Proceedings of the
Third International Symposium on Highway Capacity
PREFACE

Capacity and level of service are important parameters for almost all tasks of transportation. These parameters affect specific traffic facility aspects to the wider cost-benefit analysis. The concepts of capacity and level of service are known in almost every country and sometimes even specified by standards. Probably the most widely known, used and highly regarded document is the Highway Capacity Manual HCM published by the US Transportation Research Board (TRB) under the responsibility of the Highway Capacity and Quality of Service Committee.

Seven years ago, in 1991, the First International TRB Symposium on Highway Capacity was held in Karlsruhe, Germany and in 1994 the Second International Symposium was held in Sydney, Australia – each characterised by the high standard of the papers read and discussed and by the informal atmosphere which prevailed both during and after the formal sessions. Prospects are good that this Symposium can be held in tradition of the previous ones. Many excellent papers have been submitted and it has been hard work for the referees and selection group to decide which paper to select for presentation.

These proceedings contain 64 technical papers on different topics related to highway capacity and 12 country reports on current research and applications on highway capacity, which will be presented at the Third International Symposium on Highway Capacity in Copenhagen, Denmark in June 1998. The papers and reports are written by authors coming from 21 countries from all continents in the world. All technical papers were selected after a comprehensive process with a lot of reviewers involved. Irrespective of the paper topic, the papers are given in alphabetic order of the first authors surname, and the page numbering is continuous.

As the local organiser and editor, I would like to acknowledge Bill Reilly for his contributions to the organisations of the Symposium, Doug Harwood for managing the complex process of paper selection and all referees for their efforts to help improve the quality of the Symposium papers. Finally, I thank all authors for their valuable contribution to the understanding of highway capacity and acknowledge the authors hard work which is very valuable for making the Highway Capacity Symposium a succes.

As the Danish Road Directorate, we are proud to host the Third International Symposium on Highway Capacity and we are very enthusiastic about the decision of the Transportation Research Board and the members of the Committee on Highway Capacity and Quality of Service (A3A10) to chose Copenhagen and the Danish Road Directorate as the host for this Symposium.

For the Danish Road Directorate
Rikke Rysgaard, Editor
FOREWORD

The Highway Capacity and Quality of Service Committee of the Transportation Research Board is very pleased to jointly sponsor the Third International Symposium on Highway Capacity in Copenhagen with the Danish Road Directorate. Previous International Symposia on Highway Capacity have been held in Karlsruhe, Germany and Sydney, Australia. Like the two previous symposia, this international meeting in Copenhagen is intended to provide an opportunity for researchers, engineers, and transportation planners from around the world to discuss current developments in capacity and level of service for all modes of surface transportation. These Proceedings describe some of the research which is being conducted in this area. These technical papers will be presented at the Symposium. During the Symposium, opportunities will be provided for Symposium participants to discuss the research findings with the authors of the papers.

This opportunity for the international community to exchange information in Highway Capacity will become an important contribution to further revisions to the Highway Capacity Manual, which is now scheduled to be completely revised in the Year 2000. Five editions of the Highway Capacity Manual have been previously published in 1950, 1965, 1985, 1994, and 1997. These previous editions of the HCM have provided guidance in many areas: they have developed the fundamental concept of capacity; described the level-of-service concept; added procedures for determining the capacity of non-highway modes (transit, pedestrian, and bicycle facilities); and provided a basis for the development of computer software applications for solving complex problems. The Highway Capacity Manual is published by the Transportation Research Board (TRB). The purpose of the TRB is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The program of the TRB is sponsored by state transportation and highway departments, the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

We appreciate the efforts made by the authors of the papers contained in these Proceedings to share their research results in the field of capacity. We invite the attendees of this Symposium to contribute their ideas to the discussions at this meeting so that we may enhance our ability to design, operate, and plan for improved transportation facilities.

For the Committee on Highway Capacity and Quality of Service
John D. Zegeer
Chairman
Signal Coordination and Arterial Capacity in Oversaturated Conditions

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ABSTRACT
Models to estimate capacity of oversaturated arterials are developed. The input variables in these models are capacities of individual intersections, offsets, and vehicle queue lengths. The paper also presents models to quantify capacity loss due to blockage caused by downstream queues. The proposed models show that when determining arterial capacity in oversaturated conditions it is not sufficient to only consider capacity of critical intersections, rather we must consider the capacity of critical subsystems. A critical subsystem is a two-intersection plus the link joining them where traffic processing capability is lowest. This traffic processing capability, or critical subsystem capacity, determines arterial capacity. It is a function of the capacities of the respective intersections, the offset between the two intersections and the queue length on the link joining them. It is shown that a critical subsystem is not unique in that it may change location over the course of the study period. To minimize capacity loss it is shown that offsets must be an explicit function of queue lengths. The practical use of the models was demonstrated for an oversaturated two-intersection system. The results show that improper setting of offsets can lead to significant capacity loss. In extreme cases all capacity in a given cycle may be lost if the offsets are not set properly.
ABSTRACT
Results of an evaluation of three analytical delay models for unsignalised intersections are presented. The delay models studied are the Highway Capacity Manual Chapter 10 (HCM 1994) model, the Akcelik-Troutbeck model, and the SIDRA 5 model. These models are applicable to sign-controlled intersections and roundabouts. The evaluation work reported in this paper is for sign-controlled intersections. Each delay model was used with its associated capacity model. The models were compared by means of extensive tests using the microscopic simulation program ModelC for a basic gap-acceptance case. Delays predicted by the current form of each model were then compared against simulated delays. Modified forms of the three models were then calibrated against the simulation data. Generally, the modified models improved delay predictions to a small extent. Overall, the SIDRA and Akcelik-Troutbeck models indicated similar levels of prediction ability whereas the HCM 94 model displayed poor performance. Improved prediction of capacities appeared to give larger levels of improvement in delay prediction. The HCM 97 delay and capacity models gave similar results compared with the HCM 94 models. Improved model comparison work is recommended using real-life collected data at sign-controlled intersections and roundabouts.
Level of Service Considerations in Connection with Capacity Adjustment by ITS Systems

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ABSTRACT
The standard answer to most capacity constraint or low level of service has been to widen roads and build new infrastructure. In recent years alternative steps, as implementation of ITS, have been taken to avoid/postpone these investments. Improvements gained from ITS are difficult to assess because no generally accepted definitions of the core concepts exist, which makes comparison of different systems difficult. If ITS is to become a mainstream way of handling congestion problems a new or an additional definition of level of service will be a necessary tool to describe the effects in quantifiable terms. This paper presents a study from a Danish city where an ITS system was installed in 1994 and integrated with intersection control in 1997. It was evaluated in its own terms, therefore the results to some extent serve to underline the need for a common definition and to show the effects of such systems.
Simulation of Traffic Flow on a Special Lane for Intelligent Vehicles

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ABSTRACT
This paper presents the result of a simulation study on the effects of a special lane for intelligent vehicles on traffic flow on motorways. The intelligent vehicles are equipped with Intelligent Cruise Control (ICC). ICC is an in-car system that automatically maintains a specified speed, taking into account a minimal distance with respect to predecessors. A solely ICC vehicle lane has a potentially greater capacity. In principle, by automating following behaviour, smaller distances and/or time headways between vehicles may be feasible, possibly at higher speeds. The question is whether and how such a „super lane“, can be filled with traffic. The microscopic traffic simulation model MIXIC was used to evaluate the traffic performance and traffic safety in a bottleneck situation. Simulation results demonstrate that the introduction of a dedicated lane for ICC vehicles in the situation of lane drops can improve the traffic throughput and traffic flow stability.
Delay-Based Truck Equivalencies at Signalized Intersections: Results and Field Data

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ABSTRACT

Previous studies used the headway concept to compute passenger car equivalents (PCE) for trucks at intersections. The headway-based methods consider only the excess headway consumed by trucks. They yield a constant PCE that is independent of traffic volume and percentage of trucks. To fully consider the adverse effects of trucks on a traffic stream, a new methodology for computing PCE is introduced. The new PCE (D-PCE) are computed based on the additional delay caused by heavy vehicles. Field data showed that the PCE for single unit trucks and combination trucks were different. The PCE are highly correlated with traffic volume and, to some degree, with percentage of heavy vehicles. The PCE computed from field data varied from 1.07 to 1.47 for single unit trucks, and from 1.19 to 1.81 for combination trucks. Although the PCE of 1.5 recommended in the 1985 HCM seems to be more reasonable than the 2.0 recommended in the 1994 HCM, both overestimate the impact of single unit trucks. For combination trucks, the 1994 HCM overestimates the capacity reduction effects of the trucks in most cases.
Generalized Uniform Delay Models for Signalized Intersections for Excellent and Poor Progression

