Proceedings of the Conference
STRATEGIC HIGHWAY RESEARCH
PROGRAM AND TRAFFIC SAFETY
ON TWO CONTINENTS in
Gothenburg, Sweden,
September 18 – 20, 1991, Part 3

– Operational Roadway and Workzone Research
– Safety and Mobility of Older Drivers
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ON TWO CONTINENTS in
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September 18 – 20, 1991, Part 3

– Operational Roadway and Workzone
  Research
– Safety and Mobility of Older Drivers
Papers presented at the seminar were as follows:

Overtaking Behaviour on Single Carriageway Roads in the United Kingdom (Hunt, J G and Mahdi, T A);
Overtaking Behaviour on Two-Lane Rural Roads (Carlsson, A);
Time and Space Criteria of Column Following (Vujanic, M);
Passing Operations on a Recreational Two-Lane, Two-Way Highway (Kaub, A R);
Reducing Risk Taking in Passing on Two Way Roads (Lipovac, K);
Guidelines for Railroad Preemption at Signalized Intersections (Marshall, P S and Berg, W D);
Old Hands on the Wheel: Exposure, Accident Experience and Problems of Elderly Drivers (Chipman, M L);
More Safety Thanks to Good Orientation: Nothing Works Without Traffic Signs (Reinsberg, H);
Elderly People and Mobile Telephone Use: Effects on Driver Behaviour? (Nilsson, L and Alm, H);
Dementia and Road Test Performance (Hunt, L A);
Predicting Accident Frequency from Older Driver Capabilities: Developing a Testable Model (Owsley, C);
Visual Function and Eye Health: Their Relationship to Older Driver Problems (Sloane, M E);
Attentional and Cognitive Factors in Predicting Older Driver Problems (Ball, K);
Attention and Driving Performance in Alzheimer's Dementia (Parasuraman, R);
Older Drivers Handling Road Traffic Informatics: Divided Attention in a Dynamic Driving Simulator (Wolffelaar, P C, Brouwer, W H and Rothengatter, J A);
Older Driver: Emergent Trends in the European Policy Environment (Greico, M S and Axhausen, K W);
Older Drivers - A Problem for Whom? (Spolander, K).
PREFACE

The Swedish Road and Traffic Research Institute (VTI) and the US Transportation Research Board (TRB) of the National Research Council were jointly organising this international conference. The objective was to cover the present and future road research with special emphasis on the Strategic Highway Research Program (SHRP), as well as the research concerning drivers and vehicles as related to highway safety.

SHRP is a fully funded, $ 150 million (US), five year program of research directed at asphalt, concrete and structures, highway operations, and long term pavement performance.

In the sessions on roads there were presentations which highlighted differences between European and US practices and needs, and the discussions were concentrated on how to promote international involvement in SHRP and application of its research, within the areas of Asphalt, Long Term Pavement Performance (LTPP), Highway Operations and Concrete and Structures.

In the different road safety sessions there were presentations of actual research in different countries and discussions of the differences that exist between Europe and the USA, trying to explain the reasons for them and examine whether they are reasonable and acceptable.

Linköping October 1991

Kenneth Asp

Proceedings of the Conference STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS in Gothenburg, Sweden, September 18-20, 1991:

VTI RAPPORT 372A, Part 1
- Opening
- Motorist Information Systems
- Accident Studies and Safety Management

VTI RAPPORT 372A, Part 2
- Roadside Safety Features
- Human Engineering, Training and Traffic Safety

VTI RAPPORT 372A, Part 3
- Operational Roadway and Workzone Research
- Safety and Mobility of Older Drivers

VTI RAPPORT 372A, Part 4
- Simulation and Measurement of Operator and Vehicle Performance
- Strategies to Increase the Use of Restraint Systems

VTI RAPPORT 372A, Part 5
- Asphalt
- Highway Operations and Concrete and Structures

VTI RAPPORT 372A, Part 6
- Long-Term Pavement Performance

VTI RAPPORT 372A
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John G Hunt and Talib A Mahdi, University of Wales College of Cardiff, United Kingdom

#### Overtaking Behaviour on Two-Lane Rural Roads
Arne Carlsson, Swedish Road and Traffic Research Institute (VTI), Sweden

#### Time and Space Criterias of Column Following
Milan Vujanic, University of Belgrade, Yugoslavia

#### Passing Operations on a Recreational Two-Lane, Two-Way Highway
Alan R Kaub, University of South Florida, USA

#### Reducing Risk Taking in Passing on Two Way Roads
Krsto Lipovac, Higher School of Internal Affairs, Yugoslavia

#### Guidelines for Railroad Preemption at Signalized Intersections
Peter S Marshall, Barton-Aschman Ass Inc and William D Berg, University of Wisconsin-Madison, USA

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SAFETY AND MOBILITY OF OLDER DRIVERS

Old Hands on the Wheel: Exposure, Accident Experience and Problems of Elderly Drivers
Mary L Chipman, University of Toronto, Canada

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More Safety Thanks to Good Orientation:
Nothing Works Without Traffic Signs
Henriette Reinsberg, 3M Deutschland GmbH, Germany

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Elderly People and Mobile Telephone Use: Effects on Driver Behaviour?
Lena Nilsson and Håkan Alm, Swedish Road and Traffic Research Institute (VTI), Sweden

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Dementia and Road Test Performance
Linda A Hunt, Washington University School of Medicine, USA

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Cynthia Owsley, University of Alabama at Birmingham, USA

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<td>Krister Spolander, Central Bureau of Statistics (SCB), Sweden</td>
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STRATEGIC HIGHWAY RESEARCH PROGRAM AND TRAFFIC SAFETY ON TWO CONTINENTS

Gothenburg, Sweden

September 18-20, 1991

WEDNESDAY SEPTEMBER 18

OPENING

9.00 - 11.30

Chairman: Mrs Gunnel Färm, Director General, Swedish Road and Traffic Research Institute (VTI), Sweden

Opening Speeches
Mr Kjell A Mattsson, Governor of the Province of Gothenburg and Bohus, Sweden
Mrs Gunnel Färm, Director General, Swedish Road and Traffic Research Institute (VTI), Sweden

Research and the International Transportation Community
Dr C Michael Walton, Chairman, Executive Committee, Transportation Research Board, National Academy of Sciences and Engineering, USA

Transport Policies and Traffic Safety in an Integrated Europe
Dr Jan C Terlouw, Secretary General of the European Conference of Ministers of Transport (ECMT), France

Getting SHRP's Products Into Practice
Dr Damian J Kulash, Executive Director, Strategic Highway Research Program (SHRP), USA

FHWA Role in SHRP Implementation
Mr E Dean Carlson, Executive Director, Federal Highway Administration, USA
(presented by Charles L Miller)

Recent European Initiatives in Research Collaboration
Mr David F Cornelius, Director, Transport and Road Research Laboratory (TRRL), United Kingdom
WEDNESDAY SEPTEMBER 18

ASPHALT

13.00 - 17.00

Chairman: Tord Lindahl, Swedish Road and Traffic Research Institute (VTI), Sweden

The Asphalt Model: Results of the SHRP Asphalt Research Program
D R Jones and T W Kennedy, University of Texas, Austin, Texas, USA

SHRP Asphalt-Aggregate Mix Analysis System
T W Kennedy and R J Cominsky, University of Texas, Austin, Texas; E T Harrigan and R B Leahy, Strategic Highway Research Program, Washington, USA

An Investigation of Asphalt-Aggregate Interaction and Their Sensitivity to Water
C W Curtis, L M Perry and C J Brennan, Auburn University, Auburn, Alabama, USA

Thermal Fatigue Cracking of Asphalt Concrete Pavements - An Experimental Approach
N W Jackson, T S Vinson, and V Janoo, Oregon State University, Corvallis, Oregon, USA

Development of Test Methods for a Performance-Related Bitumen Specification
D A Anderson, The Pennsylvania State University, USA

Characterization of Self Assemblies in Asphalt by NMR Spectroscopy and High Performance Gel Permeation Chromatography
P A Jennings, J A S Pribanic, T M Mendes, and J M Smith, Montana State University, Bozeman, Montana, USA

Asphalt Research in The Netherlands
P C Hopman, Delft University of Technology, Delft; P A J C Kunst, Netherlands Pavement Consultants bv, Hoevelaken; A C Pronk and J M M Molenaar, Roads and Hydraulic Department of Rijkswaterstaat, Delft, and A A A Molenaar, Delft University of Technology, Delft, The Netherlands
WEDNESDAY SEPTEMBER 18

MOTORIST INFORMATION SYSTEMS

13.00 - 17.00

Chairman: Conrad Dudek, Texas A&M University, College Station, USA

Changes in Driver Behaviour as a Function of Handsfree Mobile Phones: A Simulator Study
Håkan Alm and Lena Nilsson, Swedish Road and Traffic Research Institute (VTI), Sweden

Variable-Message Signs: Legibility and Recognition of Symbols
Colomb, Huberg, Bry, Carta, Laboratoire Central des Ponts et Chaussees, Dore-Picard, Institute National de Recherche sur les Transport et leur Securité, France

The Man and His Wheel: Cognitive and Perceptual Factors
Marcel Wierda, Traffic Research Centre, The Netherlands

Measuring Effects of Variable Message Signing on Route-Choice and Driving Behavior
Richard van der Horst, Wiel Janssen and J E (Hans) Korteling, TNO Institute of Perception, Soesterberg, The Netherlands

Acceptance and Benefits of the Berlin Route Guidance and Information System (LISB)
Jürg M Sparmann, SNV Studiengesellschaft Nahverkehr mbH, Berlin, Germany

Automobile Navigation Safety Issues
Robert L French, R L French & Associates, Ft Worth, Texas, USA

(16.30-17.00 Short business meeting of TRB Committee A3B08, User Information Systems - visitors welcome)
WEDNESDAY SEPTEMBER 18

ACCIDENT STUDIES AND SAFETY MANAGEMENT

13.00 - 17.00

Chairman: Gunnar Carlsson, Swedish Road and Traffic Research Institute (VTI), Sweden

Economic Appraisal and Ranking of Road Safety Measures
Karl-Olov Hedman, Swedish Road and Traffic Research Institute (VTI), Sweden

Traffic Safety on Two Continents — A Ten-Year Analysis of Human and Vehicular Involvements
Rüdiger Lamm, University of Karlsruhe, Germany and Elias M Choueiri, North Country Community College, New York, USA

Description and Testing of a Side Impact Protection System
Jan Ivarsson, Volvo Car Corporation, Sweden

A Critical View of Traffic Safety Management in a Developing Country; A Case Study of Jordan
N M Katamine and M A Salem Kiyassat, University of Jordan, Jordan

Development of a Collision Topology for Evaluation of Collision Avoidance Strategies
Kenneth L Campbell, Daniel F Blower, Dawn L Massie, Patricia F Waller and Arthur C Wolfe, UMTRI, Ann Arbor, Michigan, USA

Comprehensive Safety Management
Michael S Collins, Ergotrans, United Kingdom

The Future of Road Traffic Management: Urgent Global Harmonization Will Affect All Governments
Arthur R Olin, Sweden

Implications of Litigation for Highway and Motor Vehicle Safety Research
P Robert Knaff, K B and Assoc., Silver Spring, MD, USA

The Impact of Litigation on the Federal Highway Administration’s Highway Safety Program
Steven E Wermcrantz, Federal Highway Administration, USA
THURSDAY SEPTEMBER 19

ROADSIDE SAFETY FEATURES

9.30 - 17.30

**Chairman:** Thomas Turbell, Swedish Road and Traffic Research Institute (VTI), Sweden, co-Chairman: Hayes E Ross, Texas Transportation Institute (TTI), USA

**Roadside Safety - A Knowledge-based Approach**
Abdelkrim Ramache, University of Newcastle Upon Tyne, United Kingdom

**Safety Barriers Systems in Germany**
Bernd Wolfgang Wink, Volkmann & Rossbach GmbH & Co KG, Germany

**Side Impact Crash Testing of Highway Safety Hardware**
John F Carney and Malcolm H Ray, Vanderbilt University, Nashville, USA

**Safety Assessment of Highway Designs**
Malcolm H Ray, Standard & Ray Assoc., Franklin, USA (presented by J F Carney)

**The Importance of Using a Range of Vehicle Weights when Testing a Crash Cushion**
Michael G Dreznes, Energy Absorption Systems Inc, Chicago, USA

**Reliability of Results of Crash Testing Small and Medium Size Cars into Two Segmented Concrete Barriers**
Francis P D Navin, University of British Columbia, Vancouver, Canada

13.00 Luncheon

**Safe Road Design as Limit State**
Francis P D Navin, University of British Columbia, Vancouver, Canada

**Status of the United States Efforts in Promoting International Harmonization of Test and Evaluation Procedures for Roadside Safety Features**
Harry W Taylor, FHWA, Washington DC, USA

**Occupant Risk by Different Severity Criteria**
Vittorio Giavotto, Politecnico di Milano, Milan, Italy

Hayes E Ross Jr, Texas Transportation Institute, Texas A&M University, USA

**Status of the European Work on Harmonizing Requirements and Test Procedures for Roadside Safety Features**
Jacques Boussuge, SETRA, France

**WORKSHOP on International Harmonization**
Status reports from the ongoing update of the US test procedures and the development of a European Standard within CEN
(This workshop will be followed up in non-public informal meeting between TRB committee A2A04(2) and CEN/TC226/WG1 on Friday morning)

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THURSDAY SEPTEMBER 19

HUMAN ENGINEERING TRAINING AND TRAFFIC SAFETY

9.30 - 13.00

Chairman: Alison Smiley, Human Factors North Inc, Toronto, Canada

Development of a Methodology for Measuring Improper Seat Belt Use
Brian A Grant, Road Safety Directorate, Transport Canada, Jocelyn Pedder and Nicholas Shewchenko, Biokinetics and Assoc. Ltd, Ottawa, Canada

Mandatory Hazard Perception Testing as a Means of Reducing Casualty Crashes Amongst Novice Drivers
Michael Hull and Peter Lowe, Vic Roads, Australia

Eye Scanning Rules for Drivers – How Do They Compare With Actual Observed Eye Scanning Behavior?
Helmut T Zwahlen, Ohio University, Athens, Ohio, USA

The Effects of Moderate Heat on Driver Vigilance in a Moving Vehicle
D P Wyon and F Norin, Volvo Car Corporation, Sweden

Position Accuracy When Pushing Pushbuttons in a Car as a Function of Car Speed and Location: Implications for Design
Helmut T Zwahlen, Nuruddin Abdullah and David Kellmeyer, Ohio University, Athens, Ohio, USA

(9.00-9.30 Short meeting of TRB Committee A3B02, Vehicle User Characteristics - visitors welcome)
THURSDAY SEPTEMBER 19

OPERATIONAL ROADWAY AND WORKZONE RESEARCH

14.00 - 17.30

Chairman: Karl-Olov Hedman, Swedish Road and Traffic Research Institute (VTI), Sweden

Overtaking Behaviour on Single Carriageway Roads in the United Kingdom
J G Hunt and T A Mahdi, School of Engineering, UWCC, Cardiff, United Kingdom

Overtaking Behaviour on Two-Lane Rural Roads
Arne Carlsson, Swedish Road and Traffic Research Institute (VTI), Sweden

Time and Space Criterias of Column Following
Milan Vujanic, University of Belgrade, Yugoslavia

Passing Operations on a Recreational Two-Lane, Tow-Way Highway
A R Kaub, University of South Florida, Tampa, USA

Reducing Risk Taking in Passing on Two Way Roads
Krsto Lipovac, Higher School of Internal Affairs, Yugoslavia

Guidelines for Railroad Preemption at Signalized Intersections
Peter S Marshall, Barton-Aschman Ass Inc, Minneapolis, MN and William D Berg, University of Wisconsin-Madison, USA
THURSDAY SEPTEMBER 19

SIMULATION AND MEASUREMENT OF OPERATOR AND VEHICLE PERFORMANCE

9.30 - 13.00

Chairman: R Wade Allen, Systems Technology Inc, USA

Traffic Measurements by Means of Computer Vision Techniques
N O Jørgensen, Institute of Roads, Transport & Town Planning, Denmark

Dynamic 3-D Highway Modelling
Arthur Roberts, NJDOT Research, Trenton, USA (Presented by R Pain)

Validation of Real-Time Man-In-The-Loop Simulation
R Wade Allen, David G Mitchell, Anthony C Stein and Jeffery R Hogue, Systems Technology Inc, Hawthorne, USA

Measurement of Driver Performance in Training Simulators
J E Korteling, TNO, The Netherlands

Litigation and Driving Simulators
Slade Hulbert, Ph D, Consultant, Danville, USA

STRATEGIES TO INCREASE THE USE OF RESTRAINT SYSTEMS

WORKSHOP

14.00 - 17.30

14.00 Opening

14.05 Illustration of background paper

14.15 National reports on seat belt use and countermeasures (10 minutes each)
   - Canada
   - Finland and other Nordic countries
   - France
   - Germany
   - Great Britain
   - Netherlands
   - United States

15.45 Coffee break

16.00 Discussion with speakers and audience

17.00 Concluding remarks and closure

(17.00-17.30 Short business meeting of TRB Committee A3B06, Simulation and Measurement of Operator and Vehicle Performance)

VTI RAPPORT 372A
THURSDAY SEPTEMBER 19

LONG-TERM PAVEMENT PERFORMANCE

9.30 - 17.30

Chairman: Hans Jørgen Ertman Larsen, Danish Road Institute, Denmark

Early Evaluations of SHRP LTPP Data and Planning for Sensitivity Analyses
J B Rauhut, Brent Rauhut Engineering, Austin, Texas; M I Darter, Eres Consultants Inc, Savoy, Illinois; O Pendleton, Texas A&M University, College Station, Texas; and N F Hawks, Strategic Highway Research Program, Washington, USA

The Specific Pavement Studies: Key Issues and Potential Products
A N Hanna and N F Hawks, Strategic Highway Research Program, Washington, USA

Expected Changes to the AASHTO Design Guide
N F Hawks, Strategic Highway Research Program, Washington, USA

Cost Effectiveness of Asphalt Concrete Overlays - The Canadian Approach
G A Sparks, Clayton, Sparks & Ass Ltd, Saskatoon, Canada; D M Nesbitt, Decision Focus Inc, Los Altos, California; and G Williams, Roads and Transportation Association of Canada, Ottawa, Canada

Long Term Pavement Performance Trials and Data Analysis in The United Kingdom
H R Kerali, University of Birmingham and J F Potter, Transport and Road Research Laboratory, United Kingdom

SHRP—NL: A Research Project Parallel to SHRP
G T H Sweere, SHRP-NL, Delft, The Netherlands

Structural Assessment, Performance and Economic Maintenance of Minor Roads
J Roger Duffell, The Hatfield Polytechnic, United Kingdom

Treatment of Bearing Capacity Results
B Leben and A Petkovsek, Institute for Geotechnic and Roads, Ljubljana, Yugoslavia

A Model of IRI for Jointed Plain Concrete Pavements
P Ceza, J David, J Gonzalez and M Poblete, IDIEM, University of Chile; and P Gutierrez, National Highway Administration, Chile

The High Speed Road Deflection Meter
P W Arnberg and G Magnusson, Swedish Road and Traffic Research Institute (VTI), Sweden

PAVUE: A Real-Time Pavement Distress Analyzer
M W Burke and K Råhs, OPQ Systems AB, Linköping; and P W Arnberg, Swedish Road and Traffic Research Institute (VTI), Sweden
FRIDAY SEPTEMBER 20

SAFETY AND MOBILITY OF OLDER DRIVERS

8.30 - 12.30

Chairman: John Eberhard, TRB Task Force on Safety and Mobility of Older Drivers, USA

Old Hands on the Wheel: Exposure, Accident Experience and Problems of Elderly Drivers
M L Chipman, C G MacGregor, A M Smiley, University of Toronto, M E H Lee-Gosselin, Universite Laval, Quebec, and L Clifford, Ministry of Transportation, Toronto, Canada

More Safety Thanks to Good Orientation - Nothing Works Without Traffic Signs
Henriette Reinsberg, 3M Germany, Germany

Elderly People and Mobile Telephone Use - Effects of Driver Behaviour?
Lena Nilsson and Håkan Alm, VTI, Sweden

Driving Performance in Mild Senile Dementia of the Alzheimer Type (SDAT)
Linda Hunt, Dorothy Edwards, John C Morris and Ada Mui, Irene Walter Johnson Rehabilitation Institute at Washington University Medical Center, St Louis, USA

