Traffic Stream Modelling of Road Facilities

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Abstract: Data from traffic detectors were used to study traffic flow characteristics on four different road facilities. Two urban highways, an arterial and a rural highway were analysed. With statistical analysis of the data, various classical traffic flow models have been used to fit the data. Five minutes intervals were analysed and the average speed, flow and density were estimated. The four parameters model proposed by Van Aerde gave the best results. Based on the Van Aerde model the free flow speed, speed at maximum flow, maximum flow and density at jam were determined. These parameters were compared for the different road facilities, as well as the relationship between headways and given speed.

1. Introduction

With more vehicles on the roads the interest in enhancing knowledge of microscopic simulation of traffic streams has become more important. The number of freeways or highways that experience significant congestion during the morning and evening peak hours is always increasing. It is therefore important to increase our understanding of car-following models to help us to estimate 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. 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 obtains a measure of the model capability of revealing data from different facilities. The objective of this paper is to compare real traffic data from dual loop traffic detectors with a four parameter steady-state traffic stream model, known as the Van Aerde car-following model (Van Aerde, 1995; Van Aerde & Rakha, 1995). The traffic detectors used were located on different road facilities, two urban freeways, an arterial highway and a rural highway.

2. Traffic Flow Theory

A number of different traffic car-following models exist and most of them based on two independent variables (May, 1990). Usually these variables include the distance headway and the speed differential between the leading and the follower vehicle (Rakha & Crowther, 2002). One of the most famous of these models is Greenshield's model which requires the free speed v_f and jam density k_j as the only parameters.

The basic traffic stream modeling relationship relates flow q to the product of density k and space mean speed v as

$$q = kv \tag{1}$$

Greenshield's theory assumes a linear speed-density relationship, usually written as

$$v = v_f - \left(\frac{v_f}{k_j}\right)k \tag{2}$$

therefore the flow-speed relationship becomes parabolic as

$$q = k_j\left(v - \frac{v^2}{u_f}\right) \tag{3}$$

Greenshield's relationship results in a speed-at-capacity v_o that is half the free-speed. Furthermore, the flow-at-capacity q_m will be one fourth of the product v_f and k_j. Greenshield's relationship can be seen in Figure 1.

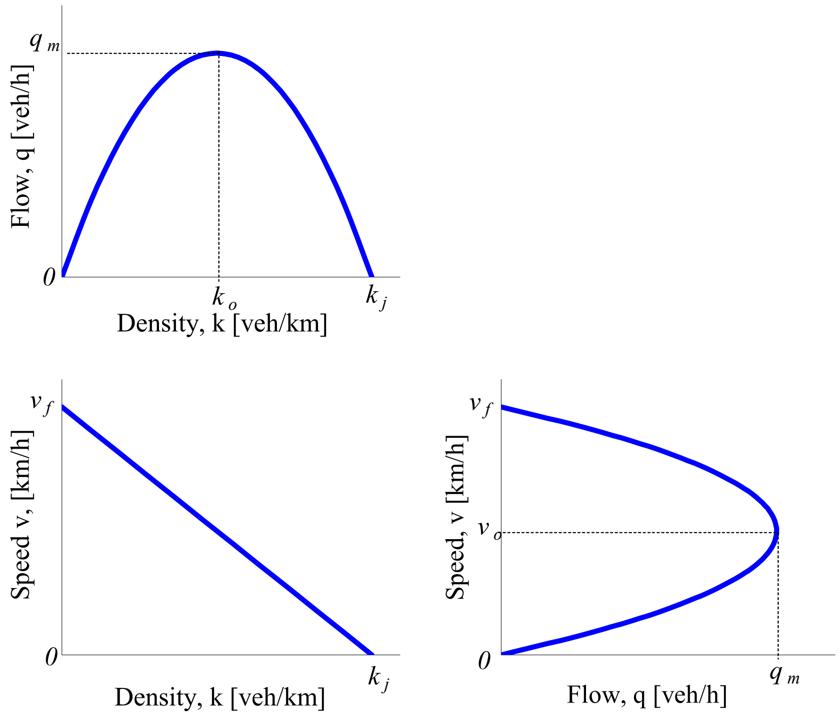

Fig. 1 Fundamental Diagrams of the Greenshield Traffic Flow Model.