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ABSTRACT

Signal coordination affects delay and level of service at signalized intersections. Two approaches may be used to account for the effects. One approach is using the progression adjustment factors (PF). The range of PF is from 0 to 256%. This paper proposes Arrival-Based approach that eliminates the needs for applying PF. The AB approach directly considers the impact of quality of progression in developing delay models. Models for uniform delay (d1 term) are developed for each arrival type. The HCM uniform delay model is a special case of the AB delay models. Delays computed using the AB delay models were compared to an extensive set of field data. For the purpose of benchmarking, the results from the AB models were also compared to the results from 1994 HCM delay model. The results indicated that the AB delay models are valid and accurate. In fact, they are more accurate than the HCM delay model. The accuracy gained is worth the additional effort that the AB approach may require.
2+1 Roads with Cable Barrier for Improved Traffic Safety

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ABSTRACT
The Swedish interurban network contains approximately 4000 km of 13 m roads carrying more than 25% of the traffic load. The safety is about 15% better than in normal two lane roads. Still, some 100 people die and about 400 are severely injured every year. This paper presents the findings and conclusions of a study aiming at improved traffic safety on existing 13 m roads:

• Speeding is an obvious problem. The 90 kph speed limit is not accepted by Swedish drivers.
• Speeds are controlled by speed limits, the degree of enforcement and fining levels.
• There is a clear tendency for a power-based relationship between accidents rates and speed with power increasing with severity.
• Fatality and casualty rates also increase with smooth curvy alignment, for some reason with open landscape, with dangerous roadside area-% and with increasing dilemma sight distance between 300 and 500 m.
• Meeting accidents dominate with 40% of fatalities and 20% of severely injured, closely followed by single run-off accidents. Overtaking is not a major safety problem. Safety problems seem to be more focused on lack of concentration, fatigue, monotonous driver perceptions on roads with high standard and low event frequencies.
• The obvious safety measures are separation of directions by barrier and improved roadside area safety standard, 2+1 designs with cable barriers within 13 m has a potential of almost 50% of fatalities.

The Swedish National Road Administration will develop the 2+1 road with a cable barrier design in a number of road projects planned to be opened for traffic in 1998 and 1999.
Heavy Vehicle Traffic in the Design Hour

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ABSTRACT
The percentage or proportion of trucks or heavy vehicles is needed for calculations regarding the capacity and level of service of a road facility. This is necessary because there are major differences between heavy and light vehicles as far as their operating characteristics are concerned. Since analyses are usually done for the design or peak hour, the percentages during the design hour is significantly lower than the annual average percentage of heavy vehicles. The difference was found to be a function of the type of traffic on the road, it is, whether it carries long distance recreational trips or short distance commuter or business trips.
Capacity and Level of Service Analysis of Freeway Systems

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ABSTRACT
This paper describes a project currently underway to develop a draft chapter in freeway systems for the year 2000 Highway Capacity manual. Work on this project began in April 1997 and is expected to be completed in early 1999.

The draft chapter will provide an analytical methodology for the evaluation of a directional freeway facility under both undersaturated and oversaturated conditions. Where possible, performance measures and capacity calculations from freeway segment based HCM chapters are being integrated into a directional freeway facility framework. Where necessary, additional procedures are being included in the analytical methodology to estimate traffic performance over time and space.
Effect of Road Lighting on Capacity of Freeways

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ABSTRACT
Road lighting on freeways is mostly installed to increase safety and driver comfort. The effect on capacity is doubted but in fact not known and hardly studied until now. An observational before-and-after study has been performed, collecting data before and after installation of the lighting and using the daylight condition as a check on possible capacity changes due to other factors. The observations refer to a 4-lane and a 6-lane freeway respectively. The capacity has been estimated by means of extrapolating a quadratic relation between rate of flow and density representing the non-congested part of the fundamental diagram. The new element in this approach is that an a priori capacity density is assumed. Results from both freeways show a small but statistically significant increase in capacity due to road lightning.
Capacity and Speed-Flow Relationships on Rural Two-Lane Highways in Germany

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ABSTRACT

The standard speed-flow relations for two-lane rural highways which are included in the current German guidelines needed significant improvements. Therefore, new calibrations have been performed. They are based on travel time measurements, on local measurements and on simulation studies. The curvature of the road, the gradient and the percentage of trucks are used as parameters.

Some rather unexpected results occurred. This was, at first, the concave shape of the speed-flow curves. Moreover the influence of trucks turned out to be rather complex, such that passenger car units could not be identified. Finally, the capacities for mountain roads proved to be far less than expected.

The new speed-flow curves will be implemented into the future German Highway Capacity Manual HBS. Here, however, some questions regarding the useful measure of effectiveness have still to be solved.
Arterial Delays Caused by Unsignalized Minor Streams

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ABSTRACT

Unsignalized intersections are the most common highway facility. The presence of two-way-stop controlled intersections reduces free-flow speed and causes delays to the through vehicles on the arterial. This paper presents analytical models to estimate average delays of arterial vehicles caused by vehicles aggressively performing crossing, merging, or diverging manoeuvres. The models require data typically available to traffic engineers.

The paper presents sensitivity analyses of the models to evaluate the magnitudes of the impact and the reasonableness of the models. The results show that the diverging manoeuvre on the arterial can cause substantial delays to the arterial vehicles while the impact of the merging manoeuvre is moderate or weak. The crossing manoeuvre appears to have a relatively weak effect.
Functioning and Operation of Bus Terminals – A Virtual Reality Simulation Study

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ABSTRACT
The paper describes the principle of a bus terminal situation program that has been developed using a virtual reality programming tool. The basic terminal operations in the model are bus arrival, unloading, waiting and parking, loading, and departure. Calibration of these operations is based on field measurements from a central bus station in Helsinki, Finland, with 1400 buses and 40,000 passengers daily. The experiences from the development and use of the terminal simulation system with advanced visualization capabilities have been encouraging, and further development of the system is going on. By using the simulation system, the operational benefits of a dynamic bus bay allocation have been demonstrated.
Traffic Performance and Passenger Car Equivalents for Road Links and Township Roads in the PRC

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ABSTRACT
A large-scale Highway Capacity Study (HCS) is currently being carried out as IBRD-funded technical assistance within the China National Highway Project for construction of a motorway network. The purpose of HCS is to develop draft capacity guidelines for motorways, interurban roads, township roads and major intersections outside of urban areas.

Data collection at 132 interurban and 12 township road segments was performed in 1996-1997 using detectors for automatic vehicle classification and determination of flow, spot-speed and headways. Video recording of license plate numbers and manual recording of side friction events was also undertaken for determination of travel time characteristics. Free-flow speed and other parameters needed for calibration and validation of the VTI simulation model for rural roads to Chinese conditions were derived from this data. The simulation model was then used in combination with speed-flow regression analysis for determination of passenger car equivalents and speed-flow relationships for all road and terrain types.

The results showed that free-flow speeds were very low, and that the capacity generally also was lower than on Western roads with the same geometry. Side-friction caused by non-motorised traffic and the abundance of very slow vehicles on Chinese roads may explain these observations.
Capacity Maximization at Three-Arm Junctions: An Extension of Webster’s Method

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ABSTRACT
Traffic lights at highly congested signalised junctions usually aim at capacity maximisation, to avoid oversaturation. Junction capacity can be effectively measured though the capacity factor, say the maximum rate by which (mean) arrival flows can be increased, still avoid oversaturation. The widely used Webster’s method allows green timing through a simple closed formulation, based on the so-called equisaturation principle. However, the maximisation of capacity factor is not assured when a stream has green in more than one stage, as it may occur for three-arm junctions. This paper presents a simple extension of Webster’s method for computing green times that maximise capacity factor for three-arm junctions. The proposed method allows defining whether a three-stage or a four-stage sequence should be preferred, and can be extended to considering constraints on minimum green time as well as pedestrian streams. It also provides useful indications to evaluate different lane allocations.
A Macro Speed-Flow Model for Multi-lane Roads

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ABSTRACT
The National Road Administration in Sweden has initiated a comprehensive research project concerning traffic on multilane roads, called TPMA (Traffic Performance on Major Arterials). One stage of this project is to develop a macro model for basic four-lane road segments. This model is based on traffic data from sites with different road performances and posted limits. Three vehicle types are analysed: car, truck and bus, and truck with trailer. The model comprises four submodels:

1. A submodel for the lane distribution of the numbers of vehicles as a function of the total traffic flow and proportion of heavy vehicles.
2. A submodel for free flow speed for each vehicle type, each lane and each posted speed limit.
3. A submodel for lane capacity for each driving lane. The model has a base capacity, and adjustment factors.
4. A submodel for the speed-flow relationship. The speed-flow curve is partly linear in three sections.