Discussant:
Robin Barr, National Institute on Aging, US Department of Health and Human Services, Bethesda, Maryland, USA

SYMPOSIUM SESSION:

VISUAL AND COGNITIVE CAPABILITIES IN OLDER DRIVERS: PREDICTING ACCIDENT RISKS

Visual Function and Eye Health: Their Relationship to Older Driver Problems
Michael Sloane, University of Alabama at Birmingham, USA

Attentional and Cognitive Factors in Predicting Older Driver Problems
Karlene Ball, Western Kentucky University, Bowling Green, USA

Attention and Driving Performance in Alzheimer’s Dementia
Raja Parasuraman, Catholic University of America, Washington, USA

Older Drivers Handling Road Traffic Informatics: Divided Attention in a Dynamic Driving Simulator
Peter C van Wolffelaar, Wiebo H Brouwer and Talib Rothengatter, Traffic Research Centre, University of Groningen, The Netherlands

Discussant:
Harvey Sterns, Institute for Life-Span Development and Gerontology, University of Akron, Ohio, USA

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FRIDAY SEPTEMBER 20

SAFETY AND MOBILITY OF OLDER DRIVERS

13.30 - 16.00

PANEL DISCUSSION:

FEASIBILITY OF INTERNATIONAL PERFORMANCE STANDARDS FOR OLDER DRIVERS

Presiding Officer: John Eberhard, Chairperson, TRB Task Force on Safety and Mobility of Older Drivers, USA

1. A USA Perspective
   Robin Barr, National Institute of Aging, Bethesda, MD, USA

2. A European Community Perspective
   Margaret Greico, Oxford University, United Kingdom
   Kay Axhausen, Imperial College of Science, Technology and Medicine, London, United Kingdom

3. A Scandinavian Perspective: Older Drivers - A Problem for Whom?
   Krister Spolander, Central Bureau of Statistics (SCB), Sweden

4. A Multi-continent Perspective
   Martin Lee-Gosselin, Université Laval Quebec, Canada

Discussion: Invited from prior presenters and all session attendees

(16.00-16.30 Short meeting of TRB Task Force A3T52, Safety and Mobility of Older Drivers, visitors welcome)
FRIDAY SEPTEMBER 20

HIGHWAY OPERATIONS AND CONCRETE AND STRUCTURES

8.30 - 12.30

Chairman: Torkild Thurmann-Moe, Road Research laboratory, Norway

Closed Track Testing of Maintenance Work Zone Safety Devices
S C Shah, Strategic Highway Research Program, Washington and F R Hanscom, Transportation Research Corporation, Haymarket, Virginia, USA

Innovative Materials for Pavement Surface Repairs: Field Installation and Evaluation
S C Shah, Strategic Highway Research Program, Washington, USA

MINSALT — A 5-Year Study to Minimize the Negative Effects of Salt
Kent Gustafson and Gudrun Öberg, Swedish Road and Traffic Research Institute (VTI), Linköping, Sweden

Deicing Salt - Its Use and Effect on Road Safety and the Living Conditions of Roadside Trees and Shrubs
Siegfried Giesa, Technical University of Darmstadt, Germany

Improving Concrete Pavements Through SHRP Research
Amir N Hanna, Strategic Highway Research Program, Washington, USA

Optimization of Highway Concrete Through Combined Use of Particle Packing Modelling, Rheological Studies, Computer Simulations and Compaction Simulations
J Holm and P J Andersen, G M Idorn Consult A/S, Birkerød, Denmark

High Performance Road-Surfacing Concrete with Good Resistance to Wear by Tyre Studs
Mårten Nilsson, Swedish Road Administration, Sweden

Maintenance and Repair of Highway Concrete Bridges: A Case Study
I Al-Babatain and A M Abbas, Ministry of Communications, Riyadh, Saudi Arabia

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Overtaking Behaviour on Single Carriageway Roads in the United Kingdom

John G Hunt
School of Engineering
University of Wales College of Cardiff
United Kingdom

and

Talib A Mahdi
School of Engineering
University of Wales College of Cardiff
United Kingdom
Title: Overtaking behaviour on single carriageway roads in the United Kingdom

Authors: J.G. HUNT and T.A. MAHDI

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ABSTRACT

This paper describes part of a study of the effect of overtaking provision on operating speed and capacity of single carriageway roads. The objective was to update and extend previous studies and to allow the influence of alignment and sight distance to be re-assessed.

More than 1100 overtaking manoeuvres were recorded using a series of three video cameras to cover a 1km length of overtaking section. Overtaking behaviour variables which include the decision time, the duration of, and distance travelled during the overtaking manoeuvre, safety margins, headways at the start and finish of overtaking and the accepted gaps were measured using a microcomputer based data logging system to extract data from video recordings.

The relationship between variables has been examined and appropriate distributions have been fitted. Formulae have been developed in which each variable may be estimated, for different types of overtaking manoeuvre, based on the speed of the overtaken vehicle and the accepted gap size. The results of the study are compared with previous research both in the U.K. and overseas.
OVERTAKING BEHAVIOUR ON SINGLE CARRIAGEWAY ROADS IN THE UNITED KINGDOM

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1. INTRODUCTION

The growth in traffic volumes in the United Kingdom over recent years has been accompanied by increasing congestion on many parts of the road network. While the most severe and widely publicised traffic queues and delays have been associated with conurbations or motorways, other parts of the road network are also operating close to capacity as drivers seek alternative routes in order to avoid congestion. Proposals to limit access to motorways at peak periods will, if implemented, significantly further increase traffic volumes on alternative roads many of which are single carriageway. The majority of single carriageway roads function as two lanes and depend for safe and efficient operation on the provision of frequent clearly identifiable overtaking sections for both directions of travel. The design of single carriageway roads was reviewed by the Department of Transport during the 1970s and revised design criteria and guidelines were issued as part of Highway Link Design (HLD)(1,2) in the early part of the 1980s. One of the objectives of HLD for single carriageway roads was to develop layouts which make it clear to drivers where overtaking is possible and where it is undesirable.

The designation of road lengths as 'overtaking' is primarily dependent on the assessment of the sight distance required for a full overtaking manoeuvre in the face of an oncoming vehicle (FOSD). The values of FOSD given in 'Layout of Roads in Rural Areas' (LRRA)(3) in 1968 were taken from the 1965 version of AASHO Blue Book(4). The FOSD used in HLD(1) were based on the results of work at TRRL(5) in the 1970s which gave new information about drivers' practice in Britain (the data were limited with only 200 observations for different speed and overtaking types) and on a set of assumptions which will be discussed later. The TRRL study remains unpublished.

The main objective of the work described in this paper was to provide overtaking behaviour data to update and extend the TRRL study and to use these data in the updating and reassessment of the overtaking sight distances specified in HLD.

2. PREVIOUS WORK

The majority of studies of overtaking behaviour have been carried out by Australian, American and Swedish researchers(5-12). Methods for data collection in overtaking behaviour studies include the use of moving vehicles equipped with time and speed measurement equipment of varying degrees of sophistication; some studies have also involved the use of photographic equipment, depending on the required parameters of overtaking behaviour. The use of a moving vehicle limited the observations to a particular range of overtaken

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vehicle speeds (60 km/h to 85 km/h), and visible instrumentation was found to affect overtaking behaviour. The numbers of overtaking manoeuvres analysed in these studies ranged from the 200 recorded by the TRRL\(^{5}\) to 3150 recorded by Troutbeck\(^{12}\).

In most of these studies the overtaking manoeuvre was assumed to commence when the overtaking vehicle first crossed the carriageway centreline and to be complete when the vehicle had returned to its original lane and was clear of the opposing traffic lane. Each overtaking manoeuvre may be classified according to the following conditions:

(a) single or multiple overtaking (a multiple overtaking occurs when a vehicle overtakes more than one vehicle),
(b) flying or accelerative overtaking (in accelerative overtaking the overtaking vehicle slows to the speed of the overtaken vehicle before starting the manoeuvre),
(c) type of overtaking vehicle,
(d) type of overtaken vehicle,
(e) oncoming vehicle or sight limited overtaking (whether an oncoming vehicle or the road geometry restricts the visibility of the overtaking driver), and
(f) position of the overtaking vehicle in the platoon.

Comparing the results of previous studies leads to the conclusion that overtaking behaviour varies between countries. This may be attributed to different driving practices, vehicle performance, weather and other factors. It is also probable that the improvement in vehicle performance and the changes in driver behaviour over the years have had some effect on overtaking behaviour.

3. CURRENT STUDY

In order to extend and update data describing overtaking behaviour on single carriageway roads in the United Kingdom it is necessary to measure parameters describing overtaking behaviour for different types of overtaking, and for a range of overtaken vehicle speeds.

Because of the limitations of the moving vehicle method, which also requires more than three observers with sophisticated instrumentation to record the data, an alternative method was used. The selected method involved the use of three cameras to record activities for three overlapping sections covering the whole of an overtaking length; coverage included the entry and exit points for the overtaking sections. The adopted method allowed all types of overtaking manoeuvres for different overtaken vehicle speeds to be recorded and had no requirement for sophisticated instrumentation. An additional advantage was that the behaviour of motorists was not affected.

Data were collected on a 1175m overtaking section which forms part of the A4059 north of Mountain Ash in Mid Glamorgan, Wales. The general layout of the section is shown in Figure 1. The A4059 is one of the busiest roads in the area with a relatively high percentage of Heavy Goods Vehicles (HGV). The road represents a
standard single carriageway (7.3m wide with 1.2m footpaths) with a design speed of 80 km/h and was in good condition at the time of the study. The section was almost straight and level, and provided long unrestricted sight distance for both oncoming limited and sight distance limited overtaking. The adjacent sections were not suitable for overtaking and were bendy which helped in the formation of long platoons hence increasing the demand for overtaking in the selected section. The cameras were positioned on the summit of an adjacent hill which was sufficiently distant to avoid attracting the drivers' attention and so affecting behaviour.

All types of overtaking which involved different types of overtaken vehicles, overtaking vehicles, sight distance restrictions and speeds of overtaken vehicles were recorded. During recording periods, the two-way traffic flow ranged from 620 veh/h, during off peak hours, to 1120 veh/h, during peak hours. The percentage of HGV ranged from 10% to about 19% with an average of 15%.

For each overtaking manoeuvre, parameters of overtaking behaviour listed in Table 1 were abstracted from the video recordings. Figure 2 defines the main measured parameters. The 30 hours of recorded data provided 1143 overtaking manoeuvres of different types. These overtaking manoeuvres were classified by type and it was found that as the speed of overtaken vehicle increased there was a tendency for less flying overtaking manoeuvres and less overtaking by HGV. The number of accelerative overtaking manoeuvres was higher than that of flying overtaking possibly because the formation of long platoons in adjacent sections increased the demand for accelerative overtaking manoeuvres in the study section.

4. ANALYSIS OF RECORDED OVERTAKING DATA

4.1 Appropriate probability distribution for each parameter

As a first stage the interdependency of the parameters for each type of overtaking was assessed by considering the correlation of each parameter with the others by regression and with the aid of scattergrams. The significance of these correlations were tested at the 5% level using the method described by Benjamin and Cornell [13].

The correlation coefficients and the scattergrams indicated that most overtaking behaviour parameters have a good correlation with the accepted gap size and the speed of the overtaken vehicle. In particular, analysis indicated that there was good correlation between the speed of the overtaken vehicle and; overtaking time and distance, accepted gaps, acceleration and speed of overtaking vehicle. Similarly all parameters except time headways at the start and finish of the overtaking manoeuvre showed good correlation with the size of accepted gap.

For the parameters, which are speed dependent, attempts to determine any appropriate probability distribution to represent the data were restricted to overtaking manoeuvres in the range 40-80 km/h. For those parameters which were not correlated with the
speed, such as, decision time, safety margins and distance headway at the finish of the overtaking manoeuvre, all the overtaking manoeuvres for all speeds were taken into consideration. Due to the small sample size of overtaking manoeuvres by HGV both types of visibility restrictions were combined together for analysis purposes.

The Chi-square test was used to judge the goodness of fit of suitable distributions to the observed data at the 5% level of significance. The results of this test indicated that safety margins can be represented by the gamma distribution, the acceleration and speeds of the overtaking vehicles can be represented by the normal distribution, and all other parameters can be satisfactorily represented by the lognormal distribution. As an example the observed data and the fitted distribution for decision times for single accelerative oncoming limited overtaking are compared in Figure 2.

4.2 Effect of the type of overtaking on overtaking behaviour

The effect of overtaking type on each parameter may be examined by comparing the results for each overtaking type with the corresponding results for another type. In this way the dependency of each parameter on overtaking type may be established.

Each parameter is represented by a distribution of values which is defined by the mean and standard deviation. The two tailed F-test was used to examine the null hypothesis that the variances were equal, and a t-test was used to examine the null hypothesis that the means were equal. For both tests a significance level of 5% was used. The samples were adjusted to equalise the weighted mean speed of overtaken vehicle for each overtaking type.

The outcome of these tests for the effect of visibility restriction, for single accelerative car overtaking car indicated that the variance of many parameters were not significantly different, but the means of all parameters, except decision time, time headway at the start, and speed of overtaking vehicle at the end of the manoeuvre, were significantly different for different visibility restrictions. This indicated that the type of visibility restriction influences overtaking behaviour. As an example Figure 4 shows the effect of the type of overtaking manoeuvre on overtaking times, when the overtaking vehicle was directly behind the overtaken vehicle immediately before starting the manoeuvre. In general drivers overtaking in the face of oncoming vehicles had shorter overtaking times, distances and distance headways at the finish of overtaking and higher acceleration. However, the accepted distance gaps were longer, than those for drivers who performed the same type of overtaking with visibility distance restricted by sight distance (curve or crest).

4.3 Relationships for overtaking parameters

The analysis has shown that many overtaking parameters have good correlation with the speed of overtaken vehicles and the size of
the accepted gap. It was also found that overtaking behaviour varies depending on the type of overtaking. Relationships for overtaking parameters expressed as a function of the speed of the overtaken vehicle, and the size of the accepted gap can now be derived, using multiple linear regression, for each type of overtaking. The effect of overtaking type was included in the relationships as dummy variables (taking the values 0 or 1). Those models with the highest $R^2$ and the lowest standard error, for each overtaking parameter, were selected and are shown in Table 2. In the Table the unexplained variation associated with low $R^2$ is probably attributable to factors, such as driver and vehicle characteristics, which it was not possible to measure.

In Table 2 the models for the decision times show that, except when the overtaken vehicle is an HGV, the decision time decreases with the speed of the overtaken vehicle. When the overtaken vehicle is a HGV the decision time increases with the speed of the overtaken vehicle which probably reflects the awareness of drivers overtaking HGV travelling at high speed. Models for the overtaking times and distances show that both these parameters increase with the speed of the overtaken vehicle. This may be caused by a reduction in vehicle performance capability as speed increases. The rate of increase of these parameters with speed is higher for overtaking HGV and lower for flying overtaking manoeuvres.

4.4. Comparison of overtaking times and distances with the results of previous studies

Table 3 lists overtaking times and distances recorded by other studies and by this study. The increase in overtaking time and distance with the speed of overtaken vehicles recorded in this study was also found previously by Prisk(7) and other investigators(11-12), with some differences in the values of the parameters. The Table indicates that the overtaking times recorded by this study for an overtaken vehicle speed of 50 km/h were near those recorded by TRRL(5) and lower than those recorded by other studies. This may be due to the improvement in vehicles' performance over the years and the shorter accepted gap associated with the higher flow at which the data of this study were recorded. The same Table shows that the overtaking distances recorded by this study were less than those recorded by Troutbeck(12) and higher than those recorded by Grabe and Stolz(10).

5. OVERTAKING SIGHT DISTANCE FOR GEOMETRIC DESIGN

5.1 Full Overtaking Sight Distance (FOSD)

There are two overtaking sight distances of interest to road designers. Firstly, the Full Overtaking Sight Distance (FOSD), which is the distance within which 85% of drivers can overtake in the face of an oncoming vehicle. Secondly, once the driver has initiated the overtaking manoeuvre there should be sufficient sight distance for the driver to either abort or complete the manoeuvre safely, this distance is termed the Abort Sight Distance (ASD). These two distances are used for the layout of the overtaking and
non-overtaking sections of single carriageway roads. The values of FOSD tabulated in Table 3 of TD 9/81(1) were calculated using the results of a limited study carried out by the TRRL(5) and a set of assumptions which can be discussed on the basis of the results of this study and other studies.

'.the time for vehicles to complete an overtaking manoeuvre...to be largely independent of vehicle speed.' The results of this study (Table 2) and other investigators' (Table 3) show that the overtaking time increases as the speed of overtaken vehicles increases. The equations given in Table 2 can be used to calculate the overtaking time as a function of the overtaken vehicle speed.

'.the overtaking driver commences the manoeuvre two Design Speed steps below the Design Speed V and accelerates to Design Speed.' The speed at which the overtaking driver commences overtaking is sometimes called the slow vehicle design speed U. Troutbeck(13) found the slow vehicle design speed to be the mean free speed which is equivalent to the 50 percentile speed as free speed is normally distributed. The design speed is taken as equal to the 85 percentile free speed. On this basis the slow vehicle design speed is one design step below the design speed. The second part of this assumption was made in the absence of data defining the overtaking distance. These data are now available from Table 2.

'.an opposing vehicle appears ... the moment the manoeuvre commences.' The results of this study and those of other investigators showed that it is highly unlikely that 85% of drivers perform accelerative overtaking with zero decision time. Since most drivers observed in this study had not overtaken in their minimum acceptable opportunity, most decision times were higher than the minimum required. Thus the mean and the 85 percentile of the observed decision times cannot sensibly be used. The most appropriate measure is the mode which represents the most common decision time. For single accelerative oncoming limited overtaking manoeuvres observed by this study the mode of the decision time is equal to 0.62 secs (Figure 3) and is effectively independent of vehicle speed.

In calculating the FOSD there is an implicit assumption of a safety margin time of 1 second (D=TV/5). This study found that only 10% of drivers observed performing accelerative overtaking had a safety margin of 1 second. Most safety margins were in excess of the minimum required and the most appropriate available measure is again the mode which was found to be equal to 2 seconds and independent of overtaken vehicle speed.

The FOSD, for the driver at the 85 percentile Design Speed, based on the above modified assumptions can be calculated as follows:

\[
\text{FOSD} = \text{mode of decision time} \times \frac{(U+V)}{3.6} + 85 \text{ percentile overtaking distance} + 85 \text{ percentile overtaking time} \times \frac{V}{3.6} + \text{mode of safety margin time} \times \frac{(V_1+V)}{3.6}
\]

where V is the Design Speed in km/h,
U is the slow vehicle design speed \( V_{4\sqrt{2}} \) in km/h, and \( V_1 \) is the 85 percentile overtaking vehicle speed at the end of overtaking.

Using the equations given in Table 2 allows the evaluation of this equation with 15 percent HGV as:

\[
\text{FOSD} = 0.87V + 73.4e^{0.0133V} + 2V_e^{0.0027V} + 45.5e^{0.0048V}
\]

A similar equation can be derived for 0 percent HGV i.e., car overtaking car. A comparison between the FOSD specified by the Department of Transport in TD9/81 and those calculated based on the results of this study is shown in Figure 5.

5.2 Abort Sight Distance (ASD)

The ASD is defined by TA 43/84(2) as '...the distance within which 50% of drivers can overtake ...the distance required for the overtaking vehicle to complete a manoeuvre safely in the face of oncoming vehicles from the stage when it has drawn alongside the vehicle it is overtaking.' The values of ASD for different design speed were calculated as FOSD/2 in TD9/81 primarily because of the absence of practical data. The results of this study can be used to calculate the ASD on the basis of the definition given.

The ASD can be calculated as:

\[
\text{ASD} = 0.55V + 51.38e^{0.0088V} + 0.76V_e^{0.00238V} + 37.15e^{0.0062V}
\]

A similar equation can be derived for 0 percent HGV i.e., car overtaking car. A comparison between the ASD specified by the Department of Transport in TD9/81 and those calculated based on the results of this study is shown in Figure 6.

Figures 5 and 6 indicate that the HLD values for FOSD and ASD are less than the values obtained by this study as a result of substantial differences in the methods used for the derivation and calculation of the values. This apparent underestimation of the values of FOSD and ASD by the Department of Transport may lead to increased accident risk on overtaking sections, and reduce the efficiency of the single carriageway roads by using overtaking sections which provide insufficient overtaking opportunities.