Greenshield's relationship has been found for many road facilities to be too simple and real data often deviate from the theory for both the uncongested as well as the congested regime. Therefore many attempts have been made to improve Greenshield's theory. One recent model is the steady-state four parameter Van Aerde car-following model (Van Aerde, 1995; Van Aerde & Rakha, 1995; Rakha & Crowther, 2002).

To use the Van Aerde model one has to start by estimating four parameters c_1, c_2, c_3 and k. These parameters are related to the free-flow speed v_f; the speed-at-capacity v_o; capacity q_m and jam density k_j. The equations for the parameters are given as:

$$c_1 = mc_2 \tag{4}$$

$$c_2 = \frac{1}{k_j\left(m + \frac{1}{v_f}\right)} \tag{5}$$

$$c_3 = \frac{-c_1 + \frac{v_o}{q_m} - \frac{c_2}{v_f - v_o}}{v_o} \tag{6}$$

and

$$k = \frac{1}{c_1 + \frac{c_2}{v_f - v} + c_3 v} \tag{7}$$

where:

c_1 = fixed distance headway constant [km]
c_2 = first variable distance headway constant [km^2/h]
c_3 = second variable distance headway constant [h]
m = a constant used to solve for the three headway constants [h/km]

The constant m is calculated by the equation:

$$m = \frac{2v_o - v_f}{(v_f - v_o)^2} \tag{8}$$

Using the basic traffic stream relationship presented in equations (1) and (7) the expression for flow in the Van Aerde model becomes:

$$q = \frac{v}{c_1 + \frac{c_2}{v_f - v} + c_3 v} \tag{9}$$

The Van Aerde model can be seen in Figure 2.

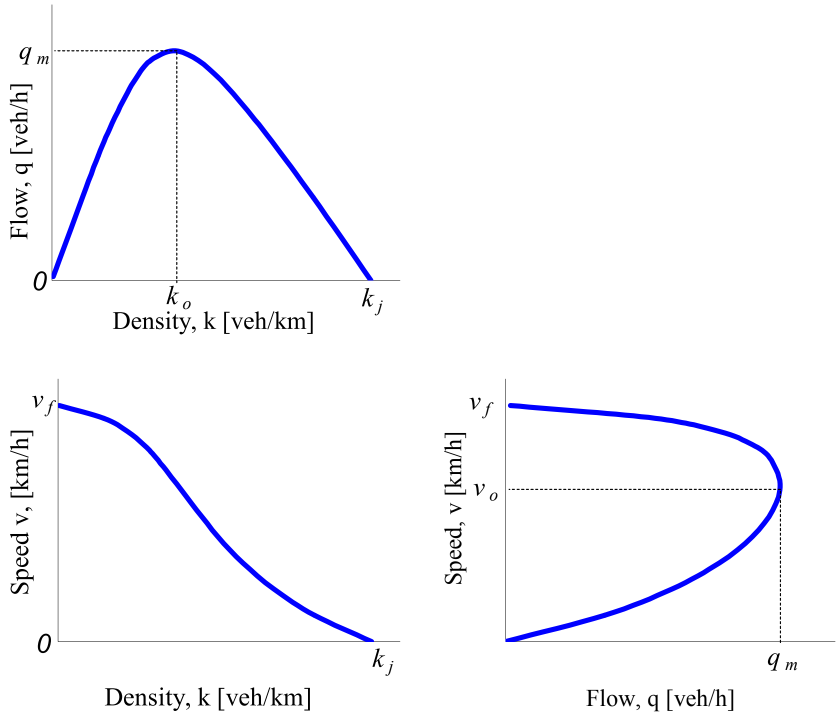

Fig. 2 The Van Aerde Traffic Stream Model.

According to Van Aerde headways can be described by:

$$h = c_1 + c_3 v + \frac{c_2}{v_f - v} \tag{10}$$

where c_1, c_2 and c_3 are the same parameters as before.

3. Field Data from Traffic Counters

To analyse how well the Van Aerde model describes real traffic behaviour, data for four different roads were analysed. The characteristics of these four roads are listed in Table 1.

Table 1 Characteristics of the four road facilities.

Road no.	1	2	3	4
Station name	Artunsbrekka	Kringlumyrarbraut	Molduhraun	Geithals
Road type	Urban freeway	Urban freeway	Arterial highway	Rural highway
No. of lanes	8	6	2	2
AADT	83,046	70,507	22,829	8,077
AAD lane volume	16,019	15,843	11,068	4,044
Speed limit [km/h]	80	70	70	90

As can be seen in Table 1 the urban freeway had the highest flow rate (AADT) and the rural highway the lowest. Additionally, the volume for the lane analysed is given in the table. The periods used were the morning and afternoon rush hours from 6:30 to 9:00 and 15:30 to 18:00 respectively on Fridays in November 2004.

