Queueing in Traffic Flows

This project studies the effects of vehicle routing on pollution levels. We aim to develop queueing theory based mathematical models to analyse highway traffic flows and focus on focus on the capacity drop and shockwaves. Then we intend to use emission models and plume model to predict air pollution in a wider region. These predictions will be tested using remote sensing data and data from measurement stations. Finally, we aim for traffic steering methods to (re)-direct road traffic to avoid pollution.

Traffic Theory

The capacity drop is a process in which the traffic system "collapses" when the number of vehicles on the road reaches a certain critical density. The achievable speeds and slow will substatially reduce and it takes some time, and a density reduction, before the system will restore itself. A shockwave is a discontinuity in the flow-density space travveling in the time-space domain that naturally occurs when density increases and circumstance will force one of the vehicles to suddenly reduce speed causing following vehicles (for safety reasons) to also reduce speed. The process in which the "new" speed is passed on to following vehicles is a typical example of a shockwave which naturally arises in highway traffic. The capacity drop and shockwaves are two of the main reasons in the formation of traffic jams.

Emission

Current emission models rely on speed and the type of a vehicle. Using remote sensing data and the fundamental information on traffic flows can be obtained and used to determine the emission for each vehicle and for all vehicles combined. A plume model combined with weather forecast can then predict how air pollution is affected by this emission.

Rerouting

Alternative routing can reduce traffic jams and air pollution. Numereous options are available to reroute traffic flows, e.g. by car-to-car communication to slow down vehicles before running into a traffic jam or by using traffic signals to steer traffic along a beltway to minimise pollution in urban regions.

Results

A key measure in evaluation mathematical models for traffic flows is the fundamental diagram (or speed-flow-density diagram) in which the relations between speed (the mean speed of vehicles), flow (the flow rate of vehicles) and density (the number of vehicles on the road) are shown.

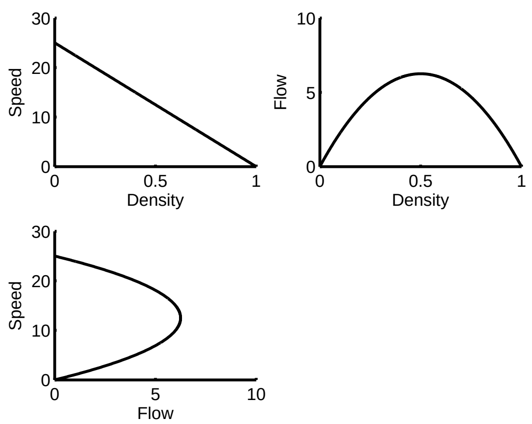

Figure 1: Basic Fundamental Diagram.

Figure 1 gives an example of a basic theoretical fundamental diagram. In this fundamental diagram the speed-density diagram shows a linear relation, causing a quadratic relation in the flow-density diagram and in the flow-speed diagram. Figure 2 presents empirical data on flow-density relations that clearly reveals the capacity drop at $\rho \approx 0.5$.

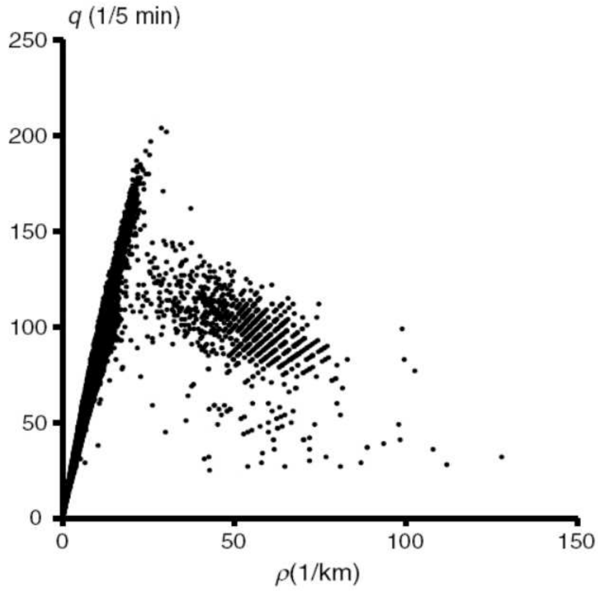

Figure 2: Empirical Data on flow-density relations.

We have developed an $M/M/1$ threshold queue that captures the capacity drop and a tandem queueing model capable of generating shockwaves. The $M/M/1$ queue is a queue with Poisson arrivals and exponential service times and this queue represents a small section of the road. The threshold policy for the $M/M/1$ threshold queue determines the service rate in the queue. Once an upper threshold is reached the service rates will reduce (comparable to speed reductions experienced in the capacity drop). The queue length must decrease before a lower threshold can be reached. Once it is reaches the service rates will increase (comparable to the system restoration). Figure 3 presents the fundamental diagram for the $M/M/1$ threshold queue that reveals a capacity drop at a density of 0.6.

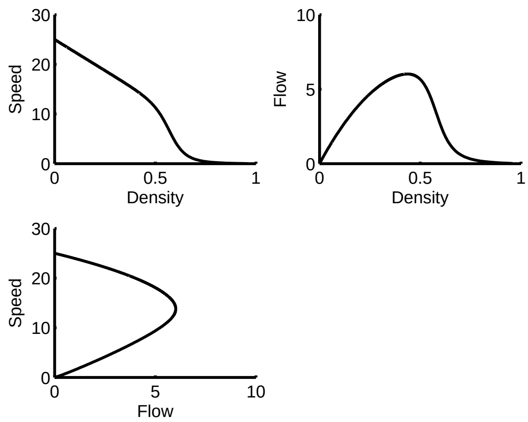

Figure 3: Fundament Diagram obtained with the $M/M/1$ threshold queue.

The tandem queueing model is an extension of the $M/M/1$ threshold queue obtained by placing several queues in series. The threshold policy is altered: instead of reducing the service rate of the queue which reaches the upper threshold, the policy will reduce the service rate of one queue earlier. Similarly, the policy will increase service rates of a queue once the next queue reaches its lower threshold. This models a shockwave since a high density in one queue (comparable to a car suddenly braking) will increase densities in previous queue (a shockwave travels backwards).