The model states that at high traffic volumes an increasing proportion of cars use the left lane with higher speeds and capacity values for this lane. The total capacity is 1,900-4,500 vehicles per hour for both lanes with about 55% of the vehicles running in the left lane. This is due to arterials with mainly inbound traffic to the city centre. For arterials with outbound traffic from the city centre the total capacity is about 500 vehicles per hour higher, i.e. 4,400-5,000 vph.
Optimisation of Traffic Signal Timings for User Equilibrium Flow

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ABSTRACT
A bi-level programming approach has been used to tackle traffic signal timings optimisation problem subject to user equilibrium flow, in which the optimisation for signal settings with respect to the common cycle time, and the starts and durations of green was dealt with as the upper level problem whilst a user equilibrium traffic assignment was dealt with as the lower level problem. A sensitivity analysis method was used and the derivatives for the performance index have been derived and used. The mixed search procedure was proposed to solve the bi-level formulation. The gradient projection method was used in deciding the optimal step length. Aalsop and Charlesworth’s road network has been used for implementing this proposed solution method. Encouraging results showed the robustness and effectiveness of the method as values of the performance index were improved further in comparison with other conventional methods.
Effect of Narrow Lanes on the Capacity of Motorways: A Trial in the Paris Region

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ABSTRACT
The trial described in this paper was realized during the spring 1996 on a 2.5 km section of the A6a motorway in the south of Paris. The initial cross section components were modified by narrowing the different lanes. An experimental design and a data collection campaign were set up in order to allow an assessment of the possible effects. This paper depicts the conditions of the trial. It consists of two parts which deal with assessment of behaviour changes (positioning, motor cycle traffic) and macroscopic analysis in traffic flows. The conclusion summarizes the main findings. There was a reduction in the lateral spacing between vehicles. Heavy lorries in particular moved closer to the edge lines. Most motorcycles continued to ride between the streams of vehicles during peak hours. Capacity was almost maintained and the congestion level was equivalent. The practical results contribute to a better knowledge of the impact of narrow lanes on the functioning of urban motorways
Development of Transit Capacity and Quality of Service Manual

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ABSTRACT
The U.S. Transit Cooperative Research Program (TCRP) is sponsoring a two-year study to develop updated principles, practices and procedures for transit capacity and quality of service. The study is being conducted with the focus of developing a new Transit Capacity and Quality of Service Manual, which will be a comprehensive document summarising transit capacity and quality of service concepts, procedures and applications. Two other key components of the study include updating the transit chapters in the new year 2000 highway Capacity Manual (HCM2000), and identifying overall research needs in transit capacity and quality of service, and conducting research in identified areas.

The interim Transit Capacity and Quality of Service Manual (TCQSM) will be completed by the end of 1998, and will be in a format similar to the Highway Capacity Manual. Five major sections of the document are proposed:

1. Concepts and Definitions,
2. Bus Transit Capacity,
3. Rail transit Capacity,
4. Terminal Capacity, and
5. Quality of Service.

In addition, a comprehensive glossary of terms and bibliography is being prepared.

For each section of the TCQSM, procedures and applications related to different capacity/quality of service topics will be prepared. Sample problems are also presented.
Capacity Improvements at Signalised Intersections Using Advanced UTC

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ABSTRACT
Modern traffic engineering now enters an interesting stage where the potential benefits of introducing advanced transport telematics could be quantified in terms of increased traffic network efficiency and increased mobility. In this paper the different aspects on Urban Traffic Control (UTC) and capacity are highlighted, including the impact of giving priority to public transport vehicles such as buses, trams and emergency vehicles. The conflict of interest between different road users is described and the possible solution – optimising traffic signal control such as SOS, SPOT, MOVA – is outlined. The socio-economic evaluation estimates a return of investment of such systems in less than one year.
CONTRIBUTION TO LEVEL OF SERVICE DEFINITION OF HIGHWAYS AND INTERSECTIONS

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ABSTRACT

This paper deals with LOS definition of highways and arterial with at-grade and signalized intersections that compose the major part of any road network. Because the sections of highways usually are analysed without taking into account the influence of intersections, and on the basis of different parameters, this paper is an attempt to prove the existence of that influence. Herein, types and required lengths of intersection approaches were determined, and an influence of control characteristics of intersection approach to previous section of road defined. In order to find some reasonable connections between the LOS parameters for highways and intersections, a brief analysis of HCM methodology and procedures was undertaken. On the basis of that analysis relevant parameters for LOS definition for considered types of intersection approaches were proposed. Procedure for determination of these parameters is suggested in final part of paper. In conclusion it is emphasised that proposed parameters are easy to compare with parameters used in capacity and LOS analysis of highways.
Capacity and Traffic Flow Characteristics at a Freeway Work Zone in Finland

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ABSTRACT
The paper deals with traffic flow characteristics and capacity of a work zone on one of the main freeways in southern Finland. The speed limit was 50 km/h. Point measurements with portable Hi-Star Traffic Counters and car following studies using an instrumented vehicle were done.

The speed level at the work zone was 30-65 km/h in the morning peak towards east and 35-65 km/h in the evening peak towards west. The spacing between the leading vehicle and the following vehicle varied between 5 and 30 m and the mode was about 12 m. The space mean speeds were found to be a little lower than the speed limit in peak hour traffic but higher than the speed limit in normal traffic. The calculated capacity was 1,636 veh/h for the basic lane and 1,828 veh/h for the passing lane and 1,828 veh/h for the passing lane towards east.
Fatalities of Heterogeneous Traffic in Large South Asian Cities

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ABSTRACT
One unique feature of large South Asian cities is the composition of its urban street traffic. Because many different traffic entities of varying sizes continuously interact on the street space, the traffic mixture is heterogeneous. Heterogeneous traffic increases street capacity. Homogeneous traffic prevails in North America, Europe, and Australian cities. Two broad categories compose heterogeneous traffic, i.e., motorised vehicles and non-motorised entities.

After collecting geometric, composition, speed and conflict data at fourteen sites at mid-block, an analysis examines the degree of heterogeneity aspect of traffic at a microscopic level. The best model showed that the high fatality midblock sites correlate to unidirectional street widths at +0.89. The degree of heterogeneity and motorised traffic flow had the strongest relationship with street width at a +0.99 correlation coefficient. Keeping motorised vehicular flow constant showed that fatalities are reduced when the traffic heterogeneity index equaled one, a 50% motorised and 50% nonmotorised composition.
Capacity Models for American Roundabouts

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ABSTRACT
The capacity of single lane roundabouts in the U.S. is currently not well documented due to a limited number of sites and their short histories. A detailed database has been developed for six single lane roundabouts located in the States of Florida and Maryland to model single lane roundabouts based on U.S. conditions. A new model for roundabout entry capacity is presented in the 1997 Highway Capacity Manual on studies conducted in Australia and a limited amount of U.S. driver performance data. An attempt was made to validate this model by comparing the HCM estimated capacity to the potential capacity measured in the field. In addition, studies were conducted on the accuracy of the assumption regarding headway distribution of the circulating stream. Average and standard deviations are also given for critical gaps and follow-up times determined for the six study sites.
Research on Capacity and Traffic Conditions at Unsignalized Urban Intersections

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ABSTRACT

The paper presents selected results of studies of capacity and traffic performance at major-minor priority intersections. Results of comprehensive field studies gave a basis for estimation of basic parameters of the departure process required for capacity models. Impacts of various geometrical and traffic factors on values of the critical gaps and follow-up times are discussed and some results are presented in the paper. Then results of simulation studies of impacts of non-stationary and nearby traffic signals on capacity and traffic performance of non-priority movements are presented. The positive effects of these were proved and examples of quantitative estimations of capacity and traffic performance measures are given. In the paper results of field measurements of blocking times of vehicles by pedestrian on crossings at intersections are given and a procedure to represent this impact in the capacity calculation method is described.
Estimation of Critical Gaps in Two Major Streams

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ABSTRACT
The maximum-likelihood method is one of the best methods for estimating critical gaps. It can be used both in cases of there being only one major lane and, if the headways in the major lanes are superposed, of there being more than one major lane.