3.1 Speed/Flow/Density Relationship

The field data were aggregated into 5-minute 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, see Table 2. Finally the four parameters c_1, c_2, c_3 and k were calculated and the Van Aerde car-following model plotted, along with the field data.

Table 2 Values for the Van Aerde Model for the four road facilities.

Road no.	1	2	3	4
v_f [km/h]	79.8	76.5	78.6	84.5
k_j [veh/km]	110	110	110	110
v_0 [km/h]	65.9	56.9	48.0	68.5
q_m [veh/h]	1612	1989	1458	1592

The traffic stream models for the lane with the highest flow rate on the four roads facilities are shown in Figures 3 to 6.

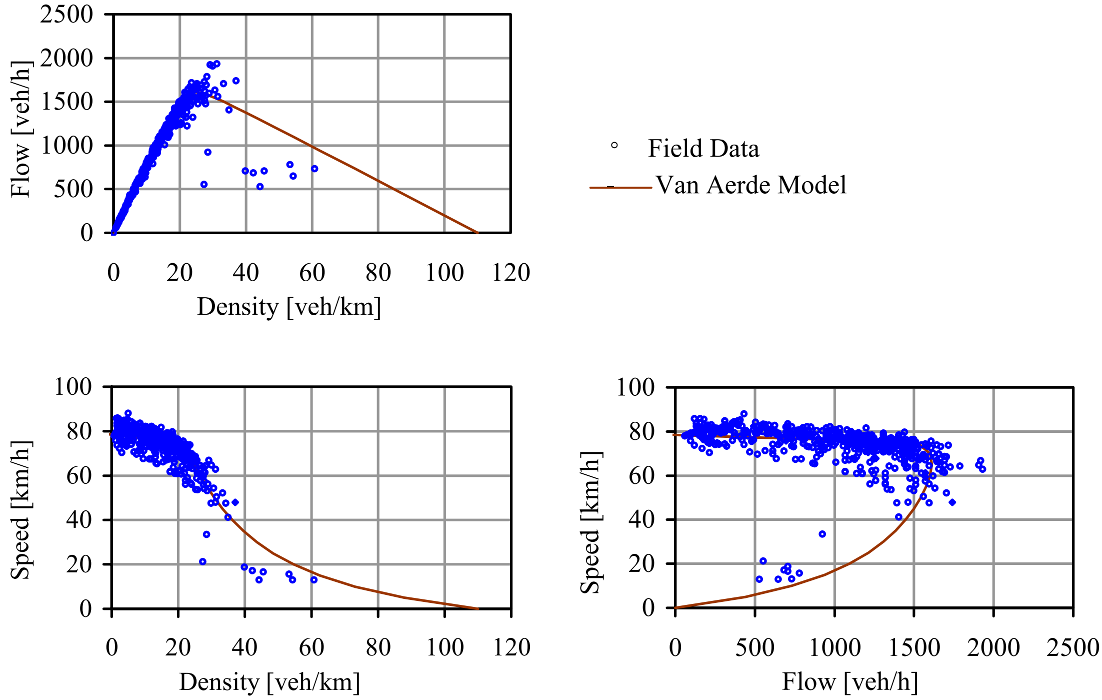

Fig 3 The Traffic Stream Model on Road 1 (Artunsbrekka - Urban freeway).