6. CONCLUSIONS

1. For the same overtaking type, the main two parameters which affect the overtaking behaviour are the size of the accepted gap and the speed of the overtaken vehicle.
2. Safety margins can be represented by the gamma distribution, the acceleration and speeds of the overtaking vehicles can be represented by the normal distribution and all other overtaking behaviour parameters can be satisfactorily represented by the lognormal distribution.

3. The type of visibility restriction, sight distance limited or oncoming vehicle limited, influences overtaking behaviour.

4. Overtaking parameters can be derived from relationships based on the speed of the overtaken vehicle, the size of the accepted gap and the type of overtaking.

5. Overtaking time and distance increase with the speed of the overtaken vehicle.

6. Overtaking times of this study for an overtaken vehicle speed of 50 km/h are consistent with those of the TRRL(5) and lower than those of overseas studies.

7. On the basis of this study the Full Overtaking Sight Distance and the Abort Sight Distance specified in Highway Link Design are an underestimate of the correct values.

7. REFERENCES


5. Transport and Road Research Laboratory. A study of overtaking on a rural trunk road. TRRL, Crowthorne, 1978.(unpublished)


Fig: 1. The layout of the overtaking section

Fig: 2. Definitions of some overtaking behaviour parameters.
Fig: 3. Observed histogram of decision time and the fitted distribution for single accelerative oncoming limited overtaking.

Fig: 4. Effect of type of overtaking manoeuvre on overtaking times.
Fig. 5. Full overtaking sight distance for different design speeds.

Fig. 6. Abort overtaking sight distance for different design speeds.
Table 1. The measured overtaking behaviour parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter abbreviation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision time</td>
<td>DT*</td>
<td>sec</td>
</tr>
<tr>
<td>Overtaking time</td>
<td>OVT</td>
<td>sec</td>
</tr>
<tr>
<td>Overtaking distance</td>
<td>OVD</td>
<td>m</td>
</tr>
<tr>
<td>Safety margin time</td>
<td>SFMT</td>
<td>sec</td>
</tr>
<tr>
<td>Safety margin distance</td>
<td>SFMD</td>
<td>m</td>
</tr>
<tr>
<td>Accepted time gap</td>
<td>AGT</td>
<td>sec</td>
</tr>
<tr>
<td>Accepted distance gap</td>
<td>AGD</td>
<td>m</td>
</tr>
<tr>
<td>Time headway at the start of overtaking</td>
<td>SHWT</td>
<td>sec</td>
</tr>
<tr>
<td>Distance headway at the start of overtaking</td>
<td>SHWD</td>
<td>m</td>
</tr>
<tr>
<td>Time headway at the finish of overtaking</td>
<td>FHTW</td>
<td>sec</td>
</tr>
<tr>
<td>Distance headway at the finish of overtaking</td>
<td>FHWD</td>
<td>m</td>
</tr>
<tr>
<td>Speed of overtaken vehicle</td>
<td>V</td>
<td>m/s</td>
</tr>
<tr>
<td>Speed of overtaking vehicle at end of the</td>
<td>VP*</td>
<td>m/s</td>
</tr>
<tr>
<td>overtaking manoeuvre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of oncoming vehicle</td>
<td>VO</td>
<td>m/s</td>
</tr>
<tr>
<td>Rejected time gap</td>
<td>RGT</td>
<td>sec</td>
</tr>
<tr>
<td>Rejected distance gap</td>
<td>RGD</td>
<td>m</td>
</tr>
<tr>
<td>Type of accepted gap</td>
<td>TOG</td>
<td></td>
</tr>
<tr>
<td>(oncoming = 0, sight distance = 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of overtaken vehicle</td>
<td>TOL</td>
<td></td>
</tr>
<tr>
<td>(car = 0, HGV = 1, multiple = 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of overtaking vehicle (car = 0, HGV = 1)</td>
<td>TOP</td>
<td></td>
</tr>
<tr>
<td>Type of overtaking (accelerative = 0, flying = 1)</td>
<td>TOOV</td>
<td></td>
</tr>
<tr>
<td>Position of the overtaking vehicle in the</td>
<td>POP</td>
<td></td>
</tr>
<tr>
<td>platoon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(directly behind = 0, not directly behind = 1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*These parameters were not measured for flying overtaking
Table 2: Equations for the means of overtaking behaviour parameters and their standard errors for single overtaking manoeuvres.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Constant Modification</th>
<th>Overtaken vehicle speed Modification</th>
<th>Accepted gap</th>
<th>R²</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(DT)*</td>
<td>-.639</td>
<td>-.496</td>
<td>.344</td>
<td>-.033</td>
<td>.002</td>
</tr>
<tr>
<td>ln(OVT)</td>
<td>.673</td>
<td>.198</td>
<td>-.073</td>
<td>-.056</td>
<td>.098</td>
</tr>
<tr>
<td>ln(OVD)</td>
<td>3.772</td>
<td>.082</td>
<td>.291</td>
<td>.081</td>
<td>.064</td>
</tr>
<tr>
<td>ln(SFNT)</td>
<td>-7.513</td>
<td>.323</td>
<td>-.287</td>
<td>1.37</td>
<td>-.041</td>
</tr>
<tr>
<td>SFHD</td>
<td>-24.88</td>
<td>51.7</td>
<td>-.702</td>
<td>98.2</td>
<td>-.941</td>
</tr>
<tr>
<td>ln(AGT)</td>
<td>2.832</td>
<td>1.43</td>
<td>-.007</td>
<td>.005</td>
<td>.014</td>
</tr>
<tr>
<td>ln(AGD)*</td>
<td>5.682</td>
<td>.082</td>
<td>.102</td>
<td>.247</td>
<td>-.162 + .176</td>
</tr>
<tr>
<td>ln(SHWT)</td>
<td>.865</td>
<td>.724</td>
<td>1.023</td>
<td>.053</td>
<td>-.064</td>
</tr>
<tr>
<td>ln(SHWD)</td>
<td>1.893</td>
<td>1.043</td>
<td>-.058</td>
<td>.016</td>
<td>.006</td>
</tr>
<tr>
<td>ln(FHWT)</td>
<td>1.375</td>
<td>.600</td>
<td>-.240</td>
<td>.717</td>
<td>-.081</td>
</tr>
<tr>
<td>ln(FHWD)</td>
<td>1.400</td>
<td>-.244</td>
<td>.471</td>
<td>.144</td>
<td>-.011</td>
</tr>
<tr>
<td>ACC*</td>
<td>3.435</td>
<td>-.800</td>
<td>.374</td>
<td>.466</td>
<td>-.050</td>
</tr>
<tr>
<td>VP*</td>
<td>12.21</td>
<td>-.197</td>
<td>1.72</td>
<td>.940</td>
<td>-.1.18</td>
</tr>
</tbody>
</table>

* these equations are for accelerative overtaking manoeuvres only.

Note: the key to the abbreviations is shown in Table 1.
Table 3. Comparison between the overtaking times and distances of different overtaking behaviour studies, for single accelerative overtaking manoeuvres by cars only.

<table>
<thead>
<tr>
<th>Overtaken vehicle</th>
<th>Speed km/h</th>
<th>Type</th>
<th>Overtaking time - secs</th>
<th>Overtaking distance - m</th>
<th>Sample size</th>
<th>Sample size</th>
<th>Country (study reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>O</td>
<td>B</td>
<td>S</td>
<td>O</td>
<td>B</td>
<td>S</td>
</tr>
<tr>
<td>50</td>
<td>car</td>
<td>8.3</td>
<td>9.7</td>
<td>7.3</td>
<td>8.5</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.7</td>
<td>11.0</td>
<td>323</td>
<td>124</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>30-70</td>
<td>car</td>
<td>50</td>
<td></td>
<td></td>
<td>60</td>
<td></td>
<td></td>
</tr>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>car</td>
<td>8.3</td>
<td>196</td>
<td>60</td>
<td>7.1</td>
<td>7.6</td>
<td>200</td>
</tr>
<tr>
<td>65-70</td>
<td>car</td>
<td>50</td>
<td></td>
<td></td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-75</td>
<td>car</td>
<td>9.4</td>
<td>169</td>
<td>70</td>
<td>9.4</td>
<td>149</td>
<td>162</td>
</tr>
<tr>
<td>70</td>
<td>car</td>
<td>7.5</td>
<td>151</td>
<td>70</td>
<td>8.0</td>
<td>183</td>
<td>193</td>
</tr>
<tr>
<td>65-70</td>
<td>car</td>
<td>10.3</td>
<td>75</td>
<td>85</td>
<td>60</td>
<td>8.7</td>
<td>161</td>
</tr>
<tr>
<td>80</td>
<td>car</td>
<td>8.7</td>
<td>161</td>
<td>80</td>
<td>10.9</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>car</td>
<td>7.9</td>
<td>8.4</td>
<td>80</td>
<td>8.9</td>
<td>392</td>
<td></td>
</tr>
<tr>
<td>60-70</td>
<td>HGV</td>
<td>8.9</td>
<td>208</td>
<td>70</td>
<td>9.9</td>
<td>257</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>HGV</td>
<td>8.8</td>
<td>208</td>
<td>60</td>
<td>10.1</td>
<td>242</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>HGV</td>
<td>11.5</td>
<td>299</td>
<td>60</td>
<td>7.7</td>
<td>167</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>HGV</td>
<td>8.3</td>
<td>8.9</td>
<td>70</td>
<td>8.2</td>
<td>206</td>
<td></td>
</tr>
</tbody>
</table>

0 = oncoming limited
B = both visibility restrictions
S = sight distance limited
* = calculated by formulae in Table 3.
Overtaking Behaviour on Two-Lane Rural Roads

Arne Carlsson
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Swedish Road and Traffic Research Institute (VTI)
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OVERTAKING BEHAVIOUR ON TWO-LANE RURAL ROADS

Arne Carlsson, Swedish Road and Traffic Research Institute (VTI)

ABSTRACT

As part of a review of the National Road Administration's rules for alignment standards, the VTI has been commissioned to investigate the overtaking behaviour of road users. The aim of the investigation is to determine how overtaking and passing behaviour depends on road width, sight distance, speed of obstructing vehicles and vehicle type.

Data has mainly been collected by videofilming from a helicopter. Using the videofilms, analyses were made of road user behaviour in regard to overtaking and utilisation of a paved shoulder.

The investigation consists of two parts. In the first part, a study was made of overtaking behaviour on 13-metre roads with a paved shoulder and a large variation in traffic flows. In this part, the study covers both behaviour in overtaking with the aid of the paved shoulder, i.e. "passing", and normal overtaking. In the first case, overtaking takes place without a change of lane, while the vehicle being overtaken is on the paved shoulder, overtaking is thus performed without the driver having to interfere with oncoming traffic. This behaviour is characteristic in about 85% of all catching up situations. The remaining 15% consists of normal overtaking, where the lane for oncoming traffic is used.

The second part of the investigation concerned overtaking behaviour on 9-metre roads, where only normal overtaking occurs. Data was collected for a large range of traffic flows, from 470 to 1,200 vehicles/hour, counting both directions.

The material has been divided into vehicle groups. For overtaking cars, a division has been made according to the speed of the obstructing vehicle, above or below 90 km/h. Heavy vehicles have been divided into a group without trailers and a group with trailers.
OVERTAKING BEHAVIOUR ON TWO-LANE RURAL ROADS

1. BACKGROUND

In recent years, the National Road Administration has discussed the overtaking standard that road users are to be offered on different types of road and in different traffic situations.

The design recommendations of the National Road Administration from 1981 had the consequence that the requirements on sight distance were significantly reduced. The reason was a general reduction in road standard resulting from profitability assessments in terms of cost-benefit analysis.

Since 1984, the recommendation has been an overtaking sight distance of at least 600 m, preferably 800-1000 m, at least once per 3 km for roads up to 9 m in width. However, no recommendations on sight distance in regard to overtaking on 13 m roads have ever been produced.

As part of a review of the National Road Administration’s rules for alignment standard, the VTI was commissioned to study the overtaking behaviour of road users. The aim of the study was to determine how overtaking and passing behaviour is affected by road width, sight distance, speed, traffic volume and vehicle type.

The commission has been carried out with the aid of videofilming from a helicopter. The films are used to analyse road user behaviour in regard to overtaking and usage of the paved shoulder.

The project has been divided into two stages. In the first stage, overtaking behaviour was studied on 13 m roads with both high and low traffic flows. In the second stage, overtaking behaviour was studied on 9 m roads.
2. DESCRIPTION OF THE TRAFFIC PROCESS AND EXPLANATION OF CONCEPTS

In order to describe the traffic process in overtaking, a number of different events have been defined, relating to differences in overtaking behaviour.

Consider what happens on a 13 m road when a faster vehicle approaches a slower vehicle in front. A catching up situation is then defined for that point in time when the vehicle behind is so close (about 50-80 m) that it has to begin to adapt its speed.

On being caught up, the leading vehicle has the opportunity of moving into the right-hand paved shoulder and beginning what is termed paved shoulder driving. This means that the vehicle crosses the side line so far that more than half its width is on the paved shoulder.

If this occurs, the vehicle behind can perform passing, which means that it passes the leading vehicle without changing lane. More than half the vehicle must be in its own lane.

If the leading vehicle does not move onto the paved shoulder, the catching up vehicle has to consider the opportunity of overtaking. This means that the vehicle behind has to use the opposite lane to get past. On a 9-metre road, obviously only overtaking occurs.

It is possible to define four different types of overtaking. A catching up situation, where the leading vehicle does not move onto the paved shoulder, allows the opportunity of a flying overtaking. This means that a vehicle overtakes immediately without first adapting speed to the vehicle in front.

If the first overtaking opportunity is rejected, the vehicle behind must begin tailing, i.e. it must adapt its speed and wait
in the queue at a suitable distance. A vehicle that is tailing has the opportunity of making an accelerated overtaking, which means that it has to increase its speed to overtake.

An opportunity for accelerated overtaking is offered both when the sight profile of the road offers maximum sight distance and also, depending on the circumstances, after each meeting.

If the driver rejects an opportunity for overtaking, either flying or accelerating and with a visible oncoming vehicle, he will have another opportunity of an accelerated overtaking immediately after meeting the visible vehicle. If there is no visible oncoming vehicle, he will have to wait for a sight maximum, where there is always an opportunity for overtaking.

To sum up, there are four different cases of overtaking: two types of overtaking each with two types of sight limitation.

The following definitions are used to describe sight distance:

The sight limitation for a driver consists either of the alignment of the road, the so-called meeting sight distance, or an oncoming vehicle, a free sight distance.

The meeting sight at a point is the longest distance within which a driver can see an oncoming vehicle. This assumes that the driver's eye level is at a height of 1.1 m and that the height of the oncoming vehicle is 1.35 m.

The free sight distance at a point is defined as the distance from this point to the nearest visible oncoming vehicle. If there is no visible meeting, the free sight distance is not defined, thus it is always shorter than the meeting sight.

The sight distance for a driver at a randomly chosen point is either defined as the free sight distance or the meeting sight at that point.
3. MEASURING SECTIONS

Four sections have been selected for measurements on 13 m roads. These are on the E4 at Jönåker, the E66 south of Söderköping, Highway 40 west of Jönköping and Highway 40 west of Borås. The speed limit is 110 km/h on three of the sections and 90 km/h on the fourth, Highway 40 west of Borås.

The measurements cover a wide range of traffic flows, from 200 to 1400 vehicles/hour.

Four sections have also been selected for measurements on 8-9 m roads. These are the E4 at Skillingaryd, the E3 east of Eskilstuna, Highway 55 south of Katrineholm and the E3 north-east of Laxå. The speed limit is 90 km/h on all four sections measured.

The measurements cover a relatively wide range of traffic flows, from 470 to 1200 vehicles/hour.

4. RESULTS

4.1 Results of measurements of passing on 13 m roads facilitated by paved shoulder driving

The table on the following page summarises the results of measurements on 13 m roads. It shows the proportion of vehicles that move onto the paved shoulder when caught up by a faster vehicle. In this case, the total number of passings has been divided by the total number of catching up for each individual road section. However, Nyköping has been divided up according to the traffic volume: low and high flow measurements.
Table 1. Summary of results for paved shoulder driving in percent of the number of catching up.

<table>
<thead>
<tr>
<th>Road section</th>
<th>Flow veh/hour both directions</th>
<th>Proportion of paved shoulder driving in %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cars</td>
</tr>
<tr>
<td>Jönköping</td>
<td>350-475</td>
<td>82</td>
</tr>
<tr>
<td>Söderköping</td>
<td>200-680</td>
<td>83</td>
</tr>
<tr>
<td>Nyköping</td>
<td>510-670</td>
<td>82</td>
</tr>
<tr>
<td>Borås</td>
<td>575-1270</td>
<td>93</td>
</tr>
<tr>
<td>Nyköping</td>
<td>1030-1400</td>
<td>85</td>
</tr>
<tr>
<td>Mean, unweighted</td>
<td>200-1400</td>
<td>85</td>
</tr>
</tbody>
</table>

The mean for all traffic flows was 85% of vehicles using the paved shoulder when caught up. For trucks, however, there is a clear variation, with a higher proportion of paved shoulder driving in increased traffic flows.

The results are independent of the sight conditions and distance to oncoming vehicles. These factors do not affect the extent to which vehicles use the paved shoulder when caught up.

This indicates that situations with three vehicles abreast are by no means unusual, i.e. meetings occur at the same time as passing. At most, this occurs in 66% of all passings at high traffic flows.

Finally, it should be noted that all the results in this section apply to daylight and dry road conditions.
4.2 Overtaking results on 13 m roads

As shown by the results in Section 4.1, few overtakings were recorded on the studied sections. To obtain sufficient data for analysis, the overtaking occasions from all four measuring sections have been combined. There is no reason to suppose that overtaking behaviour differs between the sections.

The data have been divided into three classes: overtaking a car, overtaking a truck without a trailer and overtaking a truck with a trailer. This division is functionally correct, since completely different conditions apply when overtaking these different types of vehicle.

Overtaking a car is in turn subdivided according to the speed of the caught up vehicle. Speeds of the caught up vehicle over 90 km/h constitute one group, while speeds below 90 km/h constitute another group.

An overtaking opportunity results either in commencement of overtaking or in the driver rejecting the opportunity. In the latter case, this leads to a new overtaking opportunity further along the road.

The measurements in the form of accepted and rejected overtaking opportunities can be used for estimating a so-called overtaking function for 13 m roads. This involves calculating the proportion of drivers who commenced overtaking, the overtaking probability, as a function of the sight distance.

We have assumed that this function generally resembles an S-shaped curve, which must however be asymmetric. For short sight distances, the curve rises rapidly towards its steepest section. For long sight distances, on the other hand, the curve rises very slowly and approaches asymptotically the value 1. The diagram below shows the general appearance of the overtaking function.
We have utilised a function named the Gompertz model, which is expressed as:

$$\omega = \exp\left(-A \exp(-ks)\right)$$

where $\omega$ indicates the overtaking probability (proportion of drivers accepting an overtaking opportunity)

$A$ and $k$ are constants

$s$ is the sight distance in metres.

As mentioned above, the function is asymmetric about the point of inflexion.

The median value, $s_{50}$, i.e. the sight distance where half of the drivers accept and half reject an overtaking opportunity, will be:

$$s_{50} = \frac{\ln(A/\ln2)}{k} = \frac{\ln(1.44 \cdot A)}{k}$$
Using the method of least squares, constants $A$ and $k$ have been estimated from the measurements.

Using the estimated constants $A$ and $k$, the whole overtaking function can in turn be calculated.

Table 2 below shows the median and 85 percentile of the estimated overtaking functions. The 85 percentile implies that 85% of the drivers accept and 15% reject an overtaking opportunity within the calculated sight distance.

**Table 2.** 50 and 85 percentiles in estimated overtaking functions.

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Sight distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$s_{50}$</td>
</tr>
<tr>
<td>Overtaking car speed &lt;90 km/h</td>
<td>201</td>
</tr>
<tr>
<td>Overtaking car speed &gt;90 km/h</td>
<td>259</td>
</tr>
<tr>
<td>Overtaking car total</td>
<td>240</td>
</tr>
<tr>
<td>Overtaking truck without trailer</td>
<td>200</td>
</tr>
<tr>
<td>Overtaking truck with trailer</td>
<td>327</td>
</tr>
<tr>
<td>Overtaking truck total</td>
<td>283</td>
</tr>
</tbody>
</table>

The table shows that the median sight distance, $s_{50}$, is over 300 m, only for overtaking a truck with trailer. For other groups, the median value is 200-260 m.

