QUEUEING MODELS FOR UNINTERRUPTED TRAFFIC FLOWS

An assignment submitted

by

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1 INTRODUCTION

Due to increased ownership of cars, changes in the production system (where stock is on the road and not in the warehouse), increased flexibility of the working population, etc., the demand for transport has increased exponentially. On the other hand, the supply of means for transport (roads, public transport,...) does not follow this trend or with a serious lag in time. This combination of more and more traffic on the existing road network together with a stabilization in investments of new roads, results in an inevitable increase of congestion. Congestion leads to an increase in travel time, decreasing flow, higher fuel consumption, negative environmental effects, etc. Efficiently tuning demand and supply will lead to a better use of the capacity and a better control of traffic demand. This solution can be achieved by a temporarily and local intervention on supply and demand. However, quantifying the effects of such an intervention is not straightforward. The first step should always be a good understanding of the complex phenomenon of congestion itself, e.g. what are its driving forces? Traffic will be modelled using mathematical models based on queueing theory. This analytical basis, rather than an empirical one, has the advantage to adequately pinpoint possible problems and to perform sensitivity analysis, what-if questions, etc. Once traffic is analytically analysed and modelled, the second step tries to adequately improve the traffic conditions, using these mathematical models, e.g. what is the effect of certain measurements? Starting from the existing traffic state, the potential improvements can then be quantified and compared (and implemented). In this paper, the existing single node models are extended towards queueing networks. In the first section, the queueing framework for modelling traffic flows is presented. Here, the well-known speed-flowdensity diagrams are analytically represented using queueing theory. In the next section, the extension is made towards queueing network models. The network analysis is split up into two major parts depending upon the buffer size: infinite or finite buffer sizes. We limit 636 ourselves in this paper to the discussion of the network methodology assuming infinite buffer sizes. The third section illustrates this queueing network approach with a real-life example. We end with some conclusions.

2 A QUEUEING APPROACH

Vandaele, Van Woensel and Verbruggen (2000), Van Woensel, Creten and Vandaele (2001) showed that queueing models can be a useful alternative for modelling uninterrupted traffic flows. In a queueing approach to traffic flow analysis, roads are subdivided into segments, with length equal to the minimal space needed by one vehicle on that road (Figure 1). Define C as the maximum average traffic density (i.e. average maximum number of cars on a road segment). This length is then equal to 1/C and matches the minimal space needed by one vehicle on that road. Each road segment is then considered as a service station, in which vehicles arrive at a certain rate ? and get served at another rate ? (Vandaele, Van Woensel and Verbruggen, 2000).

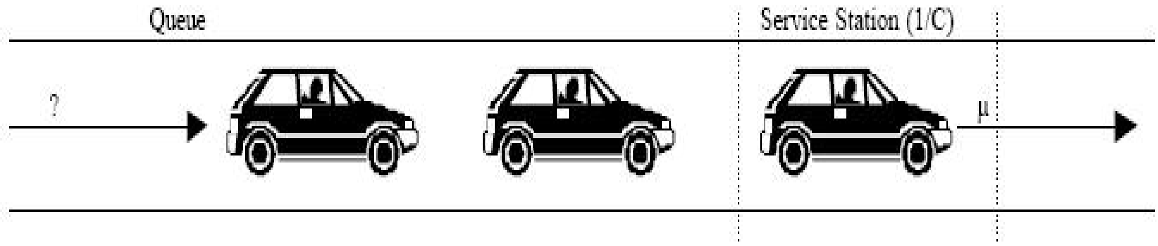

Figure 1. Queueing representation of traffic flows

It is often observed that the speed for a certain time period tends to be reproduced whenever the same flow is observed. Based on this observation, it seems reasonable to postulate that, if traffic conditions on a given road are stationary, there should be a relationship between flow, speed, and density. This relationship results in the well-known concept of speed-flowdensity diagrams.