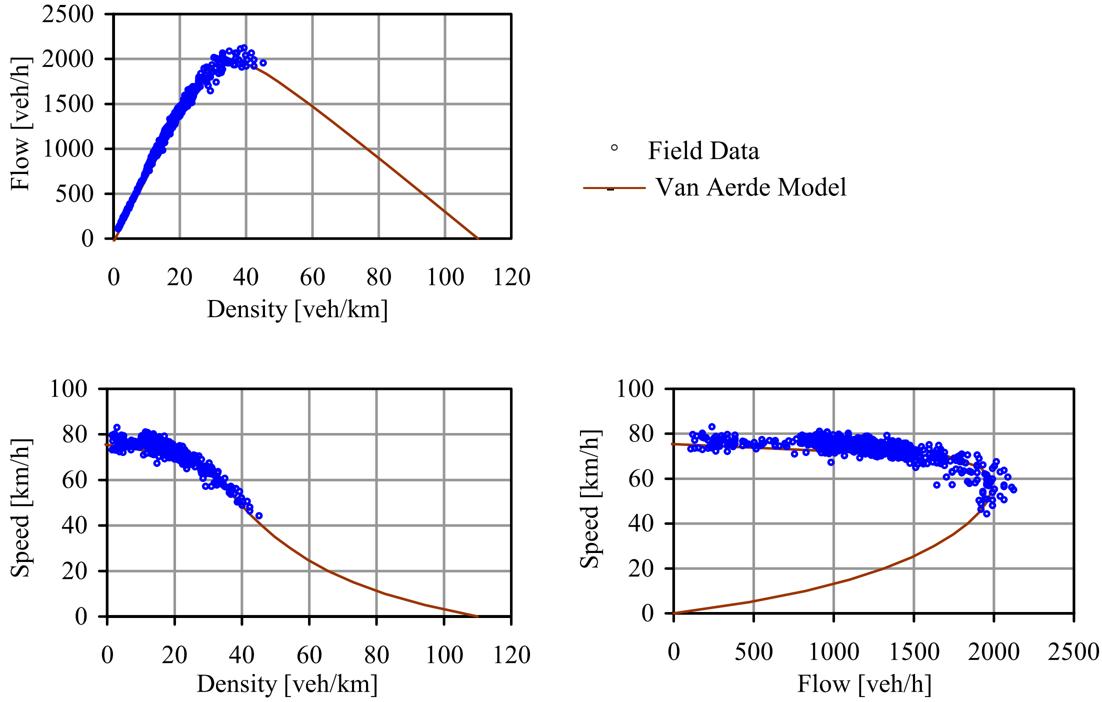

Fig. 4 The Traffic Stream Model on Road 2 (Kringlumyrabraut - Urban freeway).

From Figures 3 to 6 one can see that the Van Aerde model captures the general overall behaviour of all the four road facilities. The majority of field data plots in the uncongested regime and are represented by the model quite well in all cases. Three of the road facilities (roads 1, 2 and 4) have quite mild slopes in this regime in the speed-flow domain that the model represents quite satisfactorily. The percentage change of the free-flow speed to speed flow-at-capacity was 17.4%, 25.6% and 18.9% respectively for these three facilities. Road 2, on the other hand, showed a 38.9% drop. However, the model captures the main characteristics in the uncongested regime there as well.

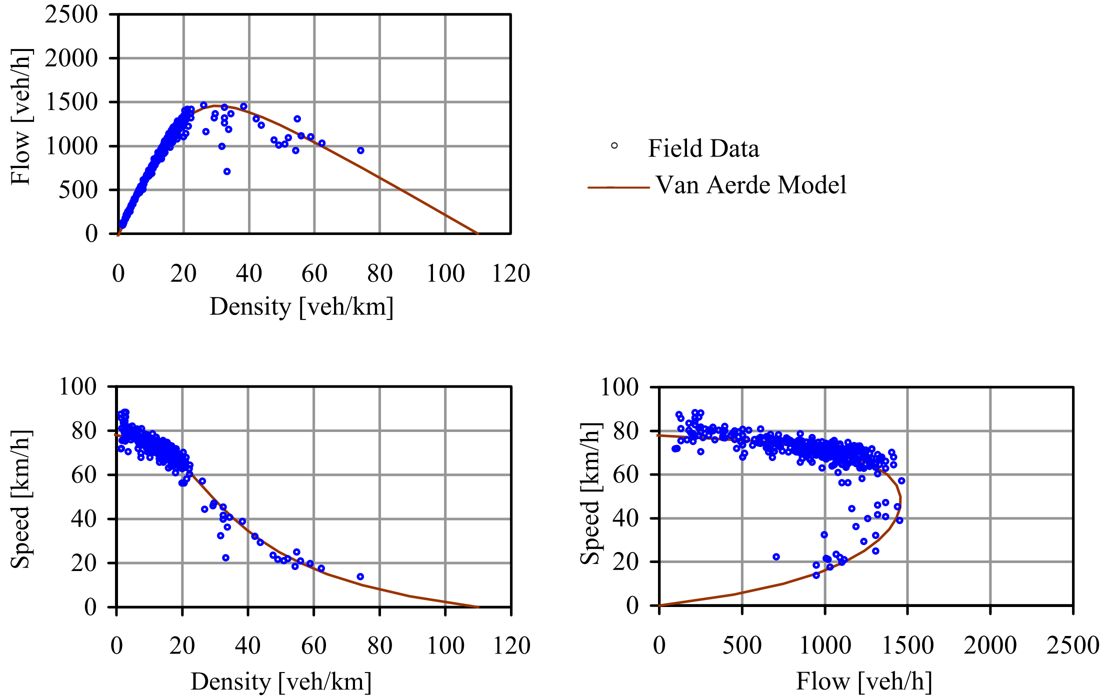

Fig. 5 The Traffic Stream Model on Road 3 (Molduhraun - Arterial highway).

