomatics group will supply the data to be included in the Excel workbook, in the appropriate sheet.

A5.2 Host Data

The Cellocate™ Host System will capture a flat file containing all location information for the cell phone that we are tracking. There are no plans at this time to use this data; however, it is being captured as reference if required.

A5.3 PCDS Data

Data from the PCDS System will be collected in raw data files that are generated by the Cellocate™ Host System. The CTMS also creates two data files.

The two data files captured by PCDS generated by the Cellocate™ Host System are:

1. CalgaryLocationInfoMessage.csv
2. CalgaryLocationInfoMessage.host

All the positions that are generated by the Cellocate™ System are captured in these two files.
The .csv file is created so it can be included in the Excel spreadsheet in place of the CTMS data if required. See Appendix A3 for a sample of the .csv file

The purpose of the .host file is to create a file in a format that our host simulator program can use so we can 'replay' the data through the CTMS as required. This gives us the opportunity to change the parameters that we are using to calculate velocities. See Appendix A4 for a sample of the .host file.

The two data files created by CTMS has data files that are captured during testing:

1. Position information
2. Calculated velocity

The position information contains all positions generated during the test cycle that fall within the defined polygon. Any positions that fall outside of the polygon are not included in this file. Phase 1 data will also not be included in this file. However, for this test, all position information is stored in the Fleet Tracking database and can be used if required. See Appendix A5 for a sample of the position information file.

The velocity information contains the velocity between points 1 and 2 as defined in the Master.properites configuration file. See Appendix A6 for a sample of the velocity data file.

A5.4 Call Sheets

The Call Sheets included in Appendix A1 contain the Host Data file name, PCDS data file name and any additional information about the pass that should be captured, such as the driver had to stop at a set of stoplights, there was an accident, etc. This information is captured manually and may not be required as part of the test results. The GPS receiver data will be used for the base line velocity calculations.

If required, the additional information about the call can be captured and applied to the workbook.

A6. TEST PREPARATION - ANONYMOUS

The configuration parameters in the Host System will be set prior to testing. These parameters may change during the course of the testing cycle. All parameters changed within a test cycle will be documented in the Excel spreadsheet in Appendix A2.

A6.1 GPS Receiver Configuration

The GPS receiver will not be used for this test cycle.

A6.2 Host Configuration Parameters

Host will be configured to do anonymous locates on azimuth C at the Fortress Supersite using Control Channel 338. This may change during testing. Tracking of a call will occur for 30 seconds and then be dropped.

A6.3 PCDS Configuration Parameters

PCDS will not be used for this test cycle.

A7. TEST PROCEDURE - ANONYMOUS

The requirement of the Traffic Study is to perform several tests. We will perform a single test or multiple tests every day for a period of five days.

The actual test procedure for one test cycle is as follows:

1. Turn anonymous on the selected sector, leaving it on when possible.
2. Ensure that the call data is being logged to the host system.
3. Periodically send a probe vehicle equipped with GPS through the monitored zone as a control.
4. Send collected data to the Geomatics group for processing.

It is the responsibility of the person setting the host system configuration settings to document the sector information if it changes.

A8. DATA COLLECTION - ANONYMOUS

Data is collected in the Cellocate™ Host System. Each day the data will be gathered and placed into an Excel spreadsheet. Each day, a separate Excel workbook will be created. The layout of this workbook can be found in Appendix A2.

Data from the GPS probe vehicle is gathered in the same manner as the first phase of the study.

A9. RESULTS

Once all the test cycles are complete for 4 days, the data gathered would be turned over to the Project Team for review. The information will then be added to the Traffic Study plan and forwarded to Michael De Santis.

A9.1 Pilot Vehicle Only

All data was collected as per the Cellocate™ Host System configuration and the data was plotted against the GPS data collected. The data generated by the Host System appears to be accurate after plotting through Excel application against the GPS data collected.

From these tests we concluded that the CTMS application needs to be refined (through parameter settings) in order to provide accurate velocities. We have captured the data in the .host file format and will continue to work with the CTMS using the host simulator program to refine the parameter settings.

A9.2 Anonymous

Preliminary results show that it is very difficult to coordinate anonymous locations with a GPS probe vehicle driving through the monitored zone. Velocity information from anonymous cell phone users can also be sanity checked using a basic understanding of traffic patterns within the monitored area during peak/normal hours.