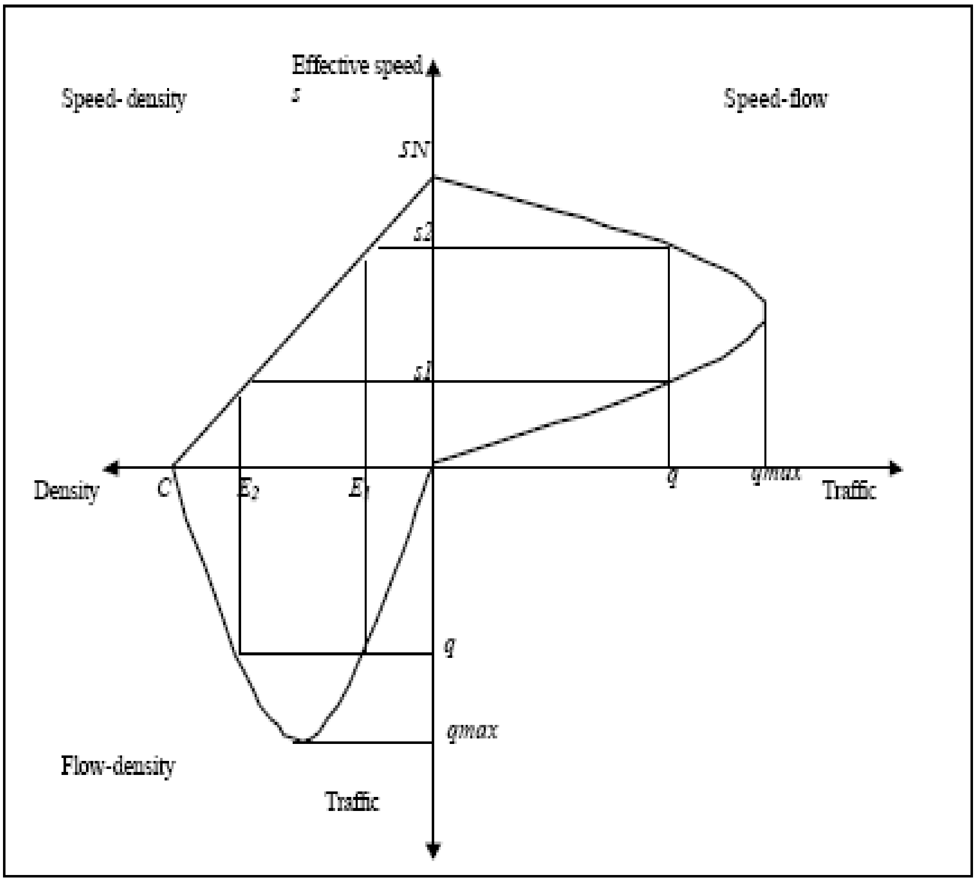

Figure 2. Speed-flow-density diagram

These speed-flow-density diagrams are analytically constructed using queueing theory. In previous work, Vandaele, Van Woensel and Verbruggen (2000) developed different queueing models for single nodes. The M/M/1 queueing model (exponential arrival and service rates) is considered as a base case, but due to its specific assumptions regarding the arrival and service processes, it is not useful to describe real-life situations. Relaxing the specifications for the service process, leads to the M/G/1 queueing model (generally distributed service rates). Relaxing both assumptions for the arrival and service processes results in the G/G/k queueing model. Moreover, following Jain and Smith (1997) a special case of the G/G/k queueing model is derived: a state dependent G/G/k queueing model. In this case vehicles are served at a certain rate, depending upon the number of vehicles already on the road. Traffic flows on a highway during noncongested hours are best described using an M/G/1 queueing model in most cases. During the congested hours, the state dependent queueing G/G/k models are more realistic. Moreover, results show that the developed queueing models can be adequately used to model uninterrupted traffic flows. This conclusion leads to the extension of the single node queueing models towards queueing networks (section 3).

3 QUEUEING NETWORKS

In practice, traffic passes more than one node. As a consequence, vehicles have to wait in several different queues before receiving the required service. A set of interconnected single queueing nodes is called a queueing network. Queueing networks have been studied extensively under different assumptions regarding service and inter-arrival distributions, service disciplines, buffer size,... . The analysis is split up in two parts depending upon the buffer size: infinite or finite. We restrict ourselves in this paper to the case with infinite buffer sizes. The assumption is thus that the buffer space between two consecutive connected nodes is infinite. Vehicles arrive in the network following a general distribution. We assume that service times also follow a general distribution. The network described is then an open queueing

G/G/1 network. Of course, this network can easily be extended towards state dependent queueing models. First, a detailed description of all building blocks used (nodes, incoming flows, connecting flows and outgoing flows) is presented. Secondly, the specific methodology for obtaining all relevant data for the queueing network is explained. This methodology can be simplified depending upon the specific traffic situation. Key results can be simplified, making basic insights possible.

4 APPLICATIONS

The use of all the developed models and methodology will be illustrated by some real-life examples and applications. Applications taken into consideration are:

- The effect of a supply measure: adding an extra lane. We use the developed models to assess the effect of adding an extra lane.
- The effect of a demand measure: implementing congestion pricing. The models can also be used to come to a more correct calculation of the external costs of traffic.
- Calculating air-born emissions produced by the vehicles. For a basic analysis of calculating emissions and the resulting possible governmental actions and regulations.

5 CONCLUSIONS

Since the policy made by public sector managers, mainly depends on the models they use, accurate operational models are mandatory. Sub optimal decisions affect the entire economy and drive companies into decision making which can rather be worse than better for the society as a whole. The models presented in this paper are a novel approach to modelling uninterrupted traffic flows. The analytical tool used, are queueing systems. These analytic models allow for parameterized experiments, which pave the way towards our research objectives: assessing what-if scenarios and sensitivity analysis for traffic management, congestion control, traffic design and the environmental impact of road traffic (e.g. emission models). The impact of the crucial modeling parameters are studied in detail. In this paper, the existing single node models are extended towards queueing networks. The analysis can be split up into two parts: infinite and finite buffer sizes. Here, we discuss the infinite buffer size case. Road networks can then be represented by queueing systems. This approach results in speeds and densities at every node in the network and allows for sensitivity analysis, evaluation of policy actions, $\cdots$

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