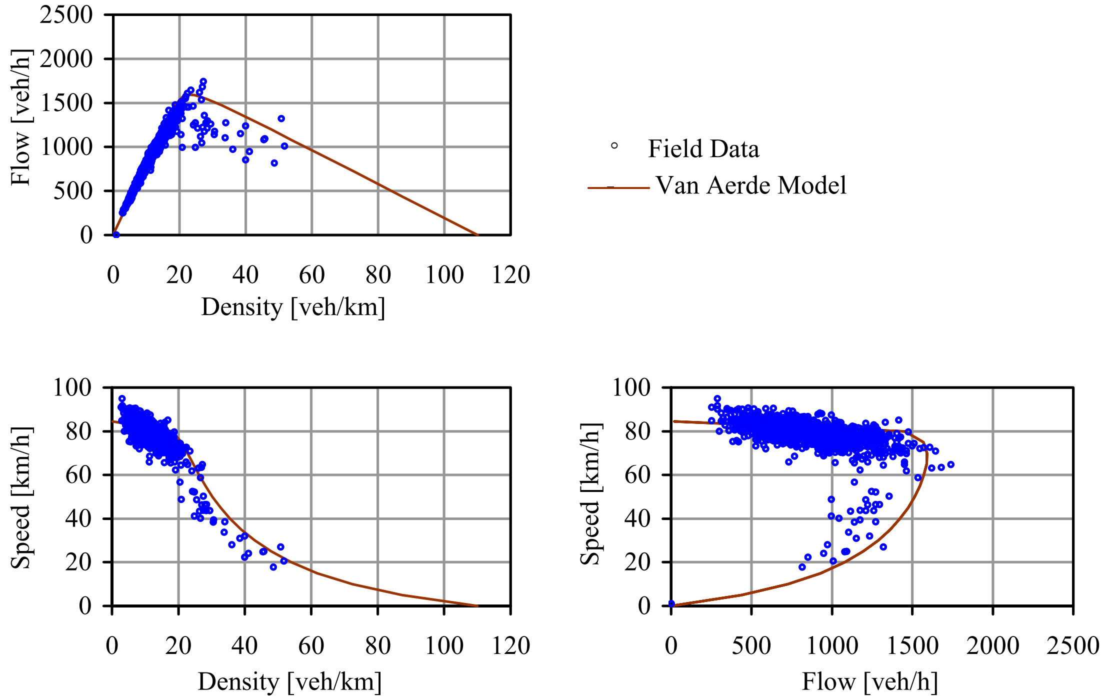

Fig. 6 The Traffic Stream Model on Road 4 (Geithals - Rural highway).

The model further demonstrates in all cases the behaviour at-density quite adequately, although the field data showed some scattering. Two of the input parameters of the model are linked to the at-density situation, the speed-at-capacity v_o and capacity q_m, ensuring good agreement between filed data and the model.

The largest deviation between the field data and the model was in the congested regime, but the number of represented field data points was much smaller there. It seems that in all cases the model overestimated the efficiency of the road facility compared to the registered field data. However, these results could have been influenced by the fact that the congested regime is highly sensitive to external influences (frictions) along the facility such as nearby junctions, traffic signals, weather conditions, etc.

The flow-at-capacity for the two urban freeways was 1612 and 1989 veh/h for road facilities 1 and 2, respectively. As these are multi-lane facilities the maximum flow should be at least 2000 – 2200 veh/h. The impact of nearby ramps was the main influence here. Improving them should increase the maximum flow.

The arterial and rural highways had a flow-at-capacity of 1458 and 1592 veh/h, respectively, which is clearly acceptable. Expected capacity for two lane rural or arterial highways is around 1600 veh/h. Road no 4, the rural highway (Geithals), which was not influenced by any nearby frictions, came close to that value. The arterial highway, road 3 (Molduhraun), was influenced by traffic lights, which probably decreased the capacity.