This paper presents a maximum-likelihood method for the estimation of separate critical gaps in the case of two major lanes. The treatment of data is illustrated by an example and the method is tested on simulated data, its being shown to yield reliable results, if the volume in each lane is not too significantly under such conditions.

This method can be used also to determine any correlation found between the critical gaps.
A Review and Evaluation of Aspects of the Operation of Rural Single Carriageway Roads in Great Britain

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ABSTRACT
In Great Britain the appropriate road category is determined based on average 24 hour flow and detailed design is then developed and evaluated using economic assessment tools such as the British Department of Transport program COBA. The paper considers the origin and development of the speed/flow/geometry relationships and the application of these relationships in COBA to determine journey speed. The absence of reliable data to define operation at or near capacity is considered and the rationale of the current approach is explored against the background of the methodology used in the Highway Capacity Manual. The paper describes the application of microscopic simulation to evaluate further, for British conditions, the influences, on journey speed of directional flow and overtaking provision. It is concluded that the overtaking provision on level sections only reduces journey speed substantially if there is minimal opposing traffic flow. The effects, on journey speed, of priority junctions are shown to be potentially more substantial.
Estimation of Fundamental Flow Relationships Using Stationary and Homogeneous Observations

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ABSTRACT
In the paper a four-step method to find stationary and space-homogeneous observations from the headway-speed data is presented. The method is based on detailed analysis and statistical testing of individual vehicle data from several consecutive cross-sections along the road. The first step is to find the observation periods and detectors when and where the observations are space-homogeneous. The second step is to make sure that the speed range of the detector is wide enough. The third and fourth steps are to test stationarity of headways and of speed. Finally, those stationary periods that last at least four minutes are accepted for estimation of fundamental flow relationships.

The paper describes the four-step process in detail and gives an example application with test data from a Dutch freeway. Further on, the advantages and the problems as well as further development needs of the process are discussed.
Microscopic Simulation of Freeway Traffic – Problems in Widening the Use of Simulation Program

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ABSTRACT
The application area of the traffic simulation program used in this study (HUTSIM) is widening to freeway surroundings. The new simulation environment causes new problems and development need to the program. The paper gives a discussion about the problems of microscopic freeway simulation based on general knowledge and experiences of a case study.

Freeway as a simulation environment requires a lot from the traffic simulation procedures. The interaction between drivers is very important. Realistic lane-change and car-following procedures have a great effect on the traffic flow and the lane distribution. Traffic has to be heterogeneous because the similarity of drivers gives too smooth traffic flow. Also the interaction between the driver and the environment and between the driver and the traffic control system should be calibrated carefully. The paper demonstrates that the use of a simulation tool is restricted by the environment where it has originally been developed and validated.
Investigating the Applicability of Commonly Used Saturation Flow Models for Brazilian Cities: A Case Study

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ABSTRACT
Saturation flow is one of the most important parameters to be considered for the development of suitable plans for signalized intersections. Although it is strongly recommended that the saturation flow rates should be measured „in loco“, in many cases this is not possible and local control agencies have to estimate this parameter to generate traffic signal timing plans. For this purpose, many saturation flow models are available. Some of these models are considered in this research for the verification of their potential applicability to the Brazilian traffic conditions, more specifically to the Brazilia City traffic. The study has shown that none of the considered models can provide acceptable values for most of the fourteen studied traffic lanes. The results recommend that the Brazilia local agency conducts studies toward the calibration of the existing saturation flow models or develops a specific model for the city’s traffic conditions.
On the Speed-Flow Relationships in Road Traffic: A Model of Driver Behaviour

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ABSTRACT
Focusing on the driver, his purposes, and the perceptual and cognitive determinants of his behaviour, a model explaining the typically observed speed-flow relations is developed. – First, a simple Basic model of queue-driving is presented, in which the desired distance-gap is determined by a minimal buffer-distance and a minimal reaction time incremented with a constant factor on speed.
– Second, the model is extended considerably. Basically, the real values of speed, distance, necessary time-gap and costs are replaced by the perceived and subjective values, and a rather large number of factors determining the driver’s perception and subjective estimates are introduced. Of general importance is the dynamically varying sources- and adaptation of perceived speed.
At low traffic densities (free-flow), the driver adjusts his speed to optimize the subjective utility of driving, and major factors are his appreciation of time vs. costs of driving, risks of penalties, breakdown, and accidents.
In dense and congested traffic, speed is limited by the vehicles ahead, focusing the factors influencing perceived speed, distances, and desired time-gaps.
– Third, the model of individual drivers is tentatively extended to reflect some effects of driver-interaction (i.e.: Start-delays, stop-and go driving, platooning, multilane driving, and anticipation of bottlenecks). Predicted maximal flow-rates at given speeds envelopes some published data rather well.
While a linear speed-time gap relation is implied in the Basic model of queue-driving, the net result of the Extended model can approximate a linear speed-distance gap relation.
Research on the Capacity of Small Roundabouts in the Czech Republic

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ABSTRACT
Small roundabouts have become very popular in most European countries during the last twenty years. Many studies show that small roundabouts have lowest accident rate of all types on-level junctions. In the Czech republic only few roundabouts exist and most of these are even under a small volume of traffic. Therefore, direct investigation and measurement under the condition of congestion is very difficult. Nevertheless in several entries to the Prague roundabout on the „Vítezné námestí“ such measurement was repeatedly done. The results were surprising; the measured capacity volumes were very high, higher than what should have been expected according to the German formulae, considered to be the most appropriate to Czech condition. A comparison of entrance capacity at a particular intersection (Praha – „Vítezné“ square) was carried out before and after the modification of its layout and road marking aiming at an increase in road traffic safety. It was found that the modification did not result in a decrease of capacity, but on the contrary, in its partial increase. Recent results of approval of the capacity formulae and decrease of accident has been obtained on two small experimental roundabouts (with 34, resp. 38 m inner diameter).
Utility Analysis of the HCM Method from 1994 for the Bus Berths Capacity Calculations

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ABSTRACT
In the paper the utility for bus berth capacity calculations is made using the HCM method from 1994 in the actual conditions in Belgrade (Yugoslavia). On several locations the attributes of usage of Specific transit lines have been measured. For the results obtained by measurements and suggested values by the HCM using comparative analysis several results are obtained, upon which was analysed the possibility for the application of this method in our actual circumstances.
Pedestrians’ and Cyclists’ Effect on Capacity of the Right-turn Movement at Signalized Intersections: An Empirical Pilot Study

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ABSTRACT

The purpose of this paper is to illustrate to what extent it is possible to model the effects of pedestrians and pedal cyclists – together called „light traffic“ – at signalised street intersections on the right turning capacity for cars (right hand driving). It is an underlying assumption that the process is based on time gap acceptance since by law car drivers must give way to the light traffic.

A set of observations from 4 intersections in the Copenhagen region form the basis of regression analyses in which the effects of pedestrian flows and cycle flows on right turn delays are estimated.

Because of the accumulation of light traffic during the red phase the delay of the first right turning car has been modeled separately. The delays of the following cars have been modeled in terms of the average time headway as a function of cycle and pedestrian flows. Non-linear regression methods have been applied. The variance explained by the models is in the order of 30 – 50% and best for the delay of the first turning car.

The regression model results are partly counterintuitive: it appears that the impact of increasing cycle traffic is small for flow values between 600 and 1200 cyclists per hour. It could be due to a change in the regular time gap acceptance behaviour by car drivers but other explanations are possible.