Appendices

Appendix A1 - Call Sheets

Traffic Testing - Crowchild Trail NW

Test Cycle#:____ Collected By:_________ Driver:_________ Date:_______ Start Time:_______

Host System Config Notes: ____
____
____
____

PCDS System Config Notes:____
____
____

Call #1 Direction NW **Data File:**

Points	Time	Speed	Notes
Charleswood Dr			
Brisebois Dr			
Northland Dr			
Shaganappi Dr			
Dalhousie Gate			

Call #2 Direction SE **Data File:**

Points	Time	Speed	Notes
Dalhousie Gate			
Shaganappi Dr			
Northland Dr			
Brisebois Dr			
Charleswood Dr			

Call #3 Direction NW **Data File:**

Points	Time	Speed	Notes
Charleswood Dr			
Brisebois Dr			
Northland Dr			
Shaganappi Dr			
Dalhousie Gate			

Call #4 Direction SE **Data File:**

Points	Time	Speed	Notes
Dalhousie Gate			
Shaganappi Dr			
Northland Dr			
Brisebois Dr			
Charleswood Dr			

Appendix A2 - Data Workbook

GPS Data Collection Sheet

TimeStamp	Latitude	Longitude	Speed (m/s)	Direction	Road Segment (Description)

Cellocate System Data Collection Sheet

TimeStamp	Latitude	Longitude	Speed (m/s)	Direction	Road Segment (Description)

Velocity Comparison

	Speed (m/s)		
Time Stamp	CTMS	GPS	Road Segment (Description)

Appendix A3 - Sample .csv File

4038639140	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:23:56	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:1	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639134	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:6	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:11	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639134	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:16	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:21	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:26	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.10368204	-114.1617105	5665186.6	698700.3	3/2/2001_22:24:31	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.09314301	-114.141238	5664070.4	700178.8	3/2/2001_22:24:36	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES
4038639140	51.09314301	-114.141238	5664070.4	700178.8	3/2/2001_22:24:41	02/27/2001_14:32:54_PM	0	0	2	eSOLUTION_TYPE_LEAST_SQUARES

Appendix A4 - Sample .host file

point1 < eMessageType eMESSAGE_TYPE_LOCATIONINFO dtmDateTimeOfCall 02/27/2001_14:32:54_PM ePageType ePAGE_TYPE_ORIGINATION cnRvc 607 byMinLen 16 telMin 4038639140000000000 byCalledNumLen 16 telCalledNum 0000000000000000 dNorthing 5665186.60000000 dEasting 698700.30000000 dHeight 1000.00000000 eSolutionType eSOLUTION_TYPE_LEAST_SQUARES dCovarXX 0.00000000 dCovarYY 0.00000000 dCovarXY 0.00000000 dCovarZZ 0.00000000 piOriginator 6184 sqCallEventNum 4774 sqNumSamplesRemaining 0 ePositioningType ePOSITIONING_TYPE_REGISTERED dSpeed 0.00000000 dDirection 0.00000000 >

point2 < eMessageType eMESSAGE_TYPE_LOCATIONINFO dtmDateTimeOfCall 02/27/2001_14:32:54_PM ePageType ePAGE_TYPE_ORIGINATION cnRvc 607 byMinLen 16 telMin 4038639140000000000 byCalledNumLen 16 telCalledNum 0000000000000000 dNorthing 5665186.60000000 dEasting 698700.30000000 dHeight 1000.00000000 eSolutionType eSOLUTION_TYPE_LEAST_SQUARES dCovarXX 0.00000000 dCovarYY 0.00000000 dCovarXY 0.00000000 dCovarZZ 0.00000000 piOriginator 6184 sqCallEventNum 4774 sqNumSamplesRemaining 0 ePositioningType ePOSITIONING_TYPE_REGISTERED dSpeed 0.00000000 dDirection 0.00000000 >

point3 < eMessageType eMESSAGE_TYPE_LOCATIONINFO dtmDateTimeOfCall 02/27/2001_14:32:54_PM ePageType ePAGE_TYPE_ORIGINATION cnRvc 607 byMinLen 16 telMin 4038639134000000000 byCalledNumLen 16 telCalledNum 0000000000000000 dNorthing 5665186.60000000 dEasting 698700.30000000 dHeight 1000.00000000 eSolutionType eSOLUTION_TYPE_LEAST_SQUARES dCovarXX 0.00000000 dCovarYY 0.00000000 dCovarXY 0.00000000 dCovarZZ 0.00000000 piOriginator 6184 sqCallEventNum 4774 sqNumSamplesRemaining 0 ePositioningType ePOSITIONING_TYPE_REGISTERED dSpeed 0.00000000 dDirection 0.00000000 >

