Derivation of Van Aerde traffic stream model and studying the effect of Ramp Metering

Studying Van Aerde model for Deerfoot Trail, Calgary, CANADA

Karan Arora, B-Tech,
Department of Civil Engineering,
Indian Institute of Technology (IIT), Roorkee
Roorkee, India
karanarora.iitr@gmail.com

Bidoura Khondaker, PhD
Transportation Engineering,
Schulich School of Engineering, University of Calgary,
Calgary, Canada
bidourakhondaker@yahoo.com

Saeid Saidi, PhD
Transportation Engineering
Schulich School of Engineering, University of Calgary,
Calgary, Canada
ssaidi@ucalgary.ca

Lina Kattan, PhD, PEng,
Associate Professor, Transport system optimization,
Schulich School of Engineering, University of Calgary,
Calgary, Canada
lkattan@ucalgary.ca

***Abstract*—** With increase in population, demand for traffic is increasing tremendously. As a consequence congestion on urban freeways or highways during the morning and evening peak hours is always increasing. This research examines the traffic condition on Highway 2(i.e Deerfoot Trail), Calgary,Canada by providing ramp metering (funded by Government of Canada in Collaboration with MITACS Globalink Program).

In order to accommodate increasing traffic demand, constructing new highways and adding lanes is not always the best option. Instead proper management of transportation system can help in increasing its efficiency. It is therefore important to increase our understanding of traffic flow models to help estimating the efficiency of different road facilities and therefore prepare us to make enlightened decisions in the design process of new road facilities or improving older ones.

This research examines the traffic condition on Highway 2 (i.e Deerfoot Trail),Calgary,Canada by providing ramp metering

The research Project consists of 2 phases:

1. Calibration of Deerfoot Trail with Van Aerde Model using Microsimulation tool Quadstone Paramics, and

2. Analyzing the efficiency of Ramp Metering (RM) by examining its impact on the Macroscopic Fundamental Diagrams (MFD) for Deerfoot Trail.

(this research is funded by Government of Canada in Collaboration with MITACS Globalink Program).

I. Introduction

With more vehicles on the roads the interest in enhancing knowledge of microscopic simulation of traffic streams has become more important. Steady-state traffic stream modelling reveals the speed/flow/density relationship of a road facility and can provide us with answers to questions such as what parameters dictate maximum roadway throughput (capacity) as well as the speed-at-capacity.

Traffic detectors collect accurate data regarding fundamental traffic stream parameters which can be used to present real data from different road facilities. By comparing different traffic stream models with real field data it is possible to obtain a measure of the model capability of revealing data from different facilities.

II. Objective of the Research

The objective of this project is:
1. To compare real traffic data obtained from Quadstone Paramics Software with a four parameter steady-state traffic stream model, known as the Van Aerde car-following model (Van Aerde Calibration – Quadstone Paramics software)
2. To check the efficiency of Ramp Metering (RM) by examining its impact of RM on the Macroscopic Diagrams (MFD) for Deerfoot Trail.
3. To develop MFD diagrams with and without RM to examine the impact of freeway control on the shape of MFD.

III. Application of the Research

The prime application of this research is in the off-line calibration of speed-flow relationships. In the past, poor fits of speed-flow relationships have often resulted in a lack of an ability to properly calibrate the entire simulation.

Other main application of this research is to analyze the efficiency of Ramp Metering (RM) in case of Deerfoot Trail.

IV. Traffic Flow Theory

A number of different traffic car-following models exist and most of them are based on two independent variables. Usually these variables include the distance headway and the

IJARE

speed differential between the leading and the followin vehicle (Rakha & Crowther, 2002)[1]. One of the most popular of these models is Greenshield's model which requires the free speed vf and jam density kj as the only parameters. Greenshield's relationship has been found to be too simple and real data often deviate from the theory for both the uncongested as well as the congested regime[1][2]. One recent model is the steady-state four parameter Van Aerde car-following model[4].