The 85 percentile in the above table shows that 85% of the constrained vehicles require 400 m sight distance for overtaking a car and 650 m for overtaking a truck with trailer. Thus, only the 15% most cautious drivers require a longer sight distance.
The explanation for the relatively short sight distances require, must largely be the fact that oncoming vehicles facilitate overtaking by using their paved shoulder either completely or partly.

In a comparison of different vehicle types, it must be observed that different types of caught up vehicles have different mean speeds. The mean speed increases from 80 km/h for a truck with trailer to 104 km/h for the group fast cars.

The table on the previous page contains all four types of overtaking defined in Section 2. A certain variation in the overtaking probability is to be expected, depending on the type of overtaking to be performed.

If the data is broken down by overtaking type, an indication is obtained that flying overtaking without visible meeting does not require a long sight distance. This is opposed to accelerated overtaking with visible meeting, which requires a considerably longer sight distance.

The four types of overtaking have been processed individually and constants \( A \) and \( k \) calculated for each type.

Table 3 on the next page shows the overtaking function for the different types of overtaking. The median value and 85 percentile are reported exactly as in Table 2.
Table 3. 50 and 85 percentiles for different types of overtaking on 13 m roads.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Overtaking type</th>
<th>Sight distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$s_{50}$</td>
</tr>
<tr>
<td>Overtaking car, speed &lt;90 km/h</td>
<td>Flying overtaking</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking with meeting</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking no meeting</td>
<td>265</td>
</tr>
<tr>
<td>Overtaking car, speed &gt;90 km/h</td>
<td>Flying overtaking</td>
<td>218</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking with meeting</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking no meeting</td>
<td>290</td>
</tr>
<tr>
<td>Overtaking truck, no trailer</td>
<td>Flying overtaking</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking</td>
<td>519</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking no meeting</td>
<td>340</td>
</tr>
<tr>
<td>Overtaking truck with trailer</td>
<td>Flying overtaking</td>
<td>207</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking with meeting</td>
<td>519</td>
</tr>
<tr>
<td></td>
<td>Accelerated overtaking no meeting</td>
<td>372</td>
</tr>
</tbody>
</table>

The table shows that the requirements on sight distance are different for the different types of overtaking.

In the most unfavourable case, accelerated overtaking with visible meeting, the median sight distance is 360 m for overtaking a car and 520 m for overtaking a truck.
A sight distance of 600 m is in most cases sufficient for being able to overtake a car, regardless of the overtaking situation. When overtaking a truck, a sight distance of over 900 m is required if all drivers are to perform overtaking.

Again, it must be emphasised that the above results apply only to 13 m roads in daylight and dry road conditions.

4.3 Overtaking results on 9 m roads

Exactly the same analysis methods have been used for the measurements on 9 m roads as for 13 m roads in the preceding section. Overtakings from all four road sections have been combined and divided into four groups according to vehicle type and speed.

The outcome of each overtaking opportunity has been used to estimated an overtaking function, indicating the proportion of drivers accepting an overtaking opportunity within a certain sight distance.

Table 4 on the following page shows the median sight distance and 85 percentile, according to the same method as in Section 4.2 above. The estimates are now significantly more reliable, since considerably more measurements have been obtained.
Table 4. 50 and 85 percentiles in estimated overtaking functions.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Sight distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$s_{50}$</td>
</tr>
<tr>
<td>Overtaking car</td>
<td></td>
</tr>
<tr>
<td>speed &lt;90 km/h</td>
<td>436</td>
</tr>
<tr>
<td>Overtaking car</td>
<td></td>
</tr>
<tr>
<td>speed &lt;90 km/h</td>
<td>507</td>
</tr>
<tr>
<td>Overtaking car</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>460</td>
</tr>
<tr>
<td>Overtaking truck</td>
<td></td>
</tr>
<tr>
<td>no trailer</td>
<td>499</td>
</tr>
<tr>
<td>Overtaking truck</td>
<td></td>
</tr>
<tr>
<td>with trailer</td>
<td>589</td>
</tr>
<tr>
<td>Overtaking truck</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>560</td>
</tr>
</tbody>
</table>

The table shows that the median value, $s_{50}$, for the sight distance when overtaking a car is 440-510 m, depending on the speed of the overtaken vehicle. When overtaking a truck, a somewhat longer sight distance is required, 500-590 m.

The 85 percentiles in the above table shows that the 15 % most cautious drivers generally require fairly long sight distances, over 700-800 m for overtaking a car.

Overtaking a truck with trailer differs markedly from the other groups. Here, the 85 percentile is at about 920 m sight distance.

In a comparison between different vehicle types, it should be observed that the mean speed differs for the various vehicle types. The group Cars > 90 km/h has clearly the highest speed, about 95 km/h, while the other three types generally keep the same mean speed, about 80 km/h. Although these three groups keep the same speed, the sight distance demands differ. In this case it is thus the difference in the length of the overtaken vehicle that causes the difference in the demands on sight distance.
The estimate of the overtaking function, which is reported in the above table, is a total estimate that includes all types of overtaking. As expected, it can be seen that the sight distance for accepting an overtaking opportunity varies greatly with the type of overtaking. A flying overtaking without visible meeting is accepted with a relatively short sight distance, while accelerated overtaking with meeting requires a very long sight distance.

To chart the difference, the four types of overtakings reported in Section 2, have been analysed individually.

Table 5 on the next page summarises the overtaking function for different types of overtaking. The same data as in Table 4 above are reported.
Table 5. 50 and 85 percentiles for different types of overtaking on 9 m roads.

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Overtaking type</th>
<th>Sight distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$s_{50}$</td>
</tr>
<tr>
<td>Overtaking cars</td>
<td>Flying, no meeting</td>
<td>232</td>
</tr>
<tr>
<td></td>
<td>Flying, with meeting</td>
<td>284</td>
</tr>
<tr>
<td>Overtaking trucks</td>
<td>Flying, no meeting</td>
<td>269</td>
</tr>
<tr>
<td></td>
<td>Flying, with meeting</td>
<td>325</td>
</tr>
<tr>
<td>Overtaking car, speed &lt; 90 (km/h)</td>
<td>Accelerating no meeting</td>
<td>508</td>
</tr>
<tr>
<td></td>
<td>Accelerating with meeting</td>
<td>643</td>
</tr>
<tr>
<td>Overtaking car, speed &gt; 90 (km/h)</td>
<td>Accelerating no meeting</td>
<td>576</td>
</tr>
<tr>
<td></td>
<td>Accelerating with meeting</td>
<td>693</td>
</tr>
<tr>
<td>Overtaking truck, no trailer</td>
<td>Accelerating no meeting</td>
<td>548</td>
</tr>
<tr>
<td></td>
<td>Accelerating with meeting</td>
<td>700</td>
</tr>
<tr>
<td>Overtaking truck, with trailer</td>
<td>Accelerating no meeting</td>
<td>695</td>
</tr>
<tr>
<td></td>
<td>Accelerating with meeting</td>
<td>852</td>
</tr>
</tbody>
</table>

The table shows first and foremost the great difference in the demands on sight distance between flying and accelerating overtaking. Flying overtakings have a median value of 230-325 m, depending on the vehicle type and occurrence of a meeting vehicle. A sight distance of 480 m is sufficient for 85% of the drivers to overtake a truck.
Accelerated overtaking requires a sight distance more than twice as long. The median value for overtaking a car is 500-700 m depending on speed and meeting vehicles. The corresponding distance for overtaking a truck is 550-850 m.

The 15% most cautious drivers require a very long sight distance. Over 1000 m sight distance is required for accepting an opportunity for accelerated overtaking of a car. The corresponding sight distance for overtaking a truck is over 1260 m in the most unfavourable case.

Table 5 above also shows that the difference in sight distance is very marginal between overtaking a car travelling at over 90 km/h and overtaking a truck without trailer. The greater length of trucks and the higher speed of cars thus have a similar effect on overtaking behaviour.

5. ANALYSIS AND CONCLUSIONS

It must be pointed out that the results reported in Chapter 4 apply only to daylight and dry road conditions.

On 13 m roads, sight design is less important for trafficability. The high proportion of paved shoulder driving allows good trafficability, even if the sight conditions are not ideal. Instead of aiming at long sight distances, a road designer should ensure that the road has a high minimum sight distance. In traffic situations with three vehicles abreast, it is important for safety reasons that the driver has a sufficient sight distance to comprehend the situation. Therefore, a minimum sight distance of 300-400 m should be the goal on 13 m roads.

On 9 m roads, the conditions are quite different. In the first hand, attention is drawn to the major difference in requirements on sight distance between overtaking a car and overtaking a truck, especially a truck with trailer. This means that roads with a high proportion of trucks must be designed with satisfactory sight distances.
Attention is also drawn to the major difference in demands on sight distance regarding the first overtaking attempt, i.e. flying overtaking, compared with accelerated overtaking in a queue behind a slower vehicle. The latter case requires a sight distance several times as long. This means that a road must be designed with very good sight conditions if the hourly traffic flow is so high that platoons are created.

In view of this, today's recommendations on an overtaking sight distance of 600 m, preferably 800-1000 m, at least once every three kilometres are inadequate for satisfactory traffic dispersal. The objective should be to give motorists more stretches of road with acceptable overtaking sight distances. These should be at least 800 m long, with an interval of at the most 1500 m.
Time and Space Criteria of Column Following

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Abstract

The paper deals with the differences between the brake characteristics of different vehicles and their influence on column driving. The number of vehicles which can be safely driven in a column is dealt with too. The necessary driver education will be discussed.
Time and Space Criteria of Column Following

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Dr
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Yugoslavia

(not attending the conference)
1. Introduction

High risk accidents, with more than 20 (or even 50) vehicles usually exists in cases of highway driving, with fog, rain (snow) or something like that. Bad weather conditions causes forming long columns of vehicles whose are driven (followed) using short distances.

Various types of vehicles, monotony in driving and suddenly braking of any vehicle in column (which is not safely signalled) are making situation for traffic accident involving some dozens of vehicles.

1.1. What is vehicle column?

When at least two of vehicles are driving same lane, in same direction, and when the way of driving of the first driver influences the way of driving driver behind, than we can talk about a column driving.

If "m" vehicles are driven in same direction and for every two of vehicles (Wn , Wn+1 , n < m) we can say that vehicle "Wn" influences driving of vehicle "Wn+1", then we have the column of "m" vehicles.

2. Safety distance problem

It is possible to find in papers and books that suggested safety distance between vehicles in column is

\[ D = 0.5 \times V \ (m) \]

where there are

D - safety distance in (m)
V - column speed in (km/h)

This means that for city driving (50 or 60 km/h) one must use distance between 25 and 30 meters, which is not common, and for this reason specific research was made.
2.1. Real sample

Measurement, on highway through Belgrade, in case of 435 vehicles on three way lane, shows that average speed was

\[ S = 89.5 \text{ km/h} \]

average following distance was

\[ D = 187.1 \text{ m} \]

and average time following interval was

\[ dt = 7.8 \text{ s} \]

The most significant speed classes were

<table>
<thead>
<tr>
<th>Class</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 - 80 km/h</td>
<td>22.8%</td>
</tr>
<tr>
<td>80 - 100 km/h</td>
<td>41.4%</td>
</tr>
<tr>
<td>100 - 120 km/h</td>
<td>20.5%</td>
</tr>
<tr>
<td>Total</td>
<td>84.7%</td>
</tr>
</tbody>
</table>

with speed limit of 80 km/h.

It was not possible to approximate distance - speed function even with 10th degree polinom, because coeff. of determination was

\[ R = 0.345 \]

which leads to conclusion that all vehicles were not in same column.

Trying to find what distance is average for column driving, from this sample we could take 135 vehicles (app. 30%) whose were driven on distance

\[ D < V \]

It was possible to approximate distance - speed function with 5th degree polinom, with coeff. of determination

\[ R = 0.6 \]

which leads to conclusion that vehicles were might be column driving.

Next step was to exclude extreme low distances, so then were taken distances

\[ 0.5 V < D < V \]

and that operation gave us very good determination with coeff.
R = 0.78

for

\[ D = 170.657 - 4.93V + 0.060192V^2 - 2.0266V^{-0.4} \]

If we use deeper analyse speed-distance function, we could see that there are some interesting facts:

<table>
<thead>
<tr>
<th>distances (m)</th>
<th>average speed km/h</th>
<th>number of veh.</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>89.50</td>
<td>435</td>
</tr>
<tr>
<td>D &lt; V</td>
<td>86.40</td>
<td>135</td>
</tr>
<tr>
<td>D &lt; 0.5 V</td>
<td>85.14</td>
<td>41</td>
</tr>
<tr>
<td>D &lt; 0.45 V</td>
<td>84.64</td>
<td>32</td>
</tr>
<tr>
<td>D &lt; 0.40 V</td>
<td>84.42</td>
<td>26</td>
</tr>
<tr>
<td>D &lt; 0.35 V</td>
<td>90.96</td>
<td>13</td>
</tr>
<tr>
<td>D &lt; 0.30 V</td>
<td>94.80</td>
<td>9</td>
</tr>
<tr>
<td>D &lt; 0.28 V</td>
<td>96.30</td>
<td>6</td>
</tr>
</tbody>
</table>

Using these results one could easy conclude that drivers are in dangerous situation because of two reasons:

- driving very fast
- taking lesser distances as speed is higher

2.2. Necessary and safe column distance

If we analyse case of column driving where first vehicle could make higher decelerating, and use criteria to stop second vehicle behind first without impact, then we get next relation

\[ D = \frac{V^2}{2} \left( 1 - \frac{1}{r} \right) + V(tsf - tsf + tdf) + \frac{d}{2 + \frac{r}{24}} (tbf - r \times tbs) \]

where there are:

- \( d \) - first vehicle decelerating
- \( r \) - (second/first) vehicle decelerating
- \( tdf \) - first driver reaction time (s)
- \( tsf \) - first driver and vehicle response time (s)
- \( tss \) - second driver and vehicle response time (s)
- \( tbf \) - first vehicle brake response time (s)
- \( tbs \) - second vehicle brake response time (s)
- \( V \) - column speed (m/s)

In a case of same vehicles and same drivers we could make simple relation

\[ D = V \times \frac{d}{24} \]
Also, in a case of second driver and vehicle reaction time of 1 (s) after switching first vehicle "stop light", (and using same vehicles) the safe distance is

\[ D = V \times 0.8 + d \times 0.2 \times 24 ; \quad (d \times 0.2 \times 24 \ll 0.8 \times V) \]

\[ D = \frac{V}{3.6} \]

\[ D = 0.28 \frac{V}{km/h} \]

When we use "D" as a measure of "safe" or "not safe" following in sample it is possible to say that 6 of 435 drivers drove safeless. They represent 1.38 % of sample.

3. Conclusions

When teacher educates driver in column driving he must explain that distance must be at least app. 30 % of car speed.

Models with distances of 50 % of car speed are not real in city driving, because it means that for speed 50 km/h distances would be 25 meters. It is easy to understand that that kind of distances are never used in column driving.

This method is important when we make estimating roads capacity.

If vehicles and drivers have not same reaction (response) time we could calculate whether or not the column would be safe, and specially in case of organized column driving.

REFERENCES:

2. FOX D., F.G. LEHMAN: SAFETY IN CAR FOLLOWING, Newark College of engineering, Newark, 1967.
\[ D = a + bx + cx^2 + dx^3 + \ldots \]

\[ a = 4.8944 \times 10^{-1} \]
\[ b = -8.8018 \times 10^{-1} \]
\[ c = 1.3752 \times 10^{-2} \]
\[ d = -3.3580 \times 10^{-5} \]
\[ \text{coeff.} = 0.60 \]

\[ D \text{ (m)} \leq V \text{ (km/h)} \]
\[ D = a + bx + cx^2 + dx^3 + \ldots \]

\[ a = 1.7065 \times 10^{-02} \]

\[ b = -4.9300 \times 10^{-01} \]

\[ c = 6.0154 \times 10^{-02} \]

\[ d = -2.0266 \times 10^{-04} \]

\[ \text{coeff.} = 0.784 \]

\[ 0.5 \, V \, (\text{km/h}) \leq D \, (m) \leq V \, (\text{km/h}) \]
DISTANCE - SPEED FOR ALL VEHICLES

\[ D = a + bx + cx^2 + dx^3 + \ldots + kx^{10} \]

\[ R = 0.345 \]
Passing Operations on a Recreational Two-Lane, Two-Way Highway

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PASSING OPERATIONS ON A RECREATIONAL TWO-LANE, TWO-WAY HIGHWAY
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1. INTRODUCTION - CHAPTER 1

Prior research on the passing maneuver has suggested that passing related accidents in the United States may be responsible for over 6000 fatalities and 100,000 serious injuries each year. (1) With such potential for fatal and serious injury consequences, the provision for adequate passing opportunity on two-lane, two-way highways is emerging as a research area deserving of in-depth study and emphasis. This project presents the results of field measured passing performance to help establish the effects of delay on the drivers performance and safety of the passing maneuver over variable traffic volume levels. To establish this effect, passing performances were examined over a 11 mile segment of USH 63 from Turtle Lake to Cumberland which is a two-lane, two-way rural, principal arterial highway located in Barron County, Wisconsin. The project is approximately 1 hour northeasterly of the Minneapolis-St. Paul Twin Cities metropolitan area and the route is a major recreational highway to northern Wisconsin and Lake Superior from the Twin Cities. The roadway was originally constructed in 1936 as a 20 ft. wide concrete pavement with 8 ft. gravel shoulders which were resurfaced and widened in 1973 to 24 ft. bituminous with 10 ft. gravel shoulders.

The 55 mph roadway geometrics are satisfactory for 60 mph horizontal operations although several long horizontal curves limit passing sight distance. The vertical alinement has 53 vertical curves of which 46 have stopping sight distance adequate for 55 mph operations, 5 locations are adequate for 50 mph, and one location for 45 mph stopping sight distance. In general, the combined geometrics offer an MUTCD marked passing opportunity of approximately 32 percent northbound and 33 percent southbound within the 11.1 mile segment.

The Average Daily Traffic (ADT) volume in 1985 was recorded as 2530 vehicles per day (vpd) with a peak hour volume of 24 percent of the ADT. However, a nearby permanent recording (AADT) station reported Sunday, July peak traffic volumes which were 235 percent in excess of the annual weekday ADT (or approximately 6000 vpd), with average summer (May to September) weekend volumes approximately 80 percent in excess of the monthly AADT (or approximately 4500 vpd). From video-recorded weekend data of this project, passenger vehicles comprise approximately 67 percent of the traffic flow, light trucks and vans contribute 26 percent, passenger vehicles with trailers 6 percent, and large Recreational Vehicles and large trucks contribute 1 percent.
From 1978-1986 (8 years), this roadway produced a total of 90 accidents or an average of 11 accidents per year. These accidents resulted in 71 injuries and 6 fatalities or about 1 fatality and 9 injuries per year. A review of the 1985-1987 accidents indicated that 67 percent of the accidents were vehicle-vehicle, and 22 percent were passing related. While the average annual accident rate for this roadway indicates a safe roadway on average, a severity of 77 fatalities and injuries per 90 total accidents indicates the risk of substantial severity when an accident does occur.

2. SITE LOCATIONS AND DATA COLLECTION - CHAPTER 2

Collection of the roadway passing data was performed on three non-concurrent weekends including July 4th, 15th, and 30th in 1988. These particular weekends were selected for their significance since the 4th is the peak traffic weekend of the year, and by retaining the weekends in one month, large shifts in driver population should be minimized. Also by selecting non-concurrent weekends the driving population should not become sensitized to expectancies of traffic studies in progress on the roadway.

Five passing zone observation sites were selected to provide both depth and breadth to the data collection. Three sites 2, 3, and 4 were selected for observation within the 11.1 mile project limits while two sites 1 and 5 were selected for observation significantly beyond the termini of the project at each end. The external sites 1 and 5 were selected at a distance of approximately 5 miles from the termini of the project to establish if as reported by Harwood such passing lanes have an impact upon operations a significant distance from the project itself (2). The external sites were selected as the longest and closest passing zones from each termini such that passing in these zones is relatively easy and safe if flow levels are low. Both external zones are about 1 mile in length with relatively flat, tangent geometrics. The internal observation sites (2, 3, 4) were selected at approximately 2-3 mile intervals from one another to provide data from the short 2000 foot passing zones at sites 2 and 4 to the longer 3600 foot zone at site 3. Sites 2 and 4 were selected for placement of the video-recorders since these sites offer a well balanced perspective of traffic flow at about 2 miles from each termini.