point4 < eMessageType eMESSAGE_TYPE_LOCATIONINFO dtmDateTimeOfCall 02/27/2001_14:32:54_PM ePageType ePAGE_TYPE_ORIGINATION cnRvc 607 byMinLen 16 telMin 4038639140000000000 byCalledNumLen 16 telCalledNum 0000000000000000 dNorthing 5665186.60000000 dEasting 698700.30000000 dHeight 1000.00000000 eSolutionType eSOLUTION_TYPE_LEAST_SQUARES dCovarXX 0.00000000 dCovarYY 0.00000000 dCovarXY 0.00000000 dCovarZZ 0.00000000 piOriginator 6184 sqCallEventNum 4774 sqNumSamplesRemaining 0 ePositioningType ePOSITIONING_TYPE_REGISTERED dSpeed 0.00000000 dDirection 0.00000000 >

point5 < eMessageType eMESSAGE_TYPE_LOCATIONINFO dtmDateTimeOfCall 02/27/2001_14:32:54_PM ePageType ePAGE_TYPE_ORIGINATION cnRvc 607 byMinLen 16 telMin 4038639134000000000 byCalledNumLen 16 telCalledNum 0000000000000000 dNorthing 5665186.60000000 dEasting 698700.30000000 dHeight 1000.00000000 eSolutionType eSOLUTION_TYPE_LEAST_SQUARES dCovarXX 0.00000000 dCovarYY 0.00000000 dCovarXY 0.00000000 dCovarZZ 0.00000000 piOriginator 6184 sqCallEventNum 4774 sqNumSamplesRemaining 0 ePositioningType ePOSITIONING_TYPE_REGISTERED dSpeed 0.00000000 dDirection 0.00000000 >

Appendix A5 - Sample Position Information

```
TestPhone,51.103065386,-114.1550352583,Tue Feb 20 15:41:19 GMT-07:00 2001
TestPhone,51.102164701,-114.1547075144,Tue Feb 20 15:41:24 GMT-07:00 2001
TestPhone,51.100601455,-114.1539712873,Tue Feb 20 15:41:29 GMT-07:00 2001
TestPhone,51.102540673,-114.1542567236,Tue Feb 20 15:41:34 GMT-07:00 2001
TestPhone,51.103154606,-114.1505589422,Tue Feb 20 15:41:39 GMT-07:00 2001
TestPhone,51.100195897,-114.153796037,Tue Feb 20 15:41:49 GMT-07:00 2001
TestPhone,51.100218469,-114.150324354,Tue Feb 20 15:41:54 GMT-07:00 2001
TestPhone,51.097755518,-114.1516423746,Tue Feb 20 15:41:59 GMT-07:00 2001
TestPhone,51.098554156,-114.1502565837,Tue Feb 20 15:42:04 GMT-07:00 2001
TestPhone,51.097775168,-114.1493122627,Tue Feb 20 15:42:09 GMT-07:00 2001
TestPhone,51.096963136,-114.1467080102,Tue Feb 20 15:42:14 GMT-07:00 2001
TestPhone,51.098929066,-114.1461689895,Tue Feb 20 15:42:19 GMT-07:00 2001
TestPhone,51.097799099,-114.1450259436,Tue Feb 20 15:42:24 GMT-07:00 2001
TestPhone,51.097268131,-114.1451348365,Tue Feb 20 15:42:29 GMT-07:00 2001
TestPhone,51.096641945,-114.1456508923,Tue Feb 20 15:42:34 GMT-07:00 2001
TestPhone,51.097088995,-114.144940948,Tue Feb 20 15:42:39 GMT-07:00 2001
TestPhone,51.096061631,-114.1441270191,Tue Feb 20 15:42:44 GMT-07:00 2001
TestPhone,51.096179037,-114.144172219,Tue Feb 20 15:42:49 GMT-07:00 2001
TestPhone,51.095994239,-114.1438145169,Tue Feb 20 15:42:54 GMT-07:00 2001
TestPhone,51.102540673,-114.1542567236,Tue Feb 20 15:42:59 GMT-07:00 2001
TestPhone,51.095319088,-114.1426937245,Tue Feb 20 15:43:04 GMT-07:00 2001
TestPhone,51.095119262,-114.139835421,Tue Feb 20 15:43:09 GMT-07:00 2001
TestPhone,51.094069083,-114.1400396269,Tue Feb 20 15:43:14 GMT-07:00 2001
TestPhone,51.094032683,-114.1403524186,Tue Feb 20 15:43:19 GMT-07:00 2001
```

Appendix A6 - Sample Velocity Calculated Data

```
29,170,Tue Feb 20 18:33:49 GMT-07:00 2001
27,87,Tue Feb 20 18:34:09 GMT-07:00 2001
28,2,Tue Feb 13 15:31:28 GMT-07:00 2001,2,60,1.0,
```