A. *Van Aerde Car-Following Model*

To use the Van Aerde model one has to start by estimating four parameters c1, c2, c3 and k. These parameters are related to the free-flow speed Vf; the speed-at-capacity vo; capacity qm and jam density Kj. The equations for the parameters are given as:

*c1 = m*c2*

$$c_2 = \frac{1}{k_j\left(m + \frac{1}{v_f}\right)}$$

$$c_3 = \frac{-c_1 + \frac{v_o}{q_m} - \frac{c_2}{v_f - v_o}}{v_o}$$

and

$$k = \frac{1}{c_1 + \frac{c_2}{v_f - v} + c_3 v}$$

Where:

c1 = fixed distance headway constant[Km]
c2 = first variable distance headway constant[km^2/h]
c3 = second variable distance headway constant[h]
m = a constant used to solve for three headway constants[h/km]

The constant m is calculated by the equation:

$$m = \frac{2v_o - v_f}{(v_f - v_o)^2}$$

$$q = \frac{v}{c_1 + \frac{c_2}{v_f - v} + c_3 v}$$

According to Van Aerde Headways can be described by:

$$h = c_1 + c_3 v + \frac{c_2}{v_f - v}$$

The Van Aerde model can be seen in Figure:

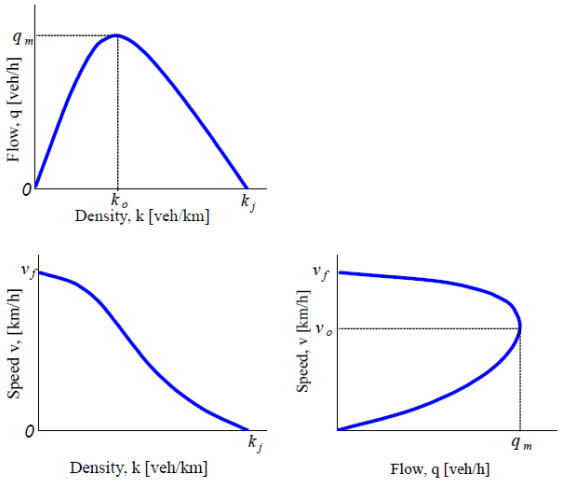


Fig. : The Van Aerde Traffic stream Model

II. Collection of Data for the Road Stretch

In order to get the three fundamental diagrams, statistical distribution of macroscopic parameters such as Flow, Density, Speed is required at specific interval of time.
There are many ways to collect or to estimate the field data, few of them includes:

1. Data from traffic detectors installed on the road.
2. Data from software such as VISSIM, Quadstone Paramics calibrated in such a way that it depicts real time data.

In this project the main focus is to gather data using software Quadstone Paramics that was calibrated based on real time data.

A. *Quadstone Paramics*

Paramics is traffic micro simulation software developed by Quadstone Paramics. Quadstone Paramics also develops pedestrian micro simulation software called the Urban Analytics Framework.

Compared to traditional empirical modelling which is based on an aggregated representation of traffic, micro simulation allows for real time vehicle movement and is able to simulate queuing conditions for congested networks.

B. *Deerfoot Trail*

Deerfoot Trail is a freeway section of the Queen Elizabeth II Highway (Highway 2) in Calgary, Alberta, Canada. It stretches 50 kilometres, from Calgary's northern city limit to its merger with Highway 2A (Macleod Trail). It is Alberta's busiest highway with traffic volumes ranging between 27,000 and 158,000 vehicles per day.

This study focuses on the busiest 8 km section of Deerfoot trail. The study area was divided into 4 sections (in Paramics with specified link number defined to them) comprising of 2 or more than 2 links

IJARE

III. Output from Quadstone Paramics

A. *Speed/Flow/Density Relationship*

The simulation data were aggregated into 30 seconds average values for speed [km/h], flow [veh/h] and density [veh/km]. Thereafter the free flow-speed, the jam density, the speed-at-capacity as well as flow rate at capacity were estimated. Finally the four parameters c1, c2, c3 and k were calculated and the Van Aerde car-following model plotted, along with the simulation data.

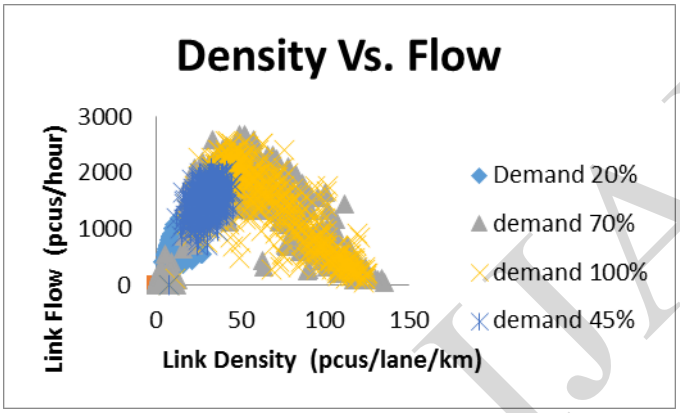
Different simulation runs are made for different level of congestion corresponding to demand factor 20%, 40%, 60%, 100% .