Since the coverage of combinations of flows at the 4 intersections is limited, a simulation model of the same conflict – right turning cars versus cyclists and pedestrians – has been set up. The model is based on time gap acceptance where cars give way to both cyclists and pedestrians. The calibration of the model consists in estimating critical time gaps from comparison between the delay observations and simulated delays. The purpose of the simulation model was to be able to extrapolate values found in the observations to flow combinations not covered directly by the observations.
A Theory of Congested Traffic Flow

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ABSTRACT
Based on recent results on observations of traffic flow dynamics new hypotheses about properties of congested flow are proposed. In particular, it is proposed that 1) There are no fundamental diagrams which may describe the whole multitude of homogeneous states of traffic flow; 2) there are no unstable homogeneous states of traffic flow with respect to infinitesimal fluctuations, i.e., there is no critical density for traffic flow: In the whole possible range of the vehicle density homogeneous states of traffic flow can exist; 3) The characteristic line of the jam’s downstream front separates the whole multitude of states of traffic in the flow-density plane into two different classes: (i) States below this line are stable with respect to any fluctuations and (ii) states above this line are metastable states where the nucleation effect leading to local phase transitions can occur. It is also noted that there is a reserve in the increasing of the highway capacity of about 50%, if an occurrence of any jams would be prevented.
Prediction of Gap Acceptance Behaviour at Traffic Circles – Recent Findings

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ABSTRACT

This paper presents some new findings on the nature of gap acceptance behaviour at traffic circles which have been obtained in the course of developing a simulation model to predict delay at such intersections. During the collection of time gap acceptance behaviour of drivers appeared to be influenced by the behaviour of vehicles on the adjacent upstream approach. Consequently, it was decided to categorise gaps/lags according to whether a conflicting vehicle had originated from the adjacent or a previous approach. The introduction of this “refinement” tended to improve the correlation between observed and simulated delays. The effect of the actual position of a conflicting vehicle on the gap acceptance behaviour led to the notion to use distance as opposed to times to quantify gaps/lags. The accuracy of using distance as opposed to time-based gaps/lags was tested using the (modified) simulation model and observed delays. It was found that in general the correlation between observed and simulated results was better when using distance-based gaps/lags. Deriving critical distances from observation proved to be a time-consuming exercise and the possibility of using distances related to the geometric characteristics of a circle was investigated. Preliminary results using this technique gave favourable results providing that the approaches to the circle were spaced at approximately 90 degrees.

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ABSTRACT
In the Paper the regularity of the changes of basic traffic flow parameters (flow rate, speed, and density) on the two-lane highway sections of ideal geometry, with the traffic flow of passenger cars being equal to the practical capacity, is analysed in the function of directional split of PC-traffic flow. The critical review of the way in which this question was treated in HCM, the leading publication dealing with the problems about the road capacity, is performed. Finally, all three basic traffic flow parameters (flow rate, speed and density) for the capacity of two-lane highway section of ideal geometry and known PC-traffic flow, in the function of directional split of traffic flow, were defined.
Characteristics of New Models for Capacity Analysis of Two-Way Stop-Controlled (TWSC) Intersections

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ABSTRACT  
The Highway Capacity Manual, 1997 update contains new procedures for the analysis of capacity and level of service of unsignalized intersections. These procedures were developed as part of a study of 120 intersections throughout the United States, funded through the National Cooperative Highway Research Program. The purpose of this paper is to present the highlights of the new procedures for two-way stop-controlled intersections, including sample calculations showing the effects of upstream traffic signals, median storage, and flared minor right turn approaches. These new procedures will provide the traffic engineer with the ability to assess the performance of a wide range of conditions typically found at unsignalized intersections.
Effects of Bus Stops on the Efficiency of City Streets

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ABSTRACT
Taking into consideration a Level of Service C for the traffic quality in public transport and a Level of Service D in motorized individual traffic, limit values of the capacity of the two- and four-lane major streets, where bus capes should be fixed, could be derived from the results of simulation. In two-lane streets these values reach 700 cars/h in one direction and in four-lane streets up to 1,600 cars/h in one direction (for fixed bus cycles ≤ 5 min). If the traffic volume of motorized individual traffic exceeds these values then bus bays should be preferred to bus capes. Otherwise the bus capes or bus stops at road edge are the most suitable stops for the public transport.
Intersection Delay Measurement using Video Detection Systems

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ABSTRACT
The paper describes the application of video detection and monitoring systems at a signalized intersection in Bend, Oregon. The system was initially installed to assist in traffic control during inclement weather when the loop detectors did not work effectively with snow on ground. The system currently provides the primary traffic control at the intersection. The capabilities of the video detection system are used to measure delay at the intersection. The measured delay is consistent with the control delay as currently defined in the Highway Capacity Manual. Measured delay is, in turn, compared with delay as computed through the use of Highway Capacity Software using 15 minute traffic counts, which are also obtained from video measurements. There is reasonable consistency for the period examined. Though further investigation is planned, there is a belief that a direct measurement of the delay could provide a dynamic characteristic of the traffic operation and may lend to making adjustments in traffic control consistent with demand volume at different times of the day.
Performance Measures and Level of Service Beyond the HCM2000

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ABSTRACT

This paper is based on the recently completed National Cooperative Highway Research Project (NCHRP) Project 3-55 (4) on „Performance measures and Levels of Service in the Year 2000 Highway Capacity Manual“.

The objective of this research was to recommend appropriate service measures and additional performance measures and to incorporate them into a level of service structure for use the Year 2000 Highway Capacity Manual and beyond. The emphasis of the research was on oversaturated flow conditions, system-wide analysis, and multi-modal considerations.

The intent of the paper is to briefly summarise the process followed and present the results obtained for U.S. and international researchers and professionals. The results are presented in terms of policy issues for which consensus has been reached, and identification of critical policy issues for which consensus was not reached. The foundation for performance measures and levels of service for the HCM2000 will be presented, and implications for beyond the HCM2000 will be discussed.
Instrumented Vehicle Studies of Traffic Flow Models

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ABSTRACT
A detailed understanding of driver behaviour, particularly on motorways, has become increasingly important as new methods to control, support, inform and influence drivers have evolved. A vital support for this understanding is the ability to measure close-following headways from within the traffic stream as they evolve, and to appreciate the characteristics of the many variabilities that are present. Situations a, or near, the on-set of flow breakdown are particularly relevant.

This paper describes experiments made over the last year using the TRG instrumented vehicle which is equipped with:

* A radar rangefinder capable of measuring inter-vehicular separation and, hence, local density.
* An optical speedometer, to accurately determine the instrumented vehicle’s speed.
* Forward and rear looking video cameras, as well as audio recording facilities, to allow driver commentary and the compilation of records on “level of service” and vehicle type.

The vehicle has been used to compile a database of car following activities observed during morning peaks on a three lane motorway. These have been examined with regard to average headway, time for a driver to adjust to a change in lead vehicle speed, and overall “stability” of the following process. These results enabled an examination to be made of the suitability of several commonly used car following models to describing the “close following” situation. The models ranged from traditional “Gazis-Herman-Rothrey“ formulation through to the “Action Point“ model of Todosiev and Weidemann. Lastly, the relative strengths and weaknesses of these models have been highlighted, and a number of modifications suggested to increase their transferability.
Impact of Passing Lanes on the Quality of Service on Two-Lane Highways

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ABSTRACT
Two main procedures have been used to determine the impact of passing lanes on the quality of service on two-lane highways in Canada. One procedure has been the use of the Australia Road Research Board TRARR two-lane highway simulation model. The second procedure, which is the focus of this paper, is the use of mathematical models based on the passing opportunities concept. These models have been developed to provide a more realistic measure of level of service as perceived by the motorist, as well as a procedure which could be used at the preliminary planning stage of determining if passing lanes are warranted. Three Canadian highway agencies have developed their own particular version of the passing opportunity concept. The passing opportunity models allow the analyst to determine the reduction in percent following for a given volume, directional split, percent of passing lanes for a given length of two-lane highway in level, rolling, and mountainous terrain. In summary, the main purpose of passing lane analysis using a simulation model such as TRARR is warranted. While mathematical models based on overtaking supply and demand provide a better representation of drivers perceptions of quality of service than traditional measures based on volume/capacity ratios, their limitations in terms of simplifying assumptions are noted in the paper.
Background Paper on Road Safety Situation in Uganda

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ABSTRACT

This paper mainly addresses the issue of road safety in Uganda and has been compiled from a study and analysis of the available information. For the last decade, there have been changes leading to complications in the safe use of roads:

- The two major bus companies that existed in the past, were mismanaged and became extinct. The many people they carried had to find alternatives.
- The train service also deteriorated and now it is almost non-operational.
- The many people and goods that originally went by rail came back to the roads.
- The number of Kamunye (small commuter vehicles) shot up as public transport to bridge the gaps created.
- The increase in these small vehicles created a need for more drivers.
- Many of our drivers, are quite inexperienced and others are driving vehicles of classes higher than those they are qualified to operate
- Accurate and reliable data which is coordinated is lacking

Our accidents rate in Uganda is only second to Ethiopia in the whole of Africa. As a health hazard, accidents in Uganda are only second to malaria as a single killer. A remedy needs to be found. Colleges, universities and Non-Governmental Organisation’s (NGOs) could be encouraged and assisted to conduct studies, analyses and research on road safety, while their findings could be given to relevant authorities. This paper therefore aims to highlight difficulties in handling road safety issues in Uganda in order to interest capable scholars in the field to come and contribute to the effort and solutions.
Safety Considerations in Capacity Analysis