B. EXAMPLE OF DATA COLLECTED

Time Stamp	GPS Latitude(DD)	GPS Longitude(DD)	GPS Speed(km/h)	CLQ Latitude(DD)	CLQ Longitude(DD)	CLQ Speed(km/h)	Error(km/h)
03/06/01_7:25:56 PM	51.103066	-114.160325	71.422626	51.10255	-114.155521	0	0
03/06/01_7:26:05 PM	51.102312	-114.158056	72.889854	51.101297	-114.153646	76.602931	-3.713078
03/06/01_7:26:08 PM	51.102031	-114.157288	75.041457	51.101939	-114.151529	197.555326	-122.513868
03/06/01_7:26:10 PM	51.101719	-114.156521	77.258005	51.101119	-114.151926	114.462059	-37.204054
03/06/01_7:26:13 PM	51.10139	-114.155763	77.401837	51.099906	-114.151559	164.87452	-87.472683
03/06/01_7:26:20 PM	51.100689	-114.154326	75.62674	51.099764	-114.149751	76.603364	-0.976624
03/06/01_7:26:22 PM	51.100319	-114.153649	75.495277	51.099299	-114.149462	66.640775	8.854502
03/06/01_7:26:32 PM	51.099144	-114.151647	77.7376	51.098454	-114.146522	90.56769	-12.830091
03/06/01_7:26:38 PM	51.09834	-114.15031	77.473597	51.097077	-114.145171	108.029994	-30.556397
03/06/01_7:26:41 PM	51.097949	-114.149639	76.820639	51.097241	-114.144503	60.311446	16.509193
03/06/01_7:26:43 PM	0	0	0	51.095973	-114.145058	175.695592	-175.695592
03/06/01_7:26:46 PM	51.097172	-114.148317	75.876271	51.095988	-114.145754	58.498112	17.378158
03/06/01_7:26:58 PM	51.095578	-114.145649	77.536483	51.094184	-114.141493	107.899574	-30.363091
03/06/01_7:27:40 PM	51.089893	-114.136541	64.355206	51.087293	-114.139614	66.678213	-2.323007
03/06/01_7:27:43 PM	51.0896	-114.136032	54.643131	51.086333	-114.142211	253.271878	-198.628747
03/06/01_7:27:47 PM	51.089366	-114.135625	41.615375	51.089623	-114.132156	952.880741	-911.265366
03/06/01_7:27:50 PM	51.089198	-114.135363	26.054122	51.089205	-114.132722	73.419268	-47.365146
03/06/01_7:27:52 PM	51.089118	-114.135255	8.164848	51.088772	-114.135769	262.622472	-254.457623
03/06/01_7:27:55 PM	51.089109	-114.135245	0.201246	51.089512	-114.133219	236.057654	-235.856408
03/06/01_7:28:02 PM	51.089107	-114.135246	0.062871	51.089358	-114.133484	15.151958	-15.089087
03/06/01_7:28:04 PM	51.089106	-114.135248	0.079689	51.08909	-114.133609	37.353171	-37.273481
03/06/01_7:28:07 PM	51.089106	-114.135248	0.025456	51.089662	-114.129174	380.653832	-380.628376
03/06/01_7:28:11 PM	51.089105	-114.135249	0.0252	51.088388	-114.132523	328.950351	-328.925151
03/06/01_7:28:14 PM	51.089069	-114.135204	11.804721	51.086482	-114.135035	330.690437	-318.885716
03/06/01_7:28:16 PM	51.088919	-114.135036	30.680926	51.086464	-114.133876	97.463594	-66.782668
03/06/01_7:28:19 PM	51.088695	-114.134803	39.022016	51.084766	-114.134754	238.399587	-199.377572
03/06/01_7:28:23 PM	51.088401	-114.134507	49.968602	51.085679	-114.13279	205.284586	-155.315983
03/06/01_7:28:28 PM	51.08774	-114.133613	66.035217	51.085485	-114.130461	98.741995	-32.706778
03/06/01_7:28:31 PM	51.087378	-114.132993	72.651762	51.085192	-114.128004	210.314189	-137.662427
03/06/01_7:28:35 PM	51.087013	-114.13233	74.967772	51.086894	-114.126243	271.290117	-196.322345
03/06/01_7:28:38 PM	51.08664	-114.13164	77.236979	51.08633	-114.123994	203.493844	-126.256865
03/06/01_7:28:40 PM	51.08626	-114.130941	77.818762	51.085056	-114.126778	289.354419	-211.535657
03/06/01_7:28:44 PM	51.085875	-114.130237	78.563149	51.084075	-114.125873	151.41799	-72.854841
03/06/01_7:28:47 PM	51.08548	-114.129526	80.381427	51.084429	-114.123635	194.035871	-113.654444