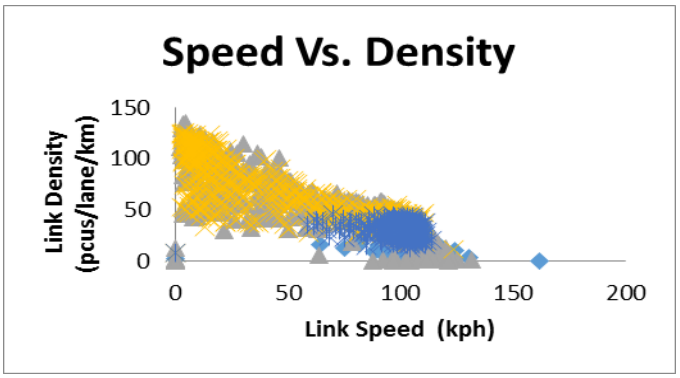
Output obtained from Paramics :-

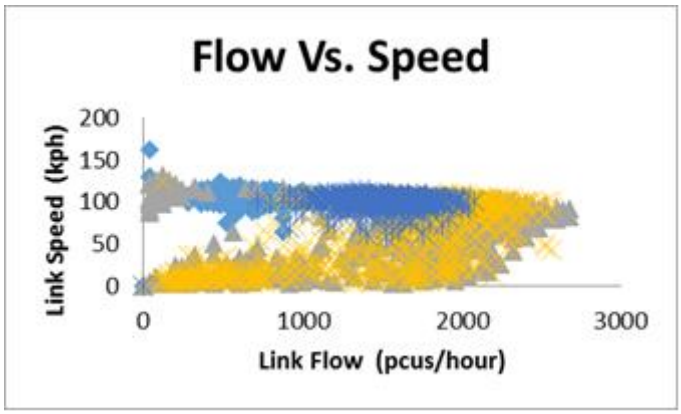
Link Count (vehicles/interval)
Link Density (pcus/lane/km)
Link Flow (pcus/hour)
Link Speed (kph)

Using the data obtain from Paramics Fundamental diagrams are plotted for every section. Below are the diagrams obtained for 4 sections, different colors represent different demand factors(30%, 40%,60%) :