Roadside observers trained in the collection of passing data appropriate to this study were placed at each of the sites. To minimize disruption to the traffic stream and external influences on driver behavior by the presence of the observers, the observers were either sufficiently hidden from the drivers view or were dressed as resting bicyclists complete with easily observed bicycle if their presence could not be hidden.
The intent of the bicycle was to alleviate the threat of affecting driver behavior by placing an unusual (not easily explainable to the drivers perception) observer on the roadside such that portable radio warnings, headlight blinking or similar initiated driver behavior modification would result thus affecting the passing behavior. Similarly, each of the observers were placed at roadside locations as far from the traveled roadway as possible, while retaining visual capability, such that their location would not interfere with driver performance by appearing as a roadside obstacle. Video-recorders with time (in minutes) imprinted on the image were stationed at two of the internal sites for two weekends and at the two external sites for one weekend. In an effort to retain integrity of the observation sites, each of the video-recorders were wrapped in a black or green plastic wrap which blended into the natural background at the site. In general, the bicycle and video-camera disguises appeared extremely effective in maintaining the integrity of the observers as a natural part of the roadway environment, and thus preserving the drivers actual operational and safety characteristics for this study.

Along with each of the observers, pneumatic road-tubes collecting directional speed and volume data were placed at each site to record flow and speed in the major direction of travel. The speed and volume recorders were set for the northbound (away-from home) direction from approximately Friday noon to Saturday 3 PM and were them transferred to the opposite southbound (to-home) direction from 4 PM Saturday through 9 PM on Sundays (or Monday July 4th).

The following presents a summary of each passing site location and the data collected:

SITE 1 - This passing zone site is the most southerly external location which is about 4.5 miles from the beginning of the project. The location of the observer is approximately midway within the 6600 ft. long passing zone. The passing zone is on a tangent alinement with a flat grade in both directions at the point of pass initiation. Data collected at this site included speed and volume recorded in 15 minute increments from road-tube counters on each weekend as well as videotape data for one weekend. This site produced 135, 15-minute intervals of data and observed 391 passes in the northbound (from home-Twin Cities) direction. In the southbound (to home) direction 74, 15-minute intervals of data were collected along with 456 passes observed.

SITE 2 - The passing zone at this internal site is approximately 1800 ft. long with the observation sites approximately 2.0 miles from the beginning of the 11 mile project. The horizontal alinement in the
northbound direction is tangent and in the southbound direction has a slight curve to the right. This passing zone has a downhill grade northbound (-1.5 percent at the pass initiation point) and a slight downhill grade (-0.5 percent at the pass initiation point) southbound. Data from this site consisted of road-tube speed and volume data recorded in 15 minute increments on three weekends and video-recorded data on two weekends. This site produced 156, 15-minutes intervals of data and observed 273 passes in the northbound direction. In the southbound direction 95, 15-minute data intervals were recorded along with 242 observed passes.

SITE 3 — The passing zone at this internal site is approximately 3600 ft. long with observers located approximately midway in the passing zone. The passing zone is located 7.2 miles from the beginning of the project. The horizontal alinement is tangent with a downhill grade northbound (-2.0 percent at the pass initiation point), with a slight downhill grade southbound (-0.5 percent at the pass initiation point). This site developed 156, 15-minute data intervals for the northbound direction with 489 passes observed. In the southbound direction 81, 15-minute data intervals were recorded and 466 passes observed.

SITE 4 - The passing zone at this internal site is approximately 2100 ft. long with the observer located midway within the passing zone. The passing zone location is about 9.5 miles northerly of the beginning of the project. The horizontal alinement is tangent throughout this site with an uphill grade northbound (+1.8 percent at the pass initiation point), and a downhill grade in the southbound direction (-3.0% at the pass initiation point). The data collected at this site consisted of three weekends of directional speed and volume data recorded in 15 minute increments with video-recording data taken on two weekends. This site developed 112, 15-minute data intervals northbound with 210 observed passes. In the southbound directions 96, 15-minute data intervals were recorded along with 318 observed passes.

SITE 5 - The passing zone at this external site is located approximately 7.1 miles northerly of the north terminus of this project or 18 miles northerly of the beginning of the project. This passing zone is approximately 5800 ft. in length with observers located near the northerly end of the passing zone. This passing zone is on a slight uphill grade northbound (+0.5 percent at the pass initiation point), and on a downhill grade southbound (-1.5 percent at the pass initiation point). The horizontal alinement is essentially tangent throughout the passing zone. This site developed 175, 15-minute data intervals in the northbound direction along with 578 observed passes. In the southbound direction 101, 15-minute data intervals were recorded along with 730 observed passes.
The trained field observers were placed at each of the five sites over the three weekend periods and instructed to observe all passing maneuvers and specifically to record each of the following:

**TIME IN THE OPPOSING LANE** -
This characteristic of the passing maneuver is similar to AASHTO's time in the opposing lane (t2) and was estimated with a stopwatch from crossing of the centerline by the left-front tire to the return of the passing vehicle to the lane of origin by the left-rear tire (3). While it is often difficult to measure this event precisely because of the distance and skew between the vehicle and the observer, with experience it becomes easier to note which vehicles intend to pass and to record the event with relative precision.

**PASS WITH NO OPPOSITION** -
This type of pass represents those which were completed with no opposition to the pass in sight at the critical position (alongside the passed vehicle), and with no difficulty or conflict encountered in the completion of the pass. Observers were instructed to note the presence of opposing vehicles when the passing vehicle was alongside the passed vehicle. This is assumed to be a critical position where the passing driver evaluates the final outcome of the pass attempt and either proceeds or aborts the pass based upon the presence of opposition to the passing maneuver.

**PASS WITH OPPOSITION GREATER THAN 10 SECONDS** -
This type of pass represents those which had an opposing vehicle in sight at the critical position (alongside the passed vehicle), and completed the pass with no conflict where the opposing vehicle was 10 seconds or more from the completion of the pass (return of the passing vehicle left rear tire to the original lane). The time from return to the original lane (by the left rear tire) to the opposing vehicle (where vehicle trajectories met) was estimated using verbal counting such as 1001, 1002, 1003. In this type of pass, the time from return of the passing vehicle (to the original lane) to the time when both vehicles paths crossed was 10 seconds or more using a verbal count. While this is an inaccurate data collection technique, this does present a relative measure of the clearance time between vehicles, which is an estimate of the AASHTO t3 clearance interval. The lack of funding precluded a more refined measurement of this passing clearance (t3) characteristic.
PASS WITH OPPOSITION 5 BUT LESS THAN 10 SECONDS -
This type of pass represents those passes which were completed with an opposing vehicle in sight at the critical position (alongside the passed vehicle), and with the vehicle clearance within the range of more than 5 seconds but less than 10 seconds (verbal counting) from the completion of the pass (return to the lane of origin by the left rear) to the opposing vehicle. This is also referred to as a slight passing conflict since the passing driver is accepting elevated risk-taking in the passing maneuver as compared to other passing maneuvers.

PASS WITH OPPOSITION LESS THAN 5 SECONDS -
This type of pass represents those which were completed with an opposing vehicle in sight at the critical position (alongside the passed vehicle), and with the vehicle clearance of less than 5 seconds (verbal counting) from completion of the pass (return to the lane of origin by the left rear) to the opposing vehicle. This is also referred to as a major conflict since the driver is accepting a greatly elevated risk-taking event with a severe outcome to themselves and their passengers should the pass attempt fail. Roadside observers were instructed to record as much detail as possible about the vehicles and character of this type of passing event.

PASS ATTEMPT WITH FULL ABORT -
This type of pass represents the most serious and life threatening of passing maneuvers with a full vehicle entry into the opposing lane and then retreating to the lane of origin after concluding (in the face of an opposing vehicle) that the pass cannot be completed safely. The presence of this type of event is a clear indicator of the presence of great risk-taking on the part of the passing driver and indicates the trade-off between primacy which accepts safety as the ultimate goal of driving and the presence of overpowering delay which has altered the passing drivers disposition to pass from its normal risk-taking level to this level of significantly elevated risk in the presence of certain injury or death.

4. DATA COLLECTION AND ANALYSIS - CHAPTER 4

In summary of data collection, the three internal sites (2, 3 & 4) recorded 421, 15-minute data intervals in the northbound (from home on Friday/Saturday) direction recording major direction flows, speeds, and observations of passing maneuvers for 970 completed or aborted passes. At the internal sites (2, 3 & 4) in the southbound (return to home on Sunday) direction 276, 15-minute data intervals were recorded with 1026
observations of completed and aborted passes. At the two external control sites (1 and 5) 310, 15-minute data intervals were recorded in the northbound direction with 969 observed passing maneuvers, and in the southbound direction 175, 15-minute data intervals were recorded with 1577 completed or aborted passes observed. In total 1182, 15-minute data intervals were recorded with 4153 passing maneuvers observed.

An overall summary of percentage of passes cross-classified by the risk-taking in the passing maneuver (time in seconds to the opposing vehicle at pass completion) in the northbound and southbound directions is presented in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRECTIONAL PASSING CHARACTERISTICS</td>
</tr>
<tr>
<td>USING TIME FROM OPPOSITION</td>
</tr>
<tr>
<td>(Directional percentage of total passes)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NO OPPOSITION</th>
<th>&gt;10 sec</th>
<th>5&lt;10 sec</th>
<th>&lt; 5 sec</th>
<th>ABORTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NB</td>
<td>SB</td>
<td>NB</td>
<td>SB</td>
</tr>
<tr>
<td>SITE 1</td>
<td>76</td>
<td>50</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>SITE 2</td>
<td>81</td>
<td>76</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>SITE 3</td>
<td>63</td>
<td>68</td>
<td>14</td>
<td>12</td>
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<td>SITE 4</td>
<td>64</td>
<td>80</td>
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<tr>
<td>SITE 5</td>
<td>65</td>
<td>75</td>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>70</td>
<td>70</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

A comparison of the data gathered in this study with other research indicated the following:

The overall number of passes with no opposition to the pass was recorded as 70 percent. Within this study, the actual site conditions recorded variations from 50 percent to 81 percent which may be caused by the individual characteristics of the sites and the traffic flows experienced at the time of observation. Given that prior research found that 60 percent of all passes occurred with no opposition in sight, it may be concluded that the passing data conforms with prior passing research results. (4)
The time in the opposing lane was recorded for each passing maneuver and averaged 10.6 seconds over the 4153 passing observations. This estimate of the AASHTO time during which the passing driver occupies the left lane (t2) conforms with AASHTO results of 10.7 seconds at 60 mph operating conditions, where the average operating speed for this study was approximately 59 mph (3).

Given the overall acceptability of the data based on the comparison to other research, Tables 2 and 3 present a summary of the data recorded at each site by direction in terms of 15-minute data intervals. The northbound data intervals consist of both Friday and Saturday peak and off-peak data records which averaged approximately 150-180, 15-minute data intervals at each site, while the southbound data intervals were composed of more highly peaked 15-minute intervals recorded only on Sundays (or Monday July 4th) which averaged approximately 75-100, 15-minute data intervals at each site. In general, the northbound Table 2 and 3 data collected from each of the sites can be compared directly with other northbound sites, but caution must be used when comparing northbound to southbound data summaries because the large quantity of off-peak data in the northbound direction may depress the mean values.

A comparison of the northbound average flow rates suggests that sites 1,2,3 & 4 are not significantly different from one another, but the northbound average flow levels at site 5 are significantly lower than those at sites 1-4. This suggests that the northbound flows within sites 1-4 develop from the same parent population and are maintained throughout the project, but the northbound flow at site 5 represents a distinctly lower population. A statistical comparison of the flow levels in the southbound direction suggests the same conclusion in that sites 1-4 have similar flow levels while site 5 has significantly lower flow levels than sites 1-4. This significant difference between traffic volumes is reasonable and expected since traffic volumes on the route are split between two routes at the end of this project (approximately 12 miles from the start of the project).

From the Table 2 and 3 data for sites 1-5, two distinct passing relationships were noted which involve the passing characteristics at the lower traffic flows at Site 5, and the passing characteristics which were observed at the higher traffic flows of Sites 1-4. These two sets of passing characteristics will be examined separately as a scenario of Low Flow Level Passing Characteristics (from Site 5), and a second scenario of High Flow Level Passing Characteristics from Sites 1-4.
## TABLE 2
NORTHBOUND PASSING DATA SUMMARY

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>15 MINUTE INTERVAL MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INDIVIDUAL</td>
</tr>
<tr>
<td>NORTHBOUND FLOW (veh/15-minutes)</td>
<td>71.70</td>
</tr>
<tr>
<td>SOUTHBOUND FLOW (veh/15-minutes)</td>
<td>50.70</td>
</tr>
<tr>
<td>TOTAL FLOW (veh/15-minutes)</td>
<td>121.20</td>
</tr>
<tr>
<td>TOTAL NUMBER OF PASSES (15 minutes NB)</td>
<td>3.00</td>
</tr>
<tr>
<td>t2 (average time in opposing lane)</td>
<td>10.45</td>
</tr>
<tr>
<td>PASS WITH NO OPPOSITION</td>
<td>2.26</td>
</tr>
<tr>
<td>PASS WITH OPPOSITION &gt; 10 SEC.</td>
<td>0.18</td>
</tr>
<tr>
<td>PASS WITH OPPOSITION 5 - 10 SEC.</td>
<td>0.27</td>
</tr>
<tr>
<td>PASS WITH OPPOSITION &lt; 5 SEC.</td>
<td>0.23</td>
</tr>
<tr>
<td>PASS ABORTS</td>
<td>0.04</td>
</tr>
<tr>
<td>MULTIPLE PASSES</td>
<td>0.66</td>
</tr>
</tbody>
</table>

## TABLE 3
SOUTHBOUND PASSING DATA SUMMARY

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>15 MINUTE INTERVAL MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INDIVIDUAL</td>
</tr>
<tr>
<td>SOUTHBOUND FLOW (veh/15-minutes)</td>
<td>92.00</td>
</tr>
<tr>
<td>NORTHBOUND FLOW (veh/15-minutes)</td>
<td>41.80</td>
</tr>
<tr>
<td>TOTAL FLOW (veh/15-minutes)</td>
<td>133.80</td>
</tr>
<tr>
<td>TOTAL NUMBER OF PASSES (15 minutes NB)</td>
<td>5.55</td>
</tr>
<tr>
<td>t2 (average time in opposing lane)</td>
<td>12.00</td>
</tr>
<tr>
<td>PASS WITH NO OPPOSITION</td>
<td>3.08</td>
</tr>
<tr>
<td>PASS WITH OPPOSITION &gt; 10 SEC.</td>
<td>1.10</td>
</tr>
<tr>
<td>PASS WITH OPPOSITION 5 - 10 SEC.</td>
<td>0.80</td>
</tr>
<tr>
<td>PASS WITH OPPOSITION &lt; 5 SEC.</td>
<td>0.70</td>
</tr>
<tr>
<td>PASS ABORTS</td>
<td>0.49</td>
</tr>
<tr>
<td>MULTIPLE PASSES</td>
<td>0.93</td>
</tr>
</tbody>
</table>

VTI RAPPORT 372A
4.1 Low Flow Level Passing Characteristics

Prior to the detailed review of the sites 1-4 data, it may be well to examine the northbound and southbound low flow data of Site 5 as presented in Figures 1 and 2 to help determine the expected character of passing operations in reduced flow levels and less pressured passing operations than those found in sites 1-4. While these Figures present two differently collected data sets (Northbound and Southbound), the data do indicate that both flow rates are statistically similar in the major direction of passing operations, and only slightly different in the minor direction.

![Figure 1](image1)

**FIGURE 1**
375 VPH PASSING CHARACTERISTICS WITH NORMAL PASSING OPPORTUNITY
(Site 5 Northbound)

- Opposition <5 SEC (7.3%)
- Opposition 5-10 SEC (9.7%)
- Opposition >10 SEC (7.3%)
- Pass-No Opposition (74.9%)
- Pass-Full Abort (0.8%)

![Figure 2](image2)

**FIGURE 2**
317 VPH PASSING CHARACTERISTICS WITH NORMAL PASSING OPPORTUNITY
(Site 5 Southbound)

- Opposition <5 SEC (5.4%)
- Opposition 5-10 SEC (9.6%)
- Opposition >10 SEC (19.4%)
- Pass-No Opposition (85.1%)
- Pass-Full Abort (0.7%)
If the above passing characteristics at site 5 are averaged to present a picture of lower flow level, weekend, recreational passing operations, the following summary would result:

Where the major directional flow is in the range of 219-224 vph, with a minor flow in the range of 93-156 vph or a total flow of 317-375 vph:

1. Approximately 13-28 passes occur each hour,
2. The time in the opposing lane passing the lead vehicle averages 12.2 seconds at 60 mph,
3. Passes with an abort of the pass after fully entering the opposing lane averages 0.75 percent (0.7-0.8 percent) of all passes,
4. Passes where the pass completion is less than 5 seconds from the opposing vehicle average 6.3 percent (5.4 - 7.3 percent) of all passes,
5. Passes where the pass completion is 5 to 10 seconds from the opposing vehicle average 9.6 percent (9.5 - 9.7 percent) of all passes,
6. While the extent of passing with no opposition in sight or with opposition greater than 10 seconds from pass completion appears to be a function of the flow rate in each direction of travel, the passes completed in the presence of no opposition ranged from 65 - 75 percent.

The above represent the character of passing operations which occur on this two-lane, two-way rural recreational roadway over the weekend low flow total volume levels of approximately 317-375 vehicles per hour.

4.2. High Flow Level Passing Characteristics

With the above background, it becomes useful to examine the operational and passing character of the higher volume sites 1-4. One of the best indicators of the effect of the inability to pass in the presence of higher flow levels occurs at site 4 northbound and at site 1 southbound as presented in Figures 3 and 4. Each of these sites are the last passing zones in each direction and indicate the effects of delay development on the safety of the passing maneuver in the presence of only 33 percent passing opportunity over an approximate 12-14 mile segment in each direction at total volume levels in the range of 443-535 vph.

Comparison of Figure 3 to Figures 1 and 2 with respect to passing aborts in the presence of an opposing vehicle (which are clearly unsafe passes) indicates that the aborts have increased from less than 1 percent of all passes to over 3 percent of total passes. Even more significant is the pass abort occurrence at Site 1 southbound (return to home on Sunday) which increased to over 7 percent of total passes as presented in Figure 4.
FIGURE 3
428-485 VPH FLOW LEVEL PASSING CHARACTERISTICS
AFTER 33 PERCENT PASSING OVER 14.0 MILES
(Site 4 Northbound - from home on Friday/Saturday)

OPPOSITION <5 SEC (1.0%)
OPPOSITION 5-10 SEC (5.7%)
OPPOSITION >10 SEC (26.2%)
PASS-FULL ABORT (3.3%)
PASS-NO OPPOSITION (63.8%)

FIGURE 4
445-535 FLOW LEVEL PASSING CHARACTERISTICS
AFTER 33 PERCENT PASSING OVER 15.6 MILES
(Site 1 Southbound - return to home on Sunday)

PASS-FULL ABORT (7.8%)
OPPOSITION <5 SEC (11.4%)
OPPOSITION 5-10 SEC (12.9%)
OPPOSITION >10 SEC (17.8%)
PASS-NO OPPOSITION (50.0%)
Clearly, the data from Sites 4 northbound and Site 1 southbound indicate that passing drivers commit far more unsafe abort passes after they have been delayed on a roadway which only offers 33 percent passing over a 14-16 mile segment, and surprisingly that these life-threatening events can occur up to a rate of 7 out of every 100 passes at volume levels of only about 450-550 vph. On several of the Sunday recording days, from 10-30 abort passes (abort from full conflict with an opposing vehicle) were observed over a five hour recording period indicating the frenzy in passing operations which were occurring on the return Sunday trip home. Several of the observers also noted that "they were physically shaken and extremely nervous after having observed the number of scary passing aborts over just one day", and that "they couldn't believe this kind of passing was occurring even with a full family in the car". Most of the observers also indicated that passing maneuvers on the Sunday return trip home (southbound) were far more hazardous and pressured than the away from home (northbound) trip on Friday afternoon or Saturday.