3.2 Speed Headway Relationship

The Van Aerde model can also be used to describe the relationship between headway and speed. Figure 7 illustrates this relationship for the four road facilities analysed.

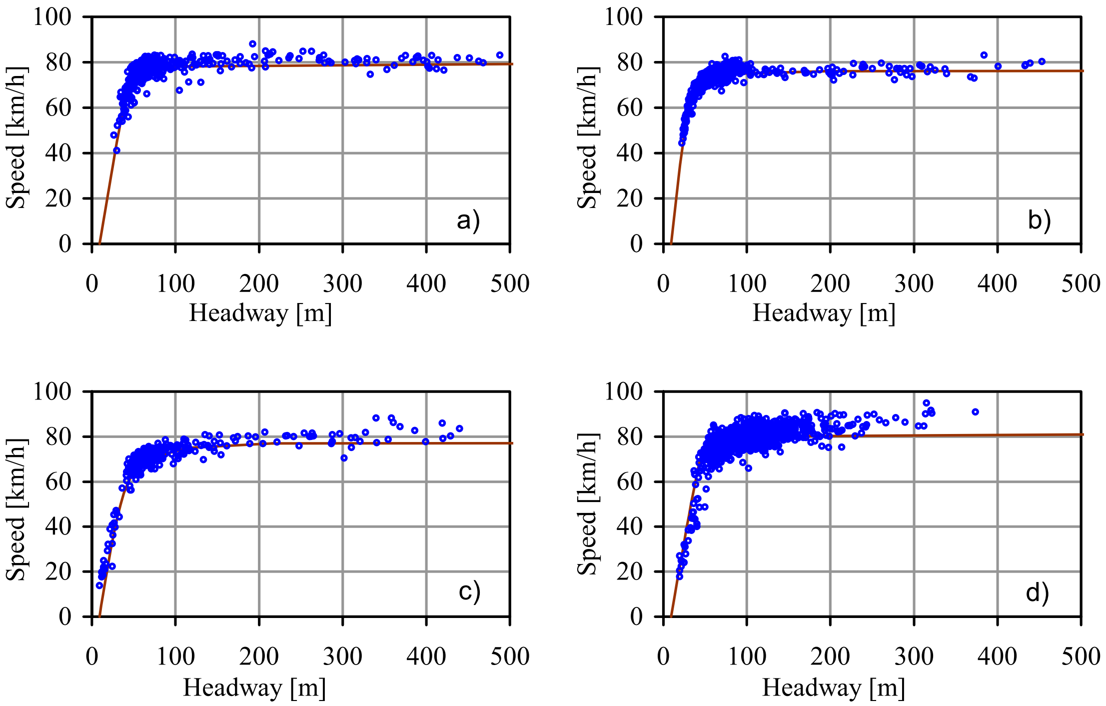

Fig. 7 The relationship between speed and headway for the traffic on the four roads. a) Road 1 Artunsbrekka, b) Road 2 Kringlumyrabraut, c) Road 3 Molduhraun and d) Road 4 Geithals.

It can be seen from Figure 7 that the free-flow speed was achieved for all road facilities as the headway was larger than approximately 60 meters. Thereafter the average speed was fairly constant and constrained by the speed limit of the facility rather than by vehicle-to-vehicle interaction. Headways lower than 50 to 60 meters seemed to increase fairly linearly with speed for all the facilities. However, the slope are steep. A milder slope would be preferable, resulting in smaller fractions of vehicles keeping too short headways in the traffic stream. This conclusion might be influenced by the fact that the number of data points was limited, especially for the two urban freeways (roads 1 and 2).

5. Conclusion

Data from dual loop traffic counters on four different road facilities were analysed and modelled according to the Van Aerde microscopic simulation model. Data for five minute intervals were analysed and the average speed, flow and density were estimated. The Van Aerde model was able to capture the general overall behaviour of all four road facilities. In all cases the model was able to represent the data quite well in the uncongested area as well at-density. The field data exhibited some scattering in the congested regime and the largest deviation between the filed data and the Van Aerde model took place at that point. However, the fact that data points in this regime were limited may have influenced the results.

The Van Aerde model has also been used to model the relationship between headway and speed. The model captures the overall behaviour quite well for all road facilities. The slope of the curves for headways smaller than 50 to 60 m are steep. A milder slope would be preferable, resulting in smaller fractions of vehicles keeping too short headways in the traffic stream.

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