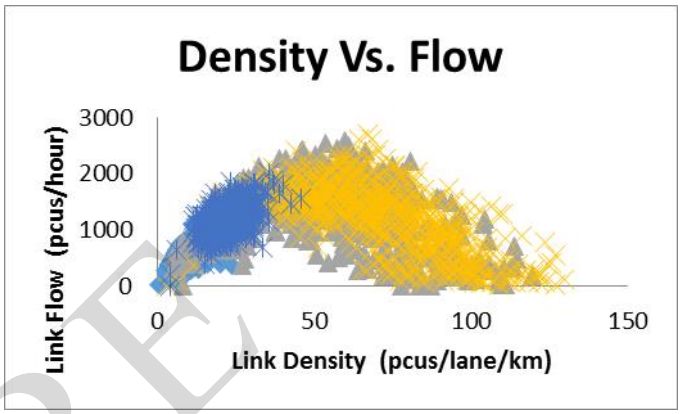
Section 1



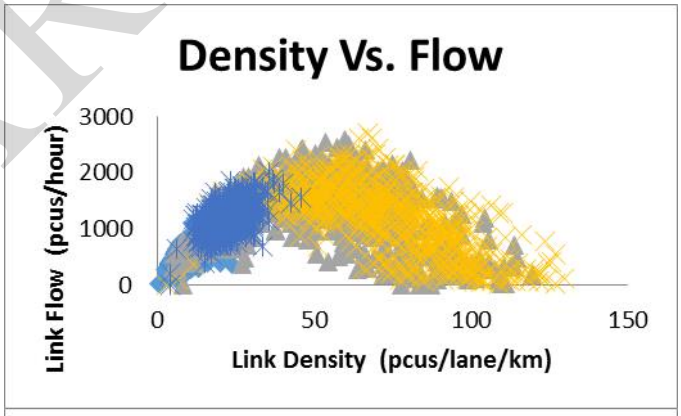


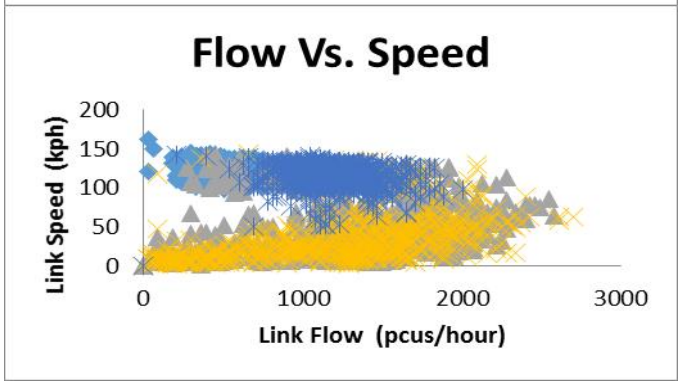


Section 2



s





IJARE

B. Combined Fundamental Diagrams

The fundamental diagrams for 4 different section of the road are then combined to obtain common fundamental diagram for the whole road stretch.

From the diagram, Maximum free flow(Vf), Jam Density(Kf), Flow at capacity(Vo), density at capacity(Ko) and Maximum Capacity(Qm) is estimated.

In case of Deerfoot trail it comes out to be as follow :

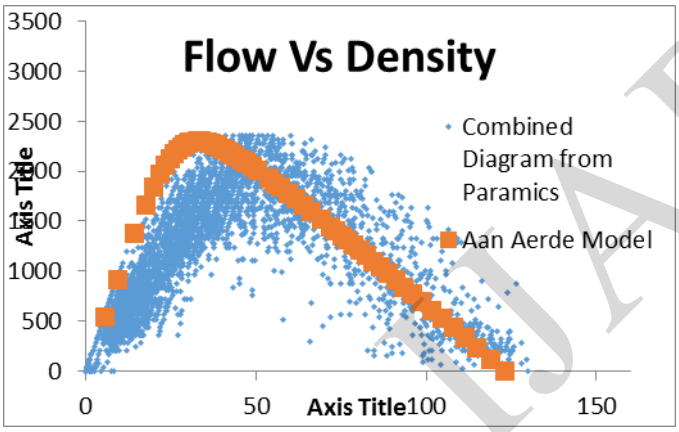
Vf = 100 km/hr
Kj = 123 pcus/lane/km
Vo = 70 km/hr
Qm = 2300 pcus/hr/lane
Ko = 30 pcus/lane/km

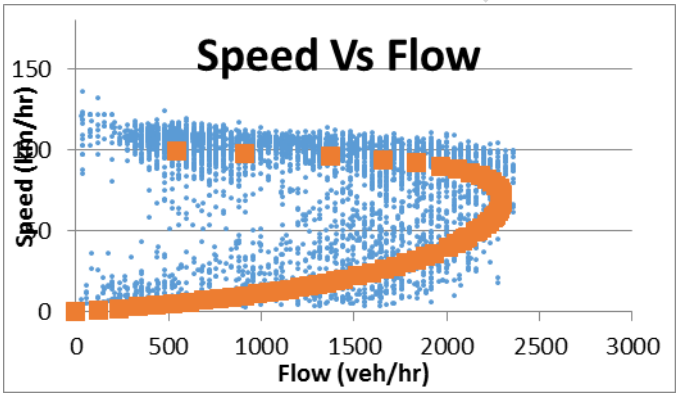
These values are then used to obtain the Van aerde Parameters as discussed above.

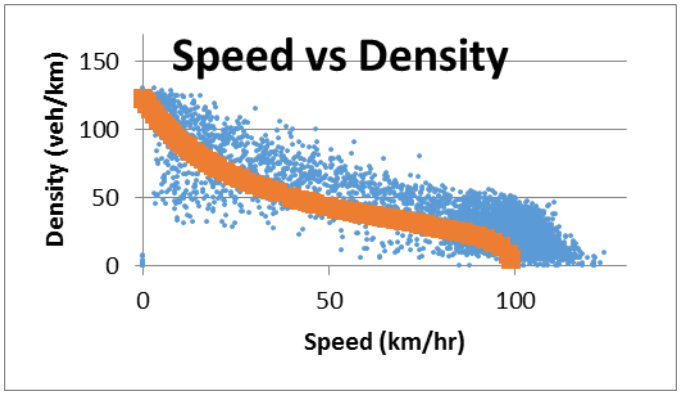
Fundamental diagrams for Van Aerde Model is then plotted and compared with the real time / Paramics data.