While the volume levels in the opposing direction at sites 4 northbound and Site 1 southbound are slightly different, their passing percentages may be averaged to present a picture of higher flow level recreational weekend passing operations as:

Where the major directional flow is in the range of 326-368 vph with the minor flow in the range of 117-167 vph and total flows of 443-535 vph:

1. Approximately 8-22 passes will occur each hour,
2. The time in the opposing lane passing the lead vehicle is approximately 8-12 sec. at 60 mph,
3. Passes with an abort of the pass after fully entering the opposing lane are an average of 5.6 percent (3.3-7.9 percent) of all passing,
4. Passes where the pass completion is less than 5 seconds from the opposing vehicle average 6.2 percent (1.0-11.4 percent) of all passes,
5. Passes where the pass completion is 5 to 10 seconds from the opposing vehicle average 9.3 percent (5.7-12.9 percent) of all passes, and
6. While the extent of passing with no opposition in sight or with opposition greater than 10 seconds from pass completion appears to be a function of the flow rate in each direction of travel, the passes completed in the presence of no opposition ranged from 50 - 64 percent.

The above represent the character of passing operations which occur on this two-lane, two-way rural recreational roadway over weekend total volume levels of 443-535 vehicles per hour.
5. SUMMARY AND CONCLUSIONS - CHAPTER 5

Based upon the passing characteristics in lower flow rates as exemplified by the data of Site 5 Northbound and Southbound which do not have the passing opportunity reduced to 33 percent over an extended distance, Table 5 presents a summary of the change in passing operations at higher flow levels and with passing opportunity restricted to 33 percent over a 14-16 mile segment:

<table>
<thead>
<tr>
<th>Table 5</th>
<th>COMPARISON OF PASSING OPERATIONS AT OBSERVED FLOW LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SITES</td>
<td>SITES</td>
</tr>
<tr>
<td>5 NB/ SB</td>
<td>4 NB/ SB</td>
</tr>
<tr>
<td>PASSING ZONE LENGTH</td>
<td>5800 ft</td>
</tr>
<tr>
<td>MAJOR FLOW (vph)</td>
<td>219 / 224</td>
</tr>
<tr>
<td>MINOR FLOW (vph)</td>
<td>156 / 93</td>
</tr>
<tr>
<td>TOTAL FLOW</td>
<td>375 / 317</td>
</tr>
<tr>
<td>PASSES/HR</td>
<td>13 / 28</td>
</tr>
<tr>
<td>TIME t2 IN OPPOSING LANE (seconds @ 60 mph)</td>
<td>11.6 / 12.9</td>
</tr>
<tr>
<td>PASS WITH NO OPPOSITION (percent of total passes)</td>
<td>75 / 65</td>
</tr>
<tr>
<td>PASS COMPLETION 5-10 SEC. FROM OPPOSING VEHICLE (percent of total passes)</td>
<td>9.7 / 9.5</td>
</tr>
<tr>
<td>PASS COMPLETION LESS THAN 5 SEC. FROM OPPOSING VEHICLE (percent of total passes)</td>
<td>7.3 / 5.4</td>
</tr>
<tr>
<td>PASS ABORT DUE TO OPPOSING VEHICLE (percent of total passes)</td>
<td>0.8 / 0.7</td>
</tr>
</tbody>
</table>

Over 4000 normally occurring passing operations were observed in this research which conformed to both AASHTO and prior research results relating to passing maneuvers. It is important to note that the volumes observed are not significant in terms of the capacity of a two-lane, two-way roadway since the total two-way flow is only 317-535 vph where two-lane capacity may be 2400-2600 vph. However, even at these relatively low flow levels, passing operations were observed to be adversely affected by the absence of passing opportunity when
contrasted to more normal passing operations at Site 5, and this negative effect increased significantly as the traffic flow levels increased. The above data also indicate that with two-way volume levels of only 535 vph where the opportunity to pass has been restricted to 33 percent over a 16 mile section, the passing driver is willing to pass in the presence of an opposing vehicle in up to 50 percent of the passes. This is a substantial increase from more normal passing operations where only 25-35 percent of all passes will be made with an oncoming vehicle in sight. This increased willingness to accept more risk is also evident in the other Site 4 and Site 1 passing parameters which show substantial variances from the more normal Site 5 data.

TWOPAS (ROADSIM) traffic simulation of this roadway over these volume levels indicated the passing driver is experiencing a delay of only approximately 3 seconds per mile or 45 seconds over the 15 mile segment and the 15 minutes of traveltime. This delay level is only about 5 percent of the total traveltime, but may be indicative of that delay level where the passing driver becomes affected by the inability to tolerate further delay, and thus also begins to accept inordinate risk in the passing maneuver by trading primacy for delay savings.

Most significantly, the data indicate that with this elevated risk-taking, the result of this pressure to pass is the occurrence of up to 7 percent of the passes being attempted, and then aborted because of the presence of an opposing vehicle so close as to force the termination of the pass attempt having already entered the passing lane. Such an abort of the pass in the face of sure and certain injury or death to the occupants of one or both vehicles is in itself an alarming finding and one that deserves attention especially since the total volumes and delay are relatively low.

Based on the above, it appears that passing drivers are creating a significant change in the primacy (safety) associated with the passing maneuver once their delay tolerance threshold has been reached. More importantly, the data indicate that a delay tolerance threshold does exist such that drivers will become adversely affected by further delay to the point that their personal safety (as well as the safety of their passengers) will be jeopardized to avoid more delay.

Interestingly, this delay tolerance level appears to begin where delay exceeds approximately 5 percent of the total traveltime and that an exponential relationship (0.75 percent at 317-375 vph, 3.3 percent at 443 vph and 7.9 percent at 535 vph) is suggested between traffic volume and abort passes where the same level of delay tolerance is present in both cases (33 percent for 14-16 miles at both Sites 4 NB and Site 1 SB). This trend suggests that passing aborts more than double for each 100 vph in volume increase and that small increases in total volumes can cause significant
increases in aborts and a potentially significant decrease in the safety of passing operations on two-lane, two-way rural recreational roadways.

In addition, the data also suggest that passing drivers are significantly overestimating their driving ability and the ability of their vehicle to complete the passing maneuver safely. Even in the presence of such delay induced unsafe behavior, the passing drivers which aborted the passing maneuvers must have believed themselves and their vehicle capable of success or the pass would not have been attempted. Such life threatening errors in driver and vehicle capability deserve special attention to provide either adequate passing opportunity or adequate protection from the severe accidents which may result.

In summary, the effect of reduced passing opportunity to only 33 percent over a 15-16 mile segment appears to have a significant relationship to the drivers delay tolerance and the relationship with primacy which presumes that passing drivers value safety above all other driving goals. The shift away from primacy in a variety of passing characteristics including aborts from less than one percent to 3 and 7 percent of all passes at two individual sites indicates that the passing drivers decision threshold is being significantly altered by the prior inability to pass, and that the provision of passing opportunity at flow levels of only 450-550 vph or delay levels in excess of approximately 3 seconds per mile can be an integral part of the safe operation of two-lane, two-way rural recreational highways.

ACKNOWLEDGEMENT

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Reducing Risk Taking in Passing on Two Way Roads

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Reducing Risk Taking in Passing on Two Way Roads

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Abstract

The paper deals with the determination of the critical point when overtaking and the necessary sight distance. A special view is taken on elderly drivers' risk in connection of overtaking.

Driver education proposals are given.
Overtaking is one of the most complex things for a driver. The road network in undeveloped countries, as well as in developing countries, is not adequate to the growth traffic demands. In the structure of the road network there is a domination of two way roads with two traffic lines, specially primary roads, even international roads.

On these roads, traffic flows are expressively unhomogeneous. On these roads there are vehicles which speeds and other characteristics are totally different. Because of that there is a growing need of overtaking.

Because of the economical situation in these countries it is very hard to expect that described traffic conditions could be improved so fast. So, the problem of overtaking will be one of the most significant sources of the traffic accidents, as a direct consequence or indirect - the fatigue of a driver and other problems.

THE PROBLEM

Based on the traffic safety analyses in Jugoslavia, there is a constatation that the significant number of traffic accidents happen during the overtaking. The consequences of these traffic accidents are very bad.

The possibility of avoiding the overtaking traffic accidents most of the time mean to find the safe way of ending the overtaking.

In road projecting there is steel a domination of two way two line roads. Because of the lack of financial sources these roads are composed of small radius curves with small sight distance. Regulated sight distances for overtaking are calculated on the condition that the overtaking must be finished safety, and because of that these distances are unreally long. The results are very long overtaking forbidden distances and small sections where overtaking is not forbidden. Also, the roads are overcrowered and the intervals for overtaking are rare, which make the overtaking a problem. The inspection and penalties are very rigorous for overtaking on the overtaking forbidden sections. Drivers very often make the unsafe overtaking after long overtaking forbidden sections as a real torture for them. Analyzing over 800 overtaking accidents in Serbia it is noticed that 94 percentage of these accidents happen on overtaking forbidden sections (6). Most of these accidents happen after long overtaking forbidden sections.
Because of the unsatisfactory attention during overtaking, a number of last very expensive road reconstructions has given very bad results. This means that the number of accidents on the reconstructed road sections is rapidly multiplied instead of reducing, specially the number of overtaking accidents.\(^1\)

The purpose of this work is to point out the significance of more actual modeling the overtaking and to point out the new way of safe overtaking modeling.

**PRESENT OVERTAKING MODELS**

**CONSTANT SPEED OVERTAKING**

This type of overtaking is the simplest type and is presented in free traffic flows.

Picture 1 shows the path diagram of the passed \((V_1)\), overtaking \((V_2)\) and the opposite direction vehicle \((V_3)\) in the constant speed overtaking. It is considered that passed and the opposite direction vehicle are running properly by the constant speed.

From the condition:
\[
S_{2\, (tp)} - S_{1\, (tp)} = S_{12} \quad \ldots \quad (1)
\]

it is very simple to get the overtaking time:
\[
\frac{S_{21} + S_{12}}{V_2 - V_1} = \ldots \quad (2)
\]

which means the overtaking neccessary sight distance:
\[
L_0 = (V_2 + V_3) \cdot \frac{S_{21} + S_{12}}{V_2 - V_1} + S_{23} \quad \ldots \quad (3)
\]

where
\[
S_{12}, S_{21}, S_{23} \quad \text{safe distance between vehicles before and after overtaking.}
\]
\[
V_1, V_2, V_3 \quad \text{speed of the passed overtaking and the opposite direction vehicle.}
\]

\(^1\) On two reconstructed road sections, 80 km long, during the 1991. happened 6 percentage of all accidents in Republic Serbia, among which dominate overtaking accidents.
CONSTANT ACCELERATION OVERTAKING

This type of overtaking is little complicated but more significant in practise. This type is applying in overtaking the column leading vehicle and usually can be related with overtaking in normal traffic flow. If the leading vehicle is running very slow, than the accelerating has to be done during the whole overtaking, as shown on picture 2.

From the condition (1) there is the nonequation:

\[
\frac{1}{2} a t_p^2 + (v_2 - v_1) \cdot t_p - (s_{21} + s_{12}) = 0 \quad \ldots (4)
\]

\( a \) - acceleration of the vehicle \( v_2 \)

From the nonequation (4) there is an overtaking time:

\[
t_p = \frac{1}{a} \left( (v_2 - v_1)^2 + 2a (s_{21} + s_{12}) - (v_2 - v_1) \right) \quad \ldots (5)
\]

The necessary sight distance for this type of overtaking can be get by the nonequation:

\[
L_o = v_1 \cdot t_p + s_{21} + s_{12} + s_{23} \quad \ldots (6)
\]

If the overtaking vehicle \( (v_2) \) was behind the passed vehicle \( (v_1) \) in the column (which means \( v_2 = v_1 \)), we can get:

\[
t_p = \frac{2(s_{21} + s_{12})}{a}
\]

which can make the analysis more simple.

OVERTAKING WITH ACCELERATION TO MAXIMUM SPEED

This is a very often type of overtaking, specially in the passed vehicle speed is not significantly different from the overtaking vehicle desire speed. Diagram of this type of overtaking is shown of the picture 3.

From the condition (1) there is the nonequation:

\[
v_m \cdot t_p - \frac{(v_m - v_2)^2}{2a} - (s_{21} + v_1 t_p) s_{12} = 0 \quad \ldots (8)
\]
from where the overtaking time can be get:

\[ t_p = \frac{S_{21} + S_{12}}{V_m - V_1} + \frac{(V_m - V_2)^2}{2a (V_m - V_1)} \] ...

... (9)

If the overtaking is done from the column \((V_1 = V_2)\) than it is more simple:

\[ t_p = \frac{S_{21} + S_{12}}{V_m - V_1} + \frac{(V_m - V_1)}{2a} \] ...

... (10)

The general nonequation for neccessary sight distance (6) will not be changed.

Here are presented three models with purpose to be shown out the logic of traffic safety needs and which is applied in other models.

CHOICE SECTION ON THE OVERTAKING DISTANCE

It is very clear that this condition is not real and is very sevear. Drivers very often start the overtaking and than, if there is the opposite direction vehicle \((V_3)\), they judge if there was a possibility of ending the overtaking or giving up. In these situations drivers very often decide to give up from overtaking and they return safely behind the "passed" vehicle \((V_1)\). Because of that in overtaking analysis it should be analized both possibilities of avoiding the accident. With that purpose it is neccessary to define the critical positions and choice distance for given road, speed and sight distance conditions.

If the overtaking was progressive, the chances for safe giving up from overtaking are smaller. After a certain phase of overtaking, it is not possible to give up safely from overtaking. The first critical position \((A)\) is that position of the overtaking vehicle \((V_2)\) in relation to the passed vehicle \((V_1)\) and the opposite direction vehicle \((V_3)\), when it is not possible to give up safely from overtaking in given conditions.

For given conditions this critical position is defined by a distance \(K_a\), which is the distance between frontal sides of the passed \((V_1)\) and overtaking \((V_2)\) vehicle, shown on the pictures 4, 6, 7 and 8.
The critical time necessary for safe return behind the "passed" vehicle \( (t_{kv}) \) is determined from the condition (picture 4):

\[
S_1 (t_{kv}) - S_2 (t_{kv}) = D_{min} \quad \ldots \quad (11)
\]

If the overtaking driver at the moment \( t = 0 \) saw the opposite direction vehicle the deceleration started after a reaction time \((t_r)\). In critical situation driver slaws down with the deceleration \( b \) (m/s²) untill he returns back behind the "passed" vehicle.

Critical distance \( K_a \) is from the condition:

\[
S_3 (t_{kv}) = S_2 (t_{kv}) + S_{23} \quad \ldots \quad (12)
\]

Section after position A is the safe giving up section.

On the other hand in the first phases of overtaking the chances for safe overtaking are very small. Second critical position \((B)\) is a position of the overtaking vehicle \( (V_2) \) to the position of the passed \( (V_1) \) and the opposite direction vehicle \( (V_3) \), when driver has, for the first time, the possibility for safe overtaking ending.

For given conditions the second critical position is defined by a distance \( K_B \), which is a distance between frontal sides of the passed \( (V_1) \) and overtaking vehicle \( (V_2) \), shown on the picture 5. When the overtaking driver saw the opposite direction vehicle \( (V_3) \) he decided to speed up by the maximum acceleration \( a \) (m/s²) and to end the overtaking. As the overtaking vehicle was accelerated from the speed \( V_2 \) to the maximum speed \( (V_m) \) the overtaking is ending by this maximum speed.

Critical time for safe overtaking ending \( (t_{kz}) \) is defined from the condition:

\[
S_2 (t_{kz}) - S_1 (t_{kz}) = D_{min} \quad \ldots \quad (13)
\]

and the critical distance \( K_B \) from the condition:

\[
S_3 (t_{kz}) = S_2 (t_{kz}) + S_{23} \quad \ldots \quad (14)
\]

As to the mutual critical positions, three situations could be realized, shown on the pictures 6, 7 and 8.
In situation I (picture 6) there is a distance which gives the possibility for save overtaking ending and safe giving up. If we name this section as a choice section, because a driver has a possibility to choose. As the distance between the overtaking and the opposite direction vehicle (Lo) is longer, the choice section is longer. If the overtaking vehicle (V2) would be behind the point B in given situation, there will be not a possibility for safe overtaking ending, which means a possibility only for safe giving up. If the overtaking vehicle would be before the point A, there will be not a possibility for safe giving up. On the picture 6 is shown the most usual situation - when the choice section existy. Those are situations of relaxed overtaking in conditions of inaugh sight distance.

The choice distance is decreasing as the sight distance is decreasing. That is the way for a coincidental situation of positions A and B (situation II, picture 7). This is a situation without the choice distance but with only one point for a driver to choose. This is a critical situation from the safe overtaking point of view. The sight distance (Lo), in given conditions, in the coincidence of positions A and B, is the minimal sight distance for overtaking. This sight distance could be determine from the condition:

\[ K_A - K_B \quad \ldots \quad (15) \]

Finally, there are conditions (relations between the vehicle speeds and distance Lo) when the choice section (situation III doesn’t exist, which means that safe overtaking ending section doesn’t touch the safe giving up section, shown on the picture 8. In that situation exist the unsafe section between positions A nad B. If the overtaking vehicle would be on unsafe section at the moment of noticing the opposite direction vehicle that would be a dangerous situation. Overtaking vehicle couldn’t get out of this situation if passed vehicle or opposite direction vehicle wouldn’t change the way of running.

CONCLUSION

From described situations there is a conclusion:

- the overtaking vehicle must not get into a dangerous situation

- situation on the picture 7 presents the critical situation from the safe overtaking point of view

- If there is an approximately constant sighting and an unsafe section, the overtaking should be forbidden
- If the sighting is increasing the overtaking could be allowed before making a choice section, because the overtaking vehicle could reach safely the position A.

The condition before all to exceed the unsafe overtaking problems is more real safe overtaking modeling. Present models are not real what have severe consequences as a result. In this work has been presented a new approach to the safe overtaking modeling based on a driver real behaviour. In that purpose are given definitions of safe giving up section and safe overtaking ending section. Based on the mutual position analysis of these sections a new criterium of safe overtaking has been defined. The safe overtaking is not possible only when the safe sections are separated. This criterium is significantly mild and more realistic than the present criterium. In following work these models should be tested and compared and than the other safe overtaking elementy should be researched.
BI O B L I O G R A P H Y


FIGURAE 1, Space-time diagram of overtaking with a constant speed
FIGURAE 2, Overtaking with constant acceleration of the overtaking vehicle (during overtaking)
FIGURAE 3, Overtaking with acceleration up to the maximum speed.
FIGURAE 4, Critical position for safe restraint from overtaking
FIGURAE 5, Critical position for safe ending of overtaking
FIGURAE 6, The safe sections overlap each other and this part is the section of choice.
SECTION I Safe Restraint from Overtaking
SECTION III Safe Ending of Overtaking

SITUATION 2°

FIGURAE 7, The safe sections touch each other and the section of choice is reduced to only one critical position.
SECTION IV Dangerous sections

SECTION I Safe Restraint from Overtaking

SECTION III Safe Ending of Overtaking

FIGURAE 8, The safe sections do not touch each other, so that there is a dangerous section.
Guidelines for Railroad Preemption
at Signalized Intersections

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GUIDELINES FOR RAILROAD PREEMPTION AT SIGNALIZED INTERSECTIONS

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INTRODUCTION

Preemption of traffic signal controllers near railroad grade crossings equipped with active warning devices is often required because queues from the intersection can extend back over the tracks, thereby creating the potential for a serious vehicle-train accident. Current textbooks, manuals, and other references published in the U.S. contain minimal information regarding preemption timing and design (1, 2, 3). Somewhat similarly, a 1978 British report on rail-highway crossing safety in Europe noted that there was apparently no satisfactory means of analytically assessing the probability of spillback, and that the need for preemption is best determined using judgement based on local knowledge (4). The need for additional research on this topic was identified in the U.S. in 1985 when the Transportation Research Board Committee on Traffic Signal Systems developed a problem statement on signal system control for non-localized flow disruptions such as these due to railroad preemption (5).