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ABSTRACT
In the current Highway Capacity Manual (HCM) procedures, there is an implicit assumption that safety, an important measure of the service a facility provides, is automatically considered when level of service (LOS) is specified. The notion is that the better the level of service the safer a facility will be and that the usual practice of designing for a „median“ LOS of C or D produces a desirable balance among cost, safety and operational measures. The paper proposes a framework for explicitly considering safety in highway capacity analysis by showing how what is known about the relationships between safety performance and the various LOS measures can be used to estimate the expected safety of a facility under prevailing operating conditions. The focus of the paper will be on freeways and signalized intersections. In the latter case, models calibrated as part of the research indicate that, for a given entering flow at signalized intersections, the expected number of accidents during the peak periods is larger for LOS D and E than it is for LOS B and C.
Delay and Queue Length for Congested Arterials

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ABSTRACT

Vehicle delay is the service measure for determining level of service at signalized intersections. It is also a major component in calculating average travel speed to determine the level of service on arterial streets. The most widely-used models for estimating delay at signalized intersections and average travel speed on arterial streets are those in the U.S. Highway Capacity manual (HCM). Unfortunately, these models are not sensitive to the impacts of link queue storage capacity during congested conditions. They also cannot be used to estimate the temporal and spatial duration of congestion.

This paper reviews the literature regarding queue interaction effects of closely-spaced signals, proposed models for estimating delays during congested conditions, and presents simulation results which verify these models. The results show that the models are sensitive to signal capacity, block length, and degree and duration of congestion. Results also show that the model is a good predictor of delays and queue lengths estimated by microscopic traffic simulation models. The resultant models are recommended for inclusion in the future HCM’s.
Pedestrian and Bicycle Impacts on Signalized Intersection Operation:
The U.S. Experience

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ABSTRACT
At signalized intersections, right of way allocation must not only consider conflicting ve-
Able movements, but also account for conflicts of vehicle with pedestrians and bicycles. Presently, the U.S. Highway Capacity Manual considers the impact of pedestrians on
right and unopposed left turn movements capacity only, while their effect on permissive left turns is ignored. Bicycles on the other hand are assumed to act as motor vehicle-
equivalents in some cases (e.g. on through lanes) and as pedestrians in others (e.g. when
conflicting with a right-turn movement). These ad-hoc approaches to pedestrian and bi-
cycle analyses reflect a lack of nation-wide research that can provide the necessary em-
pirical foundation for model development and validation.

This paper presents the results of a nation-wide U.S. study on the effect of pedestrian and
bicycles on turning movement saturation flow rates. The study included an extensive
survey of U.S. and international literature, field surveys in all regions of the U.S., and the
development of analytical and simulation procedures for modelling the impact of pedes-
trian and bicycles on vehicle movement operations. This paper describes the field studies
and recommends analytical and simulation models for capturing pedestrian and bicycles
at signalized intersections.
Merging Contra Give Way When Entering a Motorway

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ABSTRACT
Harmonising traffic regulations and road standards in the European countries is an ongoing process led by the EU Commission. One of the regulations in focus is the regulation concerning how to enter a motorway. The aim of the EU-study described here was to increase knowledge of traffic behaviour at entry ramps on motorways in EU countries with different forms of regulation, ramp geometry and driving style. For all four countries examined, the average speed in the right hand lane was almost the same but the speed of the vehicle entering from the ramp varied from 50 km/h in Spain, 60 km/h in Germany to 70 km/h in the Netherlands and Denmark in average. The speed was measured in the point where the vehicles from the ramp entered. It was found that the geometry of the ramp was of great importance – maybe even more than the traffic regulation – for the way the vehicles on the ramp chose to enter the motorway.
Modifications to the Transit Provision in the HCM2000

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ABSTRACT
The U.S. Transit Cooperative Research Program (TCRP) A-15 project is developing updated transit chapters for the year 2000 edition of the Highway Capacity Manual (HCM2000) and a new TRB Transit Capacity and Quality of Service Manual (TCQSM). This paper introduces the material that will be contained in the new HCM2000 transit chapters. These chapters will contain a subset of the material contained in the TCQSM, specially, the part relating to on-street transit modes—bus, light rail, and streetcar. The HCM2000 transit chapters will incorporate the updated bus and rail capacity methodologies developed by the TCRP A-7 (Operational Analysis of Bus Lanes on Arterials) and A-8 (Rail Transit Capacity) projects, respectively. A passenger-oriented transit level of service measure will supplement the vehicle-oriented measure presented elsewhere in the HCM. In addition, the passenger-oriented concept of transit “quality of service” used in the TCQM will be introduced. Finally, the HCM2000 transit chapters will present information reflecting advances in technology, such as low-floor transit vehicles, and the need to accommodate a variety of users, including persons with disabilities and transit users with bicycles.
Estimation of Truck Equivalents for Upgrades on Two-Lane Rural Roads in Brazil

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ABSTRACT

The truck equivalence factors for two-lane roads indicated in the 1985 HCM were developed for truck types and a traffic mix typical of North America. In Brazil, trucks are generally heavier and underpowered compared to North American trucks, and truck volumes on rural roads are usually higher (30% or more). This paper presents estimates of truck equivalence factors for up-grades on two-lane rural roads in Brazil, investigating ways of adapting the HCM to local conditions. The equivalent delay method was used with seven heavy vehicle types. Curves showing average climbing speed versus distance on grades were calculated using data from two sites. The equivalence values obtained were then compared with those in the 1985 HCM using the factor \( f_{HV} \). Using the HCM equivalents, the impacts of trucks are overestimated for grades where truck volumes exceed 30%, but on grades with less than 20% trucks the differences are not significant.
Evaluation of Weaving on Freeways with Sub-standard Geometric Characteristics

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ABSTRACT
The N2 freeway between Cape Town and Somerset West has become a major commuter route to the Cape Town Central Business District. At a distance of approximately five kilometres from the Cape town CBD the spacing of the interchanges over a 2.2 kilometre section become extremely close, the closest interchange spacing being 330 metres. In order to finalise upgrading proposals along this freeway section, a 220 metre weaving section, between the M5 and Liesbeek Parkway, was analysed. Comprehensive detail on traffic volumes and speeds was obtained and evaluated. It is shown that the measured volumes exceed the weaving capacity proposed by the Highway Capacity Manual to a considerable degree. The speed predictions of the Highway Capacity Manual appear to be inaccurate under the local conditions. Other models for speed and capacity prediction also have limitations. The use of density for determination of Level-of Service can have merits.
Saturation Flow Rates at Signalised Intersections in Local Conditions – Case Study of Belgrade

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ABSTRACT
This paper presents the most important data that influence the estimation of traffic saturation flow under special local conditions. Stress was placed on the importance of confirming and using the data gathered under local conditions for analysing and planning traffic management to bring this into better agreement with the demands of the existing system. The most recent experimental results, presented here, were obtained in the period October – November 1997. The Paper also assesses the influence of vehicle age and average driver profile changes on the level of saturation flow. The evident impact of factors considered here is not properly represented in the values of saturation flow because the method of experimentally determining operative values is idealised and inadequate for such a purpose. Therefore it is necessary to establish a corrective factor by which the operational value of saturation flow can be corrected to reflect the traffic situation more realistically.
Developments in Poland on a Method of Traffic Capacity Estimation and Evaluation of Traffic Conditions on Out-of-Town Roads

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ABSTRACT
This paper presents a new perspective on forming the fundamental traffic dependencies, which describe the formula between density, volume and speed for various characteristics of a road and its traffic. These dependencies were the basis for developing the first version of the new Polish method of estimating traffic capacity and evaluation of traffic conditions on out-of-town roads. The analyses described above are based on the result of research into road traffic that had been lasting for a number of years. The main point of the traffic model presented is the adoption of a free flow equation (defined by the author as a relation between average speed and the average effective unit power indicator of vehicles) and the overtaking demand indicator and the overtaking opportunities (also prepared by the author) as the basis for determining all traffic characteristics, including capacity.
Influence of Type Structure of Vehicles on Road Capacity and Traffic Conditions

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ABSTRACT
The paper presents a critical analysis of the currently operating ways of including the type structure of vehicle in traffic modelling. It also suggests a new method of including the type structure of vehicles in traffic modelling. The new solution enables a relatively high accuracy in traffic capacity and conditions estimation. The analyses have been carried out on the basis of the results of a national programme of research into a new Polish method of traffic capacity estimation and evaluation of traffic conditions. The field research of traffic lasted over 10 years and covered about 200 various road sections all over Poland.
Determining Passenger Car Equivalents for Freeways

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ABSTRACT

This paper describes an investigation of the effect vehicle composition has in traffic flow on Danish freeway sections. The objective involved the establishment of actual passenger car equivalent values for many vehicle types. The study comprises 4- and 6-lane freeways on level terrain.