Combined diagrams for the road stretch obtained from Paramics(4 sections) and Van Aerde Model(Red colour) is plotted and shown below :

- Diagrams from Van Aerde Model
- Combined Diagrams from Paramics / real time data(blue color)







From Figures one can see that the Van Aerde model captures the general overall behaviour of the road facilities. The majority of simulated data plots in the uncongested regime and are represented by the model quite well in all cases.

IV. Ramp Metering

A ramp meter, ramp signal or metering light is a device, usually a basic traffic light or a two-section signal (red and green only, no yellow) light together with a signal controller that regulates the flow of traffic entering freeways according to current traffic conditions. It is the use of traffic signals at freeway on-ramps to manage the rate of automobiles entering the freeway. Ramp metering systems have proved to be successful in decreasing traffic congestion and improving driver safety[3].

A. Types of Ramp Metering strategies

Ramp metering may operate either in pre-timed or adaptive:

1)Pre-timed Ramp Metering: have fixed cycle time and phase length. The ramp metering rate is mainly determined as function of historical traffic information.

2) Adaptive Ramp Metering: Adaptive ramp metering control varies their rates minute-by-minute or second by second based on real-time traffic parameters. Few examples of Adaptive Ramp metering models are :

a) Dynamic Ramp Metering Model
b) Advanced Real Time Metering System (ARMS)

B. Detection Technologies for traffic condition

From the above literature, it is clear that most ramp metering algorithms optimize the traffic based on occupancy, approximate density or flow information measured in the vicinity of the ramp.

The various traffic detection methods are reviewed and compared to the vehicle probe detection method.

B.1. Point Detection Technology

Point detection technology is currently the most widely used sensor in traffic detection systems. These sensors are mostly capable of measuring flow and occupancy, and are able to estimate speeds.

IJARE

B.2. Probe Vehicle Detection Technology

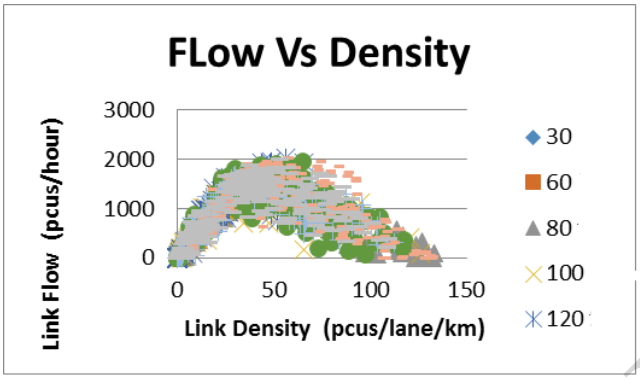
The probe vehicle technology is used in Intelligent Transportation System (ITS) applications for real time traffic data collection.

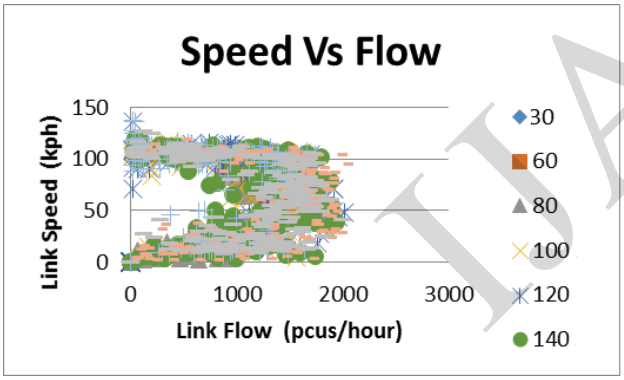
-Automatic Vehicle Location(AVL)
-Automatic Vehicle Identification(AVI)
-Global Positioning System(GPS) probes
-Vehicular Probes that collect travel time data by discreetly tracking cell phones within cellular network.