This paper reports on the findings of a research study recently completed at the University of Wisconsin-Madison (6). The objective of the study was to develop methods for determining when preemption is required at isolated intersections, and for specifying the duration of the preemption intervals. Macroscopic traffic flow models and probability theory were used to describe the behavior of traffic under preemption conditions. Human factors considerations pertinent to the driving task were adapted from criteria currently used in establishing intersection sight distance and passing sight distance requirements. Limited resources precluded implementation and field evaluation of the developed methodologies.

NEED FOR PREEMPTION

One of the fundamental issues involved in preemption design is determining the need for preemption. One of the few quantitative statements in the U.S. Manual on Uniform Traffic Control Devices (MUTCD) concerning preemption suggests that preemption be installed when a signalized intersection is located within 200 ft of a railroad grade crossing (2). There is, however, no explanation as to how this figure was derived.
Whatever the rationale, the current recommendation does not recognize that in some cases it may be appropriate to install preemption at an intersection that is more than 200 ft from a set of tracks because of prevailing queuing characteristics.

In principle, if traffic regularly queues over the tracks, preemption should be installed no matter how far the crossing is from the intersection. Similarly, if traffic rarely or never queues over the tracks, preemption would not be required. The decision to install preemption logically should be based on a queuing analysis at each particular location rather than on a single fixed criterion. A methodology for performing such an analysis was developed using macroscopic traffic flow modeling procedures and is discussed below.

The length of queue expected during any signal cycle will be a function of approach volume, cycle length, saturation flow rate, and green split. If the intersection traffic signal is already present, queue lengths can simply be measured in the field. However, because decision to use preemption will most likely need to be made before the signal is installed, it would be necessary to estimate expected queue lengths with some type of traffic flow model.

Although the signalized intersection capacity analysis procedures in the U.S. Highway Capacity Manual (HCM) provide for the calculation of maximum discharge rates, they do not include storage requirements to preclude spillback into adjacent lanes or upstream intersections (19). A simple yet practical method for doing this is to apply a macroscopic "continuum" model which assumes constant arrival and discharge flow rates (7). For unsaturated conditions, the time necessary to discharge a queue of vehicles is given by:

\[ t_e = \frac{q(C - g)}{s - q} \]  \hspace{1cm} (1)

The maximum distance the queue extends upstream from the stopline (in terms of number of vehicles) can then be expressed as:

\[ N - s t_e = s \left[ \frac{q(C - g)}{s - q} \right] \frac{1}{3600} \]  \hspace{1cm} (2)

Assuming an average spacing of 22 ft per vehicle, the maximum average distance in feet that the queue will extend upstream can then be calculated as:

\[ D = \frac{s}{164} \left[ \frac{q(C - g)}{s - q} \right] \]  \hspace{1cm} (3)
Because the continuum model is based on the assumption of uniform arrivals, the above expression for the maximum back of queue represents the average queue length that will develop over many cycles. Assuming an isolated intersection, vehicles will actually arrive in an approximately random distribution. The length of the queue during any particular cycle then will fluctuate about the mean. During some cycles the queue may extend back over the tracks, and during the other cycles it may not. Therefore, for purposes of determining the need for railroad preemption, one must first establish the probability with which queues would be expected to spill back over the tracks in the absence of any preemption signal control.

A methodology for estimating this probability was developed using the Poisson distribution to approximate random arrivals (7). This distribution gives the probability of \( x \) vehicles arriving during a given time interval (in this case the cycle length) as:

\[
P(x) = \frac{m^x e^{-m}}{x!}
\]

where \( x = \) the expected number of arrivals in a given time period, and \( m = \) the mean number of arrivals in a given time period.

By cumulatively summing the probabilities of the number of arriving vehicles, it is then possible to determine the probability that any given queue length would occur. This computational procedure is presented in the form of a nomograph in the Manual of Traffic Signal Design (6), and is shown herein as Figure 1. The nomograph is used to determine the maximum number of vehicles which may be expected to arrive at an intersection during one cycle at a preselected probability (or performance) level. For example, entering the upper graph with the critical lane volume of 320 vph and extending a horizontal line to the turning line for a 45-sec cycle length, then projecting a vertical line to the turning line for an assumed 90% probability level, and then moving left to the vertical axis of the lower graph results in an estimated maximum arrival rate of about seven vehicles per cycle.

Using this arrival rate as the design arrival rate, the expected maximum queue length can then be calculated as before using Equation 3. It should be noted that this is the maximum queue length which can be expected during \( z \) percent of the cycles, where \( z \) is performance percentile used by the designer. During the other 100 - \( z \) percent of the cycles a longer queue is likely. The resulting expected maximum queue length would be compared to the distance between the tracks and the intersection stopline. If the maximum queue length was greater than the available storage space, a need for railroad preemption would be established.
Application of this guideline for preemption requires the selection of a performance percentile, or the percentage of cycles during which a queue over the tracks will not be tolerated without the provision of signal preemption capability. This percentile should be consistent with values commonly used in other safety-related design situations. A review of the literature revealed that an 80-90 percent performance level is often used in safety design criteria (7, 8, 9). For a general highway situation, the actual probability of an accident occurring under a given design scenario is probability somewhat lower than, for example, 100 - 90 = 10 percent. This is due to the driver's ability to reduce speed or perform an avoidance maneuver. In most preemption situations, neither the approaching train nor the driver stopped on the tracks have the opportunity to do either. Therefore, for preemption evaluation, an initial performance level of 95 percent is suggested. It should be noted that at this performance level, and with moderate to heavy approach volumes, preemption would be recommended for intersections which are located farther from the tracks than the 200 ft criterion currently used in U.S. practice.
3. DETERMINING PREEMPTION INTERVAL DURATIONS

Another critical task in preemption design is determining the warning time necessary to clear any stopped vehicles off the tracks before the arrival of a train. Calculation of the necessary warning time should be based on safety. This includes the safety of vehicles which may be stopped on the tracks as well as the safety of other vehicles and pedestrians using the intersection. Because of the relative hazards involved, if the necessary warning time is not obtainable, compromises in one of more areas may have to be made. Examples include shortening the pedestrian clearance intervals when entering preemption, or reducing the "safety" interval between the clearance of the track and the arrival of the train. The research reported herein did not address the criteria or rationale for determining when such compromises would be acceptable. Rather, a methodology was developed for specifying the duration of the various preemption intervals assuming that the total warning time is or could be made available.

3.1 Terminating the Current Phase

For the purposes of design, one must assume that a preemption call could arrive at any random point in the cycle. At many points in the cycle it would be possible to terminate the operating phase immediately and proceed directly to the track clearance interval. At other points, however, it would be necessary to wait for certain minimum or clearance intervals to expire before proceeding to clear the track. Therefore, the cycle must be examined to locate the point at which the required wait would be the greatest. This delay is then built into the required warning time. The procedure for finding the critical point(s) in the cycle is more or less one of trial and error. However, the critical point will probably be at the beginning of a phase or at the beginning of a pedestrian clearance interval, whichever would cause the most delay.

Many agencies operate their traffic signals with a minimum green interval of 10 - 12 sec which is guaranteed whenever that particular phase is operated. The reason for this is rooted in safety; a driver generally will not expect a green interval shorter than this minimum and could possibly proceed into the intersection after the phase has been terminated if he is several vehicles back in the queue and does not glance at the signal head again after initially observing it turn green. As a rule, this minimum green interval should be retained when terminating a phase for a preempt call. Therefore, the entering delay would be the greatest if the preempt call occurred at the very beginning of a green interval. This would require a wait of the full 10 - 12 sec before the clearance intervals, and then the track clearance phase could be initiated. The minimum green may be the same for each phase in the cycle, but a check should be made to find the phase with the largest minimum.

Pedestrian requirements can also influence the delay incurred before the current phase can be terminated. If pedestrians are engaged in a crossing
maneuver at the time a preemption call is received, they should be given time to finish crossing before the phrase is terminated. This would necessitate timing the remaining portion of the "FLASHING DON'T WALK" interval. If a "WALK" interval is in progress, it may be terminated immediately and the pedestrian clearance interval initiated. The controlling situation would be the latter case. The length of this interval (and hence the delay before the phrase can be terminated) will be dependent on specific agency policies for timing pedestrian clearance intervals. It is recommended that the initial preemption design be based on retaining the pedestrian clearance intervals in their entirety. Reductions in the length of this interval should be considered only if other options have been exhausted.

The clearance interval at the end of the phase being terminated must also be included in the required warning time, as they must be retained in their entirety. If the preemption call occurs during a clearance interval of any phase, the remainder of the clearance interval would be timed and the track clearance phrase could be initiated immediately thereafter.

3.2 Timing the Track Clearance Phase

After the current phrase has been terminated, enough green time must be provided so that vehicles which may be queued back over the tracks can be removed before the arrival of the train. The time interval necessary to allow a vehicle to move from the track area to a safe location can be defined as the sum of two subintervals: the time needed for a queue blocking the vehicle's path to begin to move out of the way, \( t_1 \); and the time needed for the vehicle to accelerate and move to a position clear of the tracks, \( t_2 \).

The time required to remove a queue of a given length will depend on several parameters such as start-up delay, traffic composition, vehicle acceleration rates, and headways. In addition, roadway parameters such as lane width, geometronics and grades will effect driver behavior. As a simplified approach to this computational problem, a shockwave methodology was applied in which the rate of queue dissipation is equal to the rate at which the "starting" wave moves backwards through the queue. The length of queue to be removed is then divided by the dissipation rate to obtain the time required for the back of the queue to move away from the tracks. Assuming a parabolic relationship between flow rate and density \( q \), the speed of the starting wave, can be expressed as:

\[
U_w = \frac{2q_s}{k_j}
\]

where: \( q_s \) = saturation flow rate (vph), and \( k_j \) = jam density (vpm).
The U.S. Highway Capacity Manual (10) can be used to estimate the saturation flow rate, but several minor modifications to the procedure are necessary to obtain a value which is useful in the calculation of the speed of the starting wave.

1. During the track clearance phase, all other movements (both vehicles and pedestrians) are prohibited. This in effect allows all turns from the approach crossing the tracks to be considered protected during this phase. In calculating the adjustment factors for turns, \( f_{LT} \) and \( f_{RT} \), all turns should be considered protected.

2. In the case where the track crosses a multilane approach, the critical lane will be the one with the lowest saturation flow rate, as this lane will clear the slowest. Therefore saturation flow rates should be calculated on a per lane basis, and the lowest chosen for design.

Once a saturation flow rate has been calculated and a suitable value for jam density has been selected (e.g., 240 vpm), the speed of the shockwave can be determined using Equation 5. The time interval, \( t_1 \), until the last vehicle in the blocking queue departs can then be expressed as:

\[
t_1 = \frac{L}{u_w}
\]

where: \( L \) = the length of queue to be cleared as measured from the intersection stopline to the point where a vehicle needing to be cleared may be stopped.

The second component of the track clearance phase, \( t_2 \), involves determining how long it will take a vehicle stopped on or near the tracks to accelerate to a position of safety once the queue in front of it has begun to move. The first step is to define the area at the tracks from which vehicles must be removed. Obviously vehicles stopped directly over the tracks will be in danger, but it will also be desirable to clear vehicles which stop between the tracks and the upstream grade crossing signal. One definition of the area which should be cleared (as well as a methodology for determining the time required for a vehicle to accelerate across this area) is found in the U.S. procedures for determining sight distance requirements at rail-highway grade crossings (9).

Assuming the crossing geometry shown in Figure 2, any vehicle located within a fifteen-foot danger zone, \( D \), on either side of the tracks must be cleared completely out of this zone before the arrival of a train. The critical vehicle for preemption design purposes is one which may be stopped with its front located at position (a) shown in Figure 2. To clear safely, the rear of that vehicle must reach position (b) before the train arrives at the crossing.
The time required this maneuver, $t_2$, expressed as:

$$t_2 = \frac{V_G}{a_1} + \frac{L + 2D + W - d_a}{V_G}$$  \hspace{1cm} (7)

where:

- $V_G$ = maximum speed of the design vehicle in first gear (mph),
- $a_1$ = acceleration rate for the design vehicle in first gear (mph/ps),
- $L$ = length of the design vehicle (ft),
- $D$ = clearance distance on either side of the tracks (assume 15 ft),
- $W$ = width of the crossing, or distance between the outermost rails (ft),
- $d_a$ = distance travelled while accelerating to maximum speed in first gear (ft).

Alternatively, the acceleration time nomograph shown in Figure 3 can be used for purposes of estimating $t_2$.

3.3 Sensitivity Analysis

Several of the parameters used in the calculation of the required warning time require assumed values. The question arises as to how sensitive the calculated warning time is to changes in the values of jam density and saturation flow rate, and the choice of a design vehicle.

In the calculation of the time required to move the queue of vehicles, a jam density of 240 vpm was assumed. This is equivalent to an average vehicle spacing of 22 ft. To test the effect of using a higher or lower jam density, values of 220 vpm and 260 vpm were compared. Using a 200-ft
queue length, the required warning time in each case differed from that using 240 vpm by less than 1 second. Furthermore, if the assumption of 240 vpm is in error it is likely to be higher than actual field values, thus making its use conservative. Therefore, the use of 240 vpm was considered acceptable.

The saturation flow rates used in the calculation of the speed of the shock wave can be obtained from the U.S. Highway Capacity Manual (HCM) procedure. However, it may be appropriate to simply use default values of 1600 vph for through lanes and 1400 for exclusive turn lanes. When track clearance times were calculated for two typical intersections using both saturation flow rates from the HCM and the above default values, nearly the same answers were obtained. Thus the default values for saturation flow rate can provide an acceptable alternative to HCM procedure, although calculated values or field measurements are preferable.

The length of the track clearance phase will also vary with the choice of design vehicle, as it takes a smaller vehicle less time to accelerate across the track area. Comparisons were made between a SU and a WB-50 design vehicle for two typical test intersections. In each case, the acceleration times differed by approximately three seconds, with the difference becoming greater as the width of the track area increased. This difference could have a significant safety impact if the design is based on SU truck but a WB-50 is present. It is recommended that the preemption design be based on the largest vehicle type which is expected to traverse the tracks, even if the percentage of such vehicles in the traffic stream is relatively small.

Figure 3. Acceleration Time Nomograph (9).
3.4 Safety Interval

The total length of required warning interval calculated thus far assumes that an approaching train will arrive at the crossing just as a vehicle stopped on the tracks has cleared. Because of the serious potential hazard involved in a vehicle-train accident, it is appropriate to add an additional "safety" interval to the required warning time. The rational for adding such an interval is two-fold:

1. An extra interval can help account for parameters not precisely known in the calculation of the necessary warning time.

2. A close call between the arrival of the train and the clearance of the vehicle might cause the driver to panic and abandon it in an attempt to escape.

An analogy can be made to the U.S. procedure for calculating passing sight distance on two-lane highways (9). In the final segment of the passing maneuver after the passing vehicle has returned to its own lane, there is an assumed minimum clearance distance between the passing vehicle and an oncoming vehicle (segment d3). For a passing speed of 50 mph, a clearance distance of 250 ft is used. Assuming the oncoming vehicle is travelling at the same speed as the passing vehicle, this translates into a minimum clearance interval of 1.7 sec. This would seem to be too small of a safety factor, but what the methodology does not specifically point out is that the event of a close call, the actual speed of the oncoming vehicle does not necessarily remain constant. The driver would most likely reduce speed if he determines the passing vehicle to be too close. Likewise, the passing vehicle may further accelerate in an attempt to return to its lane more quickly. These two phenomena probably combine to produce a greater clearance interval in most cases.

A similar length of safety interval could be applied to a track clearance maneuver in a preemption situation, as a train-vehicle accident is potentially at least as serious as a heads-on collision caused by a possible errant passing maneuver. There is a significant difference, however, in the inherent safety factor provided by an avoidance maneuver. A train realistically can not alter its speed or path. Furthermore, a vehicle stopped on the tracks has little opportunity to accelerate faster because of the queue blocking its path. Using this reasoning, an additional safety factor should be added to account for the inflexibility. A 4 to 8-sec value would appear to be reasonable. Larger values would be appropriate when:

1. The tracks are relatively far from the intersection (and hence a long queue needs to be cleared).

2. Train speeds are high, or

3. There is a high percentage of trucks in the traffic stream.
If after determining the required warning time using the above procedure it is discovered that an existing track circuit is not capable of providing that length of warning, the first option that should be considered is lengthening the track circuit. Lengthening the track circuit can often be difficult, primarily because of the cost involved. The question of who is responsible for paying the cost is also often difficult to resolve. One State, the Public Utility Commission in the U.S. has a fund built into its budget to cover such expenses. In another state, the agency responsible for overseeing railroad company operations has the power to simply order the railroad to incur the expense. Other states undoubtedly have different arrangements.

Precisely how much it would cost to lengthen the track circuit depends on the equipment already in place. In some cases, it may be necessary to replace the entire system. In other instances, however, it may be possible to modify what is already present. For example, a simple DC track circuit might be lengthened simply by adding an additional insulated section to the end of the circuit. Some of the newer constant warning time systems have the ability to send a signal to the intersection controller after the train has entered the circuit, but before the active warning devices are activated. The amount of additional warning time available will depend on some length of the circuit and the speed of the train. This capability is available on some constant warning time hardware, and generally comes in the form of an add-on computer board.

CONCLUSIONS AND RECOMMENDATIONS

The preemption of highway traffic signals near railroad grade crossings is common in the United States. What is uncommon is published information concerning the specific details of preemption timing design. The guidelines presented herein for determining the need for preemption and the duration of the preemption timing intervals should be useful to practicing traffic engineers.

The guideline for preemption installation improves upon current recommendations because it is based on a queuing analysis rather than a single, apparently subjective, number. The guideline is simple, practical, and relies on accepted traffic engineering principles. A debatable issue could be the choice of a 95-percent performance level. As noted earlier, design at this level can suggest preemption at distances significantly greater than the currently recommended 200 ft. This may be too conservative in light of budgetary limitations. Whatever percentile is adopted, the suggested guideline should be an improvement over the current criterion.

The preemption guideline could also serve as a starting point for the development of a comprehensive warrant for preemption installation based on the probability of an accident occurring and an economic analysis of all relevant costs and benefits. Such a study was beyond the scope of this research, but would perhaps be suitable for future work.
The methodology developed for determining the duration of the preemption timing intervals is simple to apply and is based on accepted design and analysis tools. The procedure does not permit the shortening of any intervals in an attempt to clear the track more quickly. If the existing track circuit cannot provide the required warning time, it would be necessary to upgrade the track circuit by lengthening it, or installing one which is capable of providing two separate control signals: one for the grade crossing signal, and one for preemption purposes.

The timing procedure which was developed uses several assumptions concerning traffic behavior on the approach crossing the tracks. Variation between the assumed values and actual requirements is not expected to vary by more than several seconds. This variation can easily be absorbed by the 4- to 8-sec safety interval that is recommended for inclusion in the final track clearance time. In all cases, queuing behavior and track clearance times should be verified in the field after the design is implemented.

REFERENCES


Old Hands on the Wheel: Exposure, Accident Experience and Problems of Elderly Drivers

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OLD HANDS ON THE WHEEL: EXPOSURE, ACCIDENT EXPERIENCE AND PROBLEMS OF ELDERLY DRIVERS
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1. INTRODUCTION - CHAPTER 1

As populations in developed countries include larger and larger proportions of older people, so concern grows about the members of this elderly population who drive. Canada, as a relatively "young" country, has at present a lower proportion of people over 65 than many countries in the developed world; the proportion was 10.4% in 1985, lower than the United States or most European countries at the time (U.S. Bureau of the Census, 1987). This population is growing more quickly in Canada than in any of these countries, however: by 2025, nearly 19% of Canada's population will be over 65 (Statistics Canada, 1990). Although countries in northern Europe will reach such a figure early in the 21st century, only Japan, among other developed countries, will have a higher proportion of older people.

National statistics on the licensing and driving of elderly people are difficult to obtain for Canada. Detailed data on drivers are maintained by each province, but with some variation in regulations, simple aggregation at the federal level is subject to problems. We will consider data only from Ontario, one of the largest of the ten provinces, with 36% of the national population.

The proportion of Ontario drivers aged 65 or more is small but growing: it was 10.2% in 1989, representing an increase of 31% in ten years (Ministry of Transportation, 1991). In 1986, only 56% of the population over 65 was licensed to drive, including 83% of men and only 37% of women. The number of elderly drivers, especially women drivers, is expected to grow more rapidly than the overall population in this age group. The next cohorts reaching the age of 65 include many people who have relied on the private automobile for transportation for most of their lives, taking the place of an earlier generation where driving was less common.