The study has been concentrated on capacity situations. The methodology used is based on time headways between the vehicles. The time lag between the rear of the preceding vehicle to the rear of the vehicle is directly related to the capacity consumption of the vehicle. The vehicle length and the chassis height are measured, making it possible to classify and group the vehicles. Statistical analysis of the measurements has been carried out and the average values of gap and passage time for a given group of vehicles are related to the same values for passenger cars.

Among the results are that passenger car equivalents depend on the size of the vehicle and on the speed of the traffic flow. The passenger car equivalent equals 2 for a single-unit truck on a 4-lane freeway up to 3 for a tractor-trailer truck on a 6-lane freeway.
Estimating Meeting and Overtaking Rates on Low Volume Roads

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ABSTRACT
The provision of access required by rural communities, agricultural sectors, mining, defence and tourism industry indicate that low volume roads have great economic importance. However these roads are designed, constructed and operated at minimal cost. General characteristics of low volume roads include narrow carriageway widths and substandard horizontal and vertical alignments. The substandard designs restrict vehicle speeds during meeting and overtaking manoeuvres, which causes travel delays. Consequently the expected number of meeting and overtaking events provides an understanding of the performance of low volume rural roads. Existing methods of estimating vehicle meeting and overtaking rates assume constant flow conditions. However in practice, traffic flow rates vary hourly, daily and from season to season. If vehicle interaction rates are to be accurately determined, actual traffic flow profiles need to be modelled. In this paper, a basic model developed for estimating meeting and overtaking rates under any traffic conditions is outlined and new relationships for estimating vehicle interaction rates for any flow profile conditions are developed and presented. The accuracy of the models is established using a simulation model.
Effect of Traffic Metering, Splitting, and Merging on Control Delays in Signalized Networks

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ABSTRACT
An accurate estimation of the average delay is a key component in evaluating traffic signals. This paper discusses the effect of bottlenecks on the incremental delay at signalized intersections. The metering effect of bottlenecks can be incorporated through the variance-to-mean coefficient. This paper presents a method of estimating the variance-to-mean coefficient useful for most real-world cases that include metering of traffic streams at traffic signals, and splitting and merging at or between traffic signals.

It has been found that splitting of traffic flows introduces an additional variance into the arrivals observed downstream of the split. Omission of this effect in calculations causes underestimation of the variance-to-mean coefficient and, consequently, underestimation of delays and travel times. This paper proposes a simple procedure of estimating the variance-to-mean ratio including a new splitting -merging formula and modified metering formula. The procedure has been evaluated using simulation. The evaluation results indicate that the proposed procedure produces unbiased results. An example calculation is included for illustration.
Relationships Between Traffic Operations and Safety at Signalized Intersections

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ABSTRACT
Two critical issues in transportation facing the United States are congestion and safety. Several trends in the relationship between quality and safety have been identified for non-intersection facilities, but the relationships for intersections has never been well defined. The purpose of this research is to examine the relationship between the operational quality of service and the level of safety at one specific signalised intersection. When analysing the operational quality of a signalized intersection, the 1994 Highway Capacity Manual evaluates performance through two measures, volume-to-capacity ratio and average delay. This research focused on the relation between average stopped delay and safety. Preliminary investigation into the relation between traffic conflicts and delay indicates that average stopped delay for the entire intersection significantly affects total conflict frequencies, and that total conflict frequency increases as average stopped delay increases from 7 to 18 seconds/vehicle. The results also suggest that average stopped delay significantly affects slow vehicle and lane change conflicts, and that these conflict types decrease as average stopped delay increases from 2 to 20 seconds/vehicle.
Studies of the Relationships Between Level of Noise and Level of Service Measures at At-Grade Intersections

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ABSTRACT
For years road noise and other environmental impacts were not included in traffic control, capacity and LOS analyses. The paper presents mostly results of empirical studies of the relationships between level of noise and traffic performance measures conducted at at-grade junctions. After a short presentation of factors affecting acoustic climate in a surroundings of street junction presented are results of measurements including: traffic parameters, measures of junction performance and levels of road noise.

The second part presents identification and analysis of relationships between the above mentioned groups of variables, selected results of the computer correlation analysis of relationships including impacts of traffic signals co-ordination are presented. Discussed are relationship between the equivalent noise level and traffic performance characterised by LOS at the minor road approach. An issue of noise distribution and location of the loudest points in a junction surroundings is then discussed. The final part presents some details of construction of the simulation.
New Dutch Capacity Standards for Freeway Weaving Sections Based on Micro Simulation

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ABSTRACT
Traffic engineers in the Netherlands are not satisfied with the present guidelines on freeway capacity. For this reason the Dutch Ministry for Transportation, Housing and Water Management gave order to make a manual on freeway capacity. One of the chapters in this manual is on weaving sections. This paper describes the research on weaving capacity needed to make the first version of this chapter. The research consisted of a literature search on weaving capacity worldwide and a simulation study on the capacity of Type A weaving sections using the micro simulation model FOSIM. In the simulations weaving section length, weaving flow rate and truck percentage were varied. The results are presented in capacity diagrams for specific weaving sections configurations. Capacity results are combined in diagrams for all configurations together. Estimated pcu values for trucks are not the same for all configurations considered.
Research Issues Modeling Pedestrian Travel Time

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ABSTRACT
Pedestrian level of service has traditionally been determined by pedestrian space (m²/ped). Under uniform flow conditions, pedestrian space is closely related to pedestrian speed. However, pedestrians often experience significant delays that adversely affect the quality of pedestrian flow. Recent research is increasing the knowledge available for using travel time per unit distance or its reciprocal, average speed over a particular route, as an additional measure of level of service. Issues that require immediate attention are described. Models of walking time on links are summarized and the implications of using a particular model for typical sidewalk systems are discussed. Models of delay at signalized intersections are described and model assumptions are compared to data describing pedestrian behaviour. A model of delay at unsignalized intersections is described and compared to other means to describe delay at these crossings.
Effect of Highway Geometry on Freeway Queuing at Merge Sections

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ABSTRACT
To facilitate the pre-analysis of dynamic traffic management solutions for freeways (ramp metering, buffers, etc.), a quick assessment is needed of the effectiveness of such solutions. In such a pre-analysis an estimate is needed of congestion characteristics such as mean queue speed, queue growth and dissipation speed, travel time loss and queue length. Freeway merge sections with lane drops are particularly critical in such analyses, as they often contain a bottleneck. One of the key issues surrounding congested merge sections is how congestion will affect the different roadways approaching the merge.

Based on the fundamental diagram of traffic flow and Lighthill and Whitham’s shock wave theory an approximation method has been developed for estimating the queuing characteristic.

The paper shows that, for a given road section, the ratio of the total number of exiting traffic lanes to the total number of incoming traffic lanes, called the Geometric Factor, is a good determinant of queuing characteristics if the Geometric Factor is smaller than one. For geometric lane drop bottlenecks the Geometric Factor is smaller than one by definition, and congestion starts if the demand-flow exceeds the supply-flow.

Any merge configuration with a Geometric Factor smaller than one will function as a geometric bottleneck. During complete congestion, with queue growth on both the merge ramp and the freeway upstream of the ramp, all lanes upstream of the bottleneck have almost the same queue speed and flow. For this condition, supply-flow in pcphpl on both approaching roadways is a function of the Geometric Factor. Likewise the Geometric Factor determines the practical capacity of an on-ramp. During partial congestion, with queue growth only on the mainline or the ramp, the mean queue speed is only dependent on the flow rate of the uncongested roadway.

A first evaluation of the method with data from three merge locations on freeways near Amsterdam and Rotterdam gives good results.