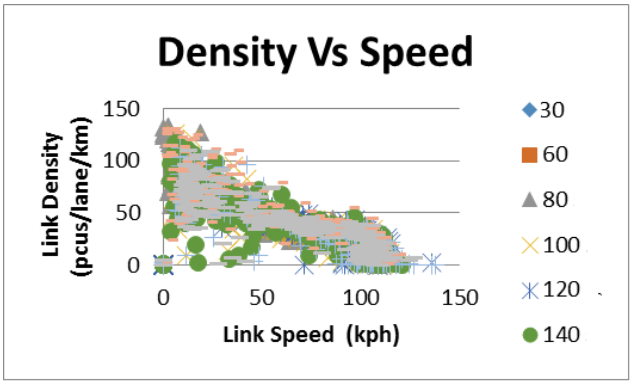
The detection technology used for in case of Deerfoot Trail was Vehicular probes.

A C++ .DLL code was developed which can be used as a plug-in for Quadstone Paramics, as the Paramics software doesn't support dynamic ramp metering strategies[9].

Section 4

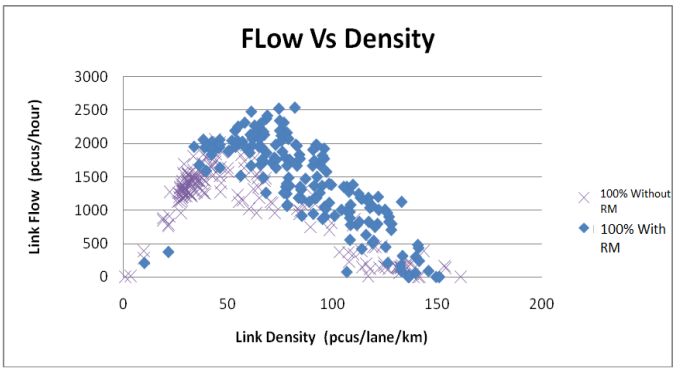






B. Diagrams comparing with and without RM case

Section 4



The results of the isolated ramp metering analysis showed an overall improvement in traffic condition (i.e. average travel time, flow and speed) for both the freeway and network-wide. The results of the analysis indicated a superior performance of the algorithm under high and medium traffic conditions on both the ramp and on the freeway and for high demand of the freeway and moderate demand on the ramp. As expected, no improvement was shown for the case of high demand on the ramp and moderate demand on the freeway.

V. Macrscopic Fundamental Diagrams

The accessibility of large cities is under high pressure. As an example, average speeds on major arterials in the city of Athens, Greece, appeared to be three to five times smaller during peak hours than during off peak hours, while in many other European cities speeds in the city centre are less than 10 km/h during peak hours. Nowadays, developing countries start to face similar problems.

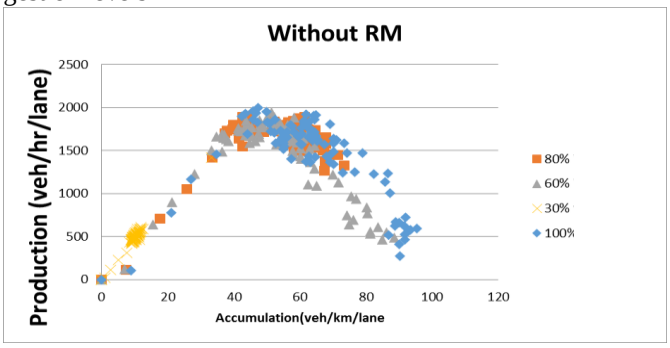
Constructing new infrastructure or extending the existing infrastructure is less likely to occur in the coming years due to the high costs and the societal impacts. In the short term, the only way to improve accessibility is to make better use of existing road capacity and to improve the production efficiency of large transportation networks. The latter can be done by applying Dynamic Traffic Management (DTM) measures.

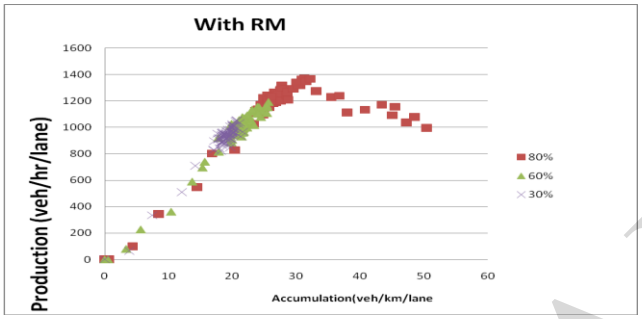
The precondition for efficient implementation of network-wide DTM is to describe the state of the network, that is, a macroscopic description of the traffic flow. This can be used to predict the states of large scale networks more efficiently, while maintaining its accuracy and to assess the network wide performance quality. Daganzo and Geroliminis [8] developed the macroscopic fundamental diagram (MFD) which describes the network-average relation between the number of vehicles in the network and the performance / outflow [8]. While monitoring the state of traffic continuously when the MFD is known, transportation managers can see if their traffic system is in the preferred state, that is, nowhere in the network the desired accessibility levels are exceeded. Using MFD, existing traffic management strategies can be refined and applied with more accuracy. However, because of the complex layout of the

IJARE

network and behavioral differences of different traffic types, the shape of the MFD changes and scatters may occur, which may lead to less accurate predictions of the traffic state. If the traffic state in a network cannot be predicted accurately, the quality of the traffic control based on these predictions may decrease as well.

Therefore as a part of this research internship, MFDs for Deerfoot trail with and without RM case was also developed by using the data obtained from Paramics for different congestion levels





At the end of the MFD, we can see that lower congestion levels lead to lower accumulation. Levels with similar congestion can be identified, where more congestion corresponds to higher accumulation and higher flow. FIGURE 6b, the MFD without ramp metering, shows that more congestion leads also to higher accumulation, but the corresponding flow is lower. This indicates a less efficient traffic situation. The shape of the MFD is therefore not only a property of the network and the demand, but also of the applied traffic control measures.

So it can be seen, Ramp-metering has a direct impact on the shape of MFD. The reduction of the inflow leads to higher flows and lower accumulation. Also, different congestion levels appear to lead to only a slight increase in both the accumulation and the flow, while in the situation without ramp metering the accumulation significantly increases while the flow decreases (heavy congestion)

It can also be seen that, by a fast decrease in demand leads to an inefficient use of the links: the links are able to process more traffic than the current demand, while the outflow is still low due to the congestion on the link. This clearly shows that the shape of the MFD is not independent of the demand.

VI. CONCLUSION

The summery of conclusions is as follow:

1. Data obtained from Quadstone Paramics was analyzed and modelled according to the Van Aerde microscopic model. Data for 30 second intervals were analyzed and the average speed, flow and density were estimated. The Van Aerde model was able to capture the general behavior. In all cases the model was able to represent the data quite well in the uncongested area as well at-density.

2. The ramp metering algorithm showed overall improvement in traffic condition (i.e. average travel time, flow and speed) on the freeway and network-wide for arbitrary demands when implemented locally. The results of the analysis indicated a superior performance of the algorithm under high and medium traffic conditions on both the ramp and on the freeway and for high demand of the freeway and moderate demand on the ramp.

3. It can be seen, Ramp-metering has a direct impact on the shape of MFD. The reduction of the inflow leads to higher flows and lower accumulation. Also, different congestion levels appear to lead to only a slight increase in both the accumulation and the flow, while in the situation without ramp metering the accumulation significantly increases while the flow decreases (heavy congestion)

Hence, in order to accommodate increasing traffic demand, constructing new highways and adding lanes is not always the best option. Instead proper management of transportation system can help in increasing its efficiency.

REFERENCES

[1] "A Comparison of the Greenshields, Pipes, and Van Aerde Car-Following and Traffic Stream Models", Hesham Rakha1 and Brent Crowther.

[2] "Traffic Stream Modelling of Road Facilities", Transport Research Arena Europe 2006

[3] "Development of a Probe-Based Proactive coordinated Ramp Metering Approach", Saeid Saidi, University of Calgary

[4] Van Aerde, M., 1995, "Single regime speed-flow-density relationship for congested and uncongested highways", 74th Transportation Research Board Annual Conference, Washington, D.C., Paper No. 95080.

[5] Van Aerde, M., 1995, "Single regime speed-flow-density relationship for congested and uncongested highways", 74th Transportation Research Board Annual Conference, Washington, D.C., Paper No. 95080.

[6] Macroscopic Fundamental Diagram: investigating its shape using simulation data, Jiyang, Daamen, Hoogendoorn, Hoogendoorn-Lanser and Qian

[7] Federal Highway Administration. CORSIM Version 5.1 Users Manual. US Department of Transportation, Washington DC., 2003.

[8] "A Macroscopic Fundamental Diagram for for Urban Traffic", Daganzo and Geroliminis,2008.

[9] "Comparative analysis of probe-based ramp metering with detector-based and pretimed ramp metering" by Saeid Saidi JOURNAL OF ADVANCED TRANSPORTATION 2012

IJARE