With a capacity speed of 90 kmph a Geometric Factor of 0.33 results during complete congestion in a queue-speed between 6 and 8.6 kmph; a Geometric Factor of 0.8 in a queue-speed between 33 and 41.6 kmph, varying with the start wave speed between 15 and 24 kmph.
Estimation of Queue Lengths and Their Percentiles at Signalized Intersections

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ABSTRACT

Queue lengths are important parameters in traffic engineering for determining the capacity and traffic quality of traffic control equipment. At signalized intersections, queue lengths at the end of red time (red-end) are of greatest importance for dimensioning the lengths of lane. While the average queue length reflects the capacity of traffic signals, the so-called 95th and 99th percentile of queue lengths at red-ends are used for determining the length of turning lanes, such that the risk of a blockage in the through lanes could be minimized. Furthermore, lengths of back-of-queue (queue length at queue-end) must be considered for determining the lengths of turning lanes at signalized intersections.

The queue length and their distribution can be numerically calculated from Markov chains. The percentiles of queue lengths can be estimated from the distribution. Based on the results of Markov chains, regression are undertaken from obtaining explicit formulas under stationary traffic conditions. For non-stationary traffic conditions, the formulas can be derived using the so-called transition techniques.
Impedance Effects for Streams of Higher Ranks at Unsignalised Intersections

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ABSTRACT
In current procedures in the Highway Capacity Manual (HCM) for calculating capacities at unsignalized intersections, the impedance effect for estimating the capacity of high ranked streams is considered. Normally, the simple product of queue-free probabilities in single major streams is used for obtaining the total queue-free probability in all major streams. For minor streams of higher (>3) ranks, the queue-free probabilities in major streams are not independent of each other. The simple product of the single probabilities underestimates the total queue-free probability, and thus overestimates the total impeding effect. To overcome this problem, HCM uses an adjustment function based on empirical work in Germany. Unfortunately, for some marginal condition, the adjustment function delivers unrealistic results. In general, the procedure in HCM overestimate the total queue-free probability and therefore also the capacity of the minor streams of rank 4.

A new approach for estimating the queue-free probability in higher-ranked streams is introduced. The approach is derived from probability theory and is verified by simulations. This approach is much more accurate than the current HCM procedure and it can be extended to streams of arbitrarily high ranks.
Country Reports
Capacity Research and Applications in Australia 1994-1998

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ABSTRACT
Country reports for Australia were presented in the First and Second International Symposia on Highway Capacity. This country report for Australia presents a summary of various capacity related research undertaken since the Second International Symposium in 1994. The subject areas covered include actuated signals, platooned arrivals at coordinated signals, intersection performance models with initial queued demand, fundamental traffic relationships, paired intersections, roundabouts, sign control, freeways, rural roads, pedestrians, SIDRA software package, and use of genetic algorithms for scheduling road capacity improvements. References to publications are given.
Research and Application of Highway Capacity and Level of Service in Canada

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ABSTRACT
Research in Canada into highway capacity and level of service dates back approximately 25 years. Activities, although limited, have been significant and the findings incorporated into various publications and manuals. This third Country Report summarizes previous work and briefly describes activities undertaken since 1994. Future anticipated activities are also presented along with a list of names and addresses of the more current researchers and practitioners. A list of references is also included covering work done since 1994.
**Review and Prospect on Capacity Study in China**

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**ABSTRACT**
This paper describes the current status of highway in China, including total mileage, traffic composition and future development plan, then it reviews the capacity studies on two-lane two way highways under mixed traffic in recent years. Some results based on Chinese traffic characteristics are introduced. They are MVE analysis progress, determination of LOS standards, capacity value as well as the application of traffic entropy for mixed traffic flow under the conditions which are different from the developed countries. The application of traffic flow theory in capacity analysis, such as weaving theory, gap-acceptance at intersections and catastrophe theory at segments, are put forward also. In addition, the preliminary application of capacity in Chinese highway technical standards is provided. Finally, the ongoing research, including highway traffic flow characteristics research and traffic simulation techniques in the future, are pointed.
Highway Capacity Research and Applications in Denmark

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ABSTRACT
Highway capacity applications and knowledge in Denmark are published as a part of the Danish Road Standards, which have the status of guidelines. The published knowledge is used for design, planning, and operational analysis. The national Danish guidelines for the field of highway capacity are currently being updated. This country report will present what is being proposed by the expert group. It therefore includes the most recent updated highway capacity knowledge. During the work, it has been realised that the knowledge of the behaviour-based factors are limited and have to be updated further in the future. The studies and increase in knowledge for specific traffic facilities are furthermore meant to supplement the development of better methodologies for system analysis in the design, planning and operation phases.
Highway Capacity Research in Finland

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ABSTRACT
With the growing interest to better utilize the existing road network, the importance of capacity and level-of-service issues are coming more to the front in Finland. Data has been gathered and analyzed on different types of roads since the beginning of 1980’s. The oldest data has now become outdated, but the introduction of the Traffic Monitoring System with more than 200 measuring points has made a huge amount of real-time data available for research. Also the statistical procedures in the analysis of traffic flow data have been evaluated, and new procedures have been suggested to correct serious flaws in current methods. Capacity studies on intersections have mostly focused on the calibration and validation of the HUTSIM simulation program for both signalized and nonsignalized intersections, including roundabouts. In the future, the capacity and level-of-service procedures will be better adapted to Finnish conditions. The increasing significance of transportation telematics and other traffic management policies will set new requirements for traffic flow research.
Capacity Improvements on Urban Express Roads in France

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ABSTRACT
How to improve urban expressway capacity on land strips constrained by urban development? To reflect on this subject, the French National Road Directorate commissioned a study group, comprising experts in road design, management, traffic regulation and safety. In order to gain one lane in the cross-section, the group investigated two contrasting options either to remove the hard shoulder, or keep it and reduce other components of the cross-section. The study group clearly proposed that the hard shoulder should be kept because of its significant functions, while reducing the width of both lanes and the off-side hard strip. It has defined a minimum width for each of these components and conditions for their use. In order to check the validity of these proposals, a trial was carried out, under real conditions, on the A6a motorway. As French knowledge of highway capacity (especially for narrow lanes) is insufficient, the study group is preparing a programme for trials and data collection.
Development of a traffic engineering handbook in Germany began in 1989. A first complete draft for this handbook was published in 1994, and is currently used extensively in engineering practice. However, some improvements to the official version are still required before it can be introduced by the Federal Minister of Transport for official use. A committee was recently appointed to oversee these further improvements. The committee has initiated several research projects that are funded by the Federal Minister of Transport. One of the results of the committee’s work is that the six levels of service used to define operations according to the American HCM have been accepted for use in analyzing traffic operations also for German conditions. In addition, capacities depending on external conditions, such as daylight/darkness or driver population, have been proposed for freeway traffic. A new method for determining ramp capacities also has been developed. Important progress also has been achieved in improving the theoretical background used for unsignalized intersection analysis. The new manual is intended to be ready for publication by the year 2000.
National Report on Highway Capacity of The Netherlands

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ABSTRACT

This report gives a picture of research carried out recently in the Netherlands in the area of capacity in general and how to make better use of existing capacity in particular. The latter is closely related to the Dutch national policy with regard to the realisation and use of infrastructure. Main topics are the new capacity values for weaving sections and the changed policy as regards traffic flow during road works, as well as the effects of lighting on highway capacity. In addition, measures are discussed to improve existing-capacity usage, such as special purpose lanes (e.g. HOW lanes, truck lanes), peak hour lanes and no-passing zones for trucks. Finally, attention is given to future developments in the field of infrastructure and automated vehicle guidance.
Capacity Research in Norway

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Research and Applications of Highway Capacity and Level of Service in Poland – Country Report

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ABSTRACT
This report presents review of the studies and research projects recently completed or currently conducted in Poland in the field of capacity and level of service. Described are: the historical context, research and applications in the areas of: major/minor priority intersections situated in urban areas including those situated near-by traffic signals, small roundabouts and investigations of relationships between the equivalent level of noise and LOS measures at at-grade intersections. Future directions for research described gaps of knowledge and needs for research as well as the new projects in the field. The report provides also some basic references and names of currently active individuals and groups in the capacity field.
**Country Report for Singapore**

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**ABSTRACT**  
Research in the area of highway capacity conducted at the Nanyang Technological University in Singapore resulted in development of traffic models on the area-wide as well as link-based scale. The speed-flow relationship calibrated for 6-lane expressways suggests a capacity value of 2,500 pcu/h/lane. For arterial roads, a new travel time-density model has been developed which includes the number of signals per kilometre and minimum intersection delay as parameters. The corresponding speed-flow model indicates capacity values of about 1,000 pcu/h/lane for arterials with signal progression and 900 pcu/h/lane for roads with uncoordinated signals. The above flow rates are expressed in passenger car units which were calibrated for local conditions.


*Country Report Sweden*

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