Surveys conducted of the elderly in Ontario, of both the population in general and drivers in particular, have provided valuable information about the need for transportation and the use of driving in this age group.

For example, many people use cars at work and to get to work, and elderly workers are no exception. While the age of 65 is the mandatory age of retirement in many
circumstances, labour force surveys in Ontario have reported that between 8-11% of men and 2-3% of women over 65 were working full-time, and 3-5% of men and 1-3% of women were working part-time (Ontario Gerontology Association, 1988).

A more traditional view of this age group is one of people with a lot of leisure time: among the leisure activities most frequently mentioned in Ontario surveys are Visiting Family, Visiting Friends and Travelling. Each of these requires access to some form of transportation; in the same survey, Distance and No Transportation were the barriers most frequently cited (after Poor Health) to participation in leisure activities, especially among respondents aged 75 or older (Ontario Gerontology Association, 1988).

The situation is similar in other countries. Rosenbloom (1990) described in some detail the need for vehicles by elderly citizens in the United States to carry out many essential functions: shopping for food, visiting the doctor, maintaining contact with family and friends. Her study emphasized, however, that the elderly individual frequently relied on other members of the household to drive, so these needs could be met.

Barjonet (1991) has reported the results of a survey in France which assessed risk perception and traffic safety behaviour at different ages. Overall, approximately half the respondents acknowledged that driving was dangerous; only one-third of those over 65 did so. On the other hand, they adopted other safety behaviours more commonly than younger people: they wore seat belts, did not smoke and kept a close eye on alcohol consumption.

In this paper, measures of exposure -- the times spent driving and distances driven -- by drivers over 60 will be related to their risk of traffic crash, and compared to those of other adult drivers aged 25-59. Their reports of problems experienced while driving will also be examined and compared by age group, sex and region.

2. METHODS - CHAPTER 2

2.1. Sources of data. Information about the driving done in different age groups was collected in a survey conducted in Ontario in 1988 (Smiley et al., 1990). Details of the survey design have been reported elsewhere (Smiley et al., 1989; Chipman et al., in press) but will be briefly described as follows.

A stratified random sample of licensed drivers was selected from Ontario driver records in September, 1988. The stratifying variables were age (6 levels), gender and region (3 levels). Altogether 12,019 questionnaires were sent out, with samples of 330-335 drawn from each of 36
strata. Among the six age groups were three groups of older drivers (60-69, 70-79 and 80+) and the age group 25-59 for comparison. The remaining two age groups, of drivers under 25, will not be part of the analysis reported in this paper.

Gender and region of residence were also stratifying variables. The more densely settled southern part of Ontario was divided into urban and rural settlements based on postal codes; the third region was the more sparsely settled northern part of the province.

The survey instrument was modelled on that developed for use in Quebec in 1984 (Lee, 1985). After a double page of demographic and descriptive data (how and when the respondent had learned to drive, global estimates of exposure, education etc.) the trip log followed. After a double page of instructions and worked examples, there was one double page to record the trips taken for each day. Diary length was determined by age: all drivers over 60 completed three-day diaries, while drivers 25-59 completed one-day diaries.

Questionnaires were mailed during a three-week period in the autumn; a reminder letter was sent after a further three weeks, followed by a brief non-respondent questionnaire to assess non-response bias. Drivers were asked to complete the diary for specific days of the week immediately following receipt of the questionnaire. Drivers who were reported to have moved, died or be no longer driving were removed from the sample.

Estimates of daily time and distance were computed from odometer readings and clock times reported in the diary, after deducting time out of the car in multi-stop trips. The ratio of daily distance to time was used as an indicator of drivers' average daily speed and to identify drivers with unreliable estimates. We excluded drivers whose average daily speed was in the upper or lower 5% of the distribution. Thus all drivers with values less than 6 km/hr or greater than 102 km/hr were excluded, on the assumption that very high or very low estimates of speed are of dubious accuracy; i.e., more likely to represent an error in recording time or distance than extreme, but accurately reported, behaviour.

Accident data for 1988 were obtained from provincial records which provided the frequencies of fatal, injury-producing and property damage accidents for each stratum. Estimates of population size for each stratum were also derived from provincial records of licensed drivers.

2.2 Analyses. Annual crash rates by stratum were calculated per 100 drivers, per million driver-kilometres and per 1000 driver-days, where each 'day' represents 24 hours of driving. Age- and sex-specific crash rates were based on weighted averages of each exposure measure.
across the regional strata (Cochran, 1977). The standard error and 95% confidence intervals were calculated using a method described by Armitage and Berry (1987). The rates for all crashes, whether resulting in fatality, personal injury or property damage, were computed initially. Fatal and injury-producing crashes were 30-40% of the total; the analyses were repeated for these events only, but the relationships among groups were so similar that only the results for total crashes are given.

For each trip reported in the daily logs, drivers indicated whether they had been bothered by specific factors. These included Heavy Traffic, Unexpected Delay, Poor Visibility, Slippery Roads, Other Drivers and Other (specify). Drivers who indicated none of these were classed as Not Bothered. The proportions indicating each type of problem were calculated and compared using logistic regression to assess the differences among age groups, gender and region.

3. RESULTS - CHAPTER 3

3.1 Exposure. Exposure in this survey was measured in terms of both time, distance and number of trips. The numbers of drivers, days and trips is given in Table 1. The mean daily distances and times spent driving appear in Table 2; the average distance and time per trip appears in Table 3.

Table 1. Drivers, Days and Trip Frequencies

<table>
<thead>
<tr>
<th>Group</th>
<th>Total No. of Drivers</th>
<th>Driver-Days</th>
<th>Total Trips</th>
<th>Mean No. Trips/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-59</td>
<td>716</td>
<td>716</td>
<td>1591</td>
<td>2.22</td>
</tr>
<tr>
<td>60-69</td>
<td>704</td>
<td>2112</td>
<td>3598</td>
<td>1.70</td>
</tr>
<tr>
<td>70-79</td>
<td>505</td>
<td>1515</td>
<td>2179</td>
<td>1.44</td>
</tr>
<tr>
<td>80+</td>
<td>167</td>
<td>501</td>
<td>492</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Table 2. Mean Daily Driving by Age Group and Sex

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km.</td>
<td>min.</td>
</tr>
<tr>
<td>25-59</td>
<td>50.1</td>
<td>74.9</td>
</tr>
<tr>
<td>60-69</td>
<td>44.3</td>
<td>64.0</td>
</tr>
<tr>
<td>70-79</td>
<td>38.1</td>
<td>54.0</td>
</tr>
<tr>
<td>80+</td>
<td>27.5</td>
<td>29.9</td>
</tr>
</tbody>
</table>

In Table 1, the differences in driver-days reflects differences in the number of days drivers maintained their trip diaries. Differences in the numbers of drivers reflects problems with differential response rates in the survey (Chipman et al., in press). In Table 2 the figures indicate that women drive consistently less, in terms of
total time and distance, than do men of the same age.

Table 3. Mean Trip Length by Age Group and Sex

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km.</td>
<td>min.</td>
</tr>
<tr>
<td>25-59</td>
<td>20.7</td>
<td>31.0</td>
</tr>
<tr>
<td>60-69</td>
<td>21.0</td>
<td>30.4</td>
</tr>
<tr>
<td>70-79</td>
<td>23.4</td>
<td>33.1</td>
</tr>
<tr>
<td>80+</td>
<td>23.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>

The steady decrease in exposure with age is related to changing numbers of trips, and not to changes in trip length (Table 3). For men, in particular, trip length varies little among different age groups. Women demonstrate greater variability in average trip length with age, but there is no consistent trend to shorter or longer trips among older women drivers.

3.2 Crash risk estimates. The annual crash rates per 100 drivers, per million driver-kilometres and per thousand driver-days are given in Table 4 which follows.

Table 4. Total Crash Rates per Driver, driver-km and driver-day (with 95% confidence intervals)

<table>
<thead>
<tr>
<th>Per 100 drivers:</th>
<th>Per 10^6 driver-km:</th>
<th>Per 10^3 driver-days:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Age:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-59</td>
<td>7.13±0.12</td>
<td>3.23±0.08</td>
</tr>
<tr>
<td>60-69</td>
<td>4.17±0.09</td>
<td>2.12±0.08</td>
</tr>
<tr>
<td>70-79</td>
<td>5.27±0.15</td>
<td>3.11±0.16</td>
</tr>
<tr>
<td>80+</td>
<td>7.22±0.53</td>
<td>6.01±0.90</td>
</tr>
</tbody>
</table>

The crash rates per 100 drivers demonstrate familiar patterns: men have higher rates than women in every age group, and older drivers, in general, exhibit lower rates than the younger control drivers. Drivers over 80 provide an exception to the pattern in Ontario statistics, which will be discussed later.
The great differences in exposure among these age and sex groups result in different patterns when time or distance is incorporated into the crash rate. The rate per million driver-kilometres is higher for men than for women aged 25-59, but the differences is reversed for drivers over 60. The difference appears more marked in the older groups. The rates in both genders are highest among drivers over 80. Among drivers aged 60 to 79, men have rates at least slightly lower than rates compared to men aged 25-59. The same is not true for women aged 60-79, whose rates remain consistently, and often dramatically, higher than those for women aged 25-59.

Differences in the rates per thousand driver-days are much less marked. The higher rate for older women compared to men disappears, and is reversed for drivers aged 60-69; the elevated rate for drivers of both genders who are over 80 remains, however.

3.3 Circumstances. Drivers were asked to report for each trip what problems they had experienced. A list of possible problems was presented, and provision for specifying other difficulties was allowed. Trips where drivers left all of these entries unchecked were classified as having 'no problems' on the data base.

A summary of the frequency with which problems are reported is given in Table 5. Problems have been grouped by type, as related to Environment, Road or Traffic conditions, and listed in decreasing order of frequency. The designation Other Problems elicited responses such as 'parking lot full', 'parade' to 'pigs loose on the road'.

Table 5. Summary of Problems Cited
N = 7860 trips

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Problems</td>
<td>6382</td>
<td>81.2%</td>
</tr>
<tr>
<td>Traffic Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congestion</td>
<td>503</td>
<td>6.40%</td>
</tr>
<tr>
<td>Other drivers</td>
<td>150</td>
<td>1.91%</td>
</tr>
<tr>
<td>Unexpected delay</td>
<td>86</td>
<td>1.09%</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>195</td>
<td>2.48%</td>
</tr>
<tr>
<td>Visibility</td>
<td>179</td>
<td>2.28%</td>
</tr>
<tr>
<td>Road Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slippery roads</td>
<td>276</td>
<td>3.51%</td>
</tr>
<tr>
<td>Poor roads</td>
<td>44</td>
<td>0.56%</td>
</tr>
<tr>
<td>Construction</td>
<td>35</td>
<td>0.45%</td>
</tr>
<tr>
<td>Other Problems</td>
<td>43</td>
<td>0.55%</td>
</tr>
</tbody>
</table>

As can be seen, most of the trips were not associated with any problem. Few of the trips where problems were reported involved more than one problem: there are a total of 1511 problems among the 1478 trips reporting any problem.

Logistic regression allowed us to examine differences in
the reports of problems for each trip by drivers' age group, controlling for the possibility of other differences in region and gender. These results indicated that problems of any kind in trips were less frequently reported by driver over 60 than by younger drivers, although drivers over 80 reported more problems than drivers aged 60-79. No differences were evident between men and women drivers, but there were statistically significant differences between regions ($P < 0.001$).

Similar analyses were done for specific commonly cited problems. In general, the differences were most marked between age groups and among the three regions, not between men and women drivers. Occasionally, an interaction effect was found, indicating that regional differences were not consistent across all age groups.

This was the case for the analysis of reports of traffic congestion. This was the most common problem cited and, as expected, was much more frequently cited by drivers living in the urban areas; however, this regional difference was much less dramatic among older drivers than for those aged 25-59. Among drivers over 80, the difference had almost disappeared, with only 1 percentage point separating the highest and lowest regions.

The next most frequently cited problem was slippery roads. No significant interaction was found between age and region here: drivers in northern Ontario reported this problem much more frequently at all ages, and across all regions younger drivers reported the problem more readily than most older drivers. Those over 80, however, reported the problem more commonly than drivers aged 60-79.

Problems of driving in bad weather exhibited no marked regional differences, but did display some variation with age and between the sexes. Women mentioned this problem significantly more often than men, and younger drivers (25-59) more frequently than those over 60.

Problems of visibility displayed no differences with age, but did vary between the sexes and by region.

4. DISCUSSION - CHAPTER 4

Each of the age groups considered in this study is subject to a variety of different social and regulatory factors which may affect both driving and licensing in the province of Ontario. Drivers aged 25-59, the control group of adult drivers, represent "typical" drivers. Drivers 60-69 are subject to identical licensing regulations as the controls, but their driving habits may be more variable as a group, due to the mix of working, retired and semi-retired individuals. Drivers aged 70-79 are likely to be fully retired. Most will be subject to normal licensing regulations, but those involved and at fault in a traffic
accident must pass a driver's test every year to maintain their license. All drivers over 80, regardless of their crash experience, are required to pass an annual driving test if they wish to keep their license.

The comparison between trip times and distances makes it clear that differences in exposure between age groups is not due to changes in trip length, but in numbers of trips taken. Certain changes in older drivers' driving environment, such as less highway driving, might be reflected in differences in trip length with age as well as total distance. Other changes in the driving environment, such as more trips taken during daylight hours, would not be expected to affect either trip length or total distance.

Comparisons between men and women at the same ages suggest that differences in driving environment exist here, as suggested by Janke (1991). Women not only drive slightly fewer trips than men but consistently shorter trips as well. This fits with the argument of different driving environments for men and women, but this survey did not make direct observations to confirm this possibility.

Shorter trips are typically undertaken at lower average speeds; in such circumstances larger differences in distance would be associated with smaller differences in time spent driving (Chipman and MacGregor, 1990). This is one explanation for the apparent differences in risk between men and women drivers per million kilometers which are much reduced when the same accident frequency is expressed per thousand driver-days.

In either measure of risk, however, male and female drivers over 80 have a substantially greater risk of crash than any other group. While the confidence limits are wide (largely due to the small population and low number of respondents) in this age group, they exclude values observed for control drivers and, for rates based on time spent driving, the values of crash risk for drivers in their 60's and 70's.

The reason for this additional hazard is unlikely to be age alone. There is certainly an increase in crash risk between drivers in their 60's and and in their 70's, which may reflect physiological changes associated with the aging process. In men, however, these rates remain as low or lower than younger control drivers. The sudden change for drivers 80 and over, affecting both men and women, is more likely due, at least in part, to an artifact of licensing in Ontario.

Because maintaining a license is so onerous in this jurisdiction, occasional drivers aged 80 or more may not take the trouble, if alternatives to driving themselves are available. This will make the drivers who maintain their license a more select group, including those who
have to drive. Such drivers may also find it more difficult to avoid hazardous driving; the proportions citing problems in their trip diaries were highest for drivers 25-59, dropped for drivers aged 60-79, but rose again for drivers over 80. Most elderly drivers can choose to drive at times when lighting, weather, traffic etc. present fewer difficulties. Drivers with limited alternatives to driving themselves may also have fewer choices when it comes to avoiding problems. Each of these factors may be associated with the increased frequency of traffic crashes experienced by this group.

The two younger groups of elderly drivers, in their 60's and 70's, have much more moderate crash rates. For men, they are lower than those of the control age group. For women, the rates based on time remain comparable to those in the control age group. Most of these drivers are licensed under no more stringent regulations than the control group of middle-aged adult drivers.

The job of regulating drivers is a difficult one, and striking a balance between reasonable access and reasonable risk presents some unexpected challenges where older drivers is concerned.

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More Safety Thanks to Good Orientation
Nothing Works Without Traffic Signs

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More safety thanks to good orientation
Nothing works without traffic signs (short version)
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Summary

Due to the complexity of the future situation of driver, vehicle and road - particularly taking into account psycho-physiological capacity of elderly drivers - road equipment serving optical guidance takes on a decisive part.

Increasing mobility of our society and the high mileage driven at night require that necessary information is ensured even under unfavourable conditions such as darkness, wet surface and dusk/dawn. Additional maintenance requirements in order to fulfill the information tasks in road traffic are an urgent demand in order to maintain or desirably improve safety on our roads. Quality rather than quantity is the request regarding traffic signs and traffic equipment. In order to achieve this it is not only necessary to thin out the forest of signs, but to also systematically check the safety quality of traffic signs in the dark in conjunction with an effective strategy for maintaining and replacing all signs and equipment.

As a result, the following requests are posed to those responsible:
- to ensure visibility and conspicuousness of traffic signs in the dark.
- to provide the necessary funds to finance these measures in the form of a maximum priority programme

taking particularly into account:
- the decreasing visual capacity of elderly motorists
- the fact that existing traffic signs are continuously becoming more and more obsolete.
More safety thanks to good orientation
Nothing works without traffic signs (long version)
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Roads fulfill significant social functions. They provide the conditions for high mobility in an efficient industrial society and extend man's living space. In addition, they are the basis for many services, production and their distribution. This means that they do not serve their own purpose, but rather economic, social and cultural purposes.

If we look at man in this context, it is inevitable to deal more closely with the problem of driver, vehicle and road. Because, despite the progress made in motor vehicle technology, man will not be replaceable as driver even in future. Although one can - thanks to micro-technology- expect positive effects on safety, people's traffic conduct remains to be determined by the extent to which their "capacity" coincides with the "set tasks" of vehicle and road.

The decisive factors in this context are quality and quantity of information presentation, speed and quality of information processing as well as precision and speed of reaction.

Before we treat this topic in more detail, let us look at some basic information on the traffic development, which is of importance in this context.

The development in the number of registered vehicles displays a clearly increasing tendency, particularly during the past few years. With about 29,2 mill, passenger and estate cars registered at the end of 1989, in the former (western part) Federal Republic of Germany clearly holds a top position in international comparison. This means in relation to the population capable of driving, 550 passenger/ estate cars per 1,000 persons with a driving licence. If the number of approx, 31,5 mill, registered vehicles predicted for 2,000 is achieved, the ratio will become increasingly more difficult and complex. I did not take into consideration that after Germany became reunited the number of vehicles has increased to 35 mill in actual 1990. Today in Europe there are 140 mill vehicles. This means an increase of 26 % within 6 years (82-87). A considerable additional increase is to be expected for the year 2000.

Another important fact is that, in the opinion of experts, goods traffic will develop overproportionately as other carriers show development rates below proportion. An increase will, logically, present an additional and considerable load for road traffic.
The overall road network is not developing to the extent to which this would be necessary for the number of registered vehicles or the amount of driving taking place. This also contributes to the fact that traffic development will reach a volume beyond anything that ever existed before.

By the year 2000 one expects in former - western - part of Germany (figures of all of Germany are not available) the number of driving licence holders to be about 70% of the population allowed to drive i.e. persons between 18 and 89 years of age. A considerable part of the growth rate in driving licence holders is accounted for by women and elderly citizens between 60 and 89. While the group of elderly drivers amounted to approx. 11% in 1980, it will be approx. 21% in the year 2000. The estimated actual number will more than double from 2.8 million to 7.1 million. Latest information published by the Federal Road Authority makes us expect up to 9 million driving licence holders over 60 years of age. A similar development can be found in Europe. Though the total population will increase by 4.6% within 20 years, the number of the more than 45 year old ones will increase by 21%.

Let us look in more detail at man's capacity which was already mentioned before. All road traffic information is perceived by the driver though his eyes, ears, skin and muscles. But man has only got a limited capacity for information perception and processing. The available reaction time, i.e. the time from perception to actual action, is frequently insufficient in critical situations.

Approximately 90% of traffic informations is perceived by the eye.

- If it is dark, we see considerably less than we should actually be able to see. This lack of information leads to the situation that we find it difficult to move on the road with the required certainty.

- The eye is under particular stress during nighttime driving and consequently presents a bottle-neck. Even experienced drivers do not know that the eye's visual capacity at nighttime amounts to only about 1/20 of the value achieved during daytime.

All behavioural studies lead to the conclusion that traffic participants have difficulties in correctly assessing the visibility conditions at night, or to take them into account.
With regard to overall accident occurrences, nighttime accidents are of special significance. The accident risk at night is considerably higher than during the day. The accident risk of passenger cars outside towns in the dark related to driving capacity increases to 1.7 times the risk existing during the day. (The number of accidents caused by insufficient visibility is probably considerably higher - about four times as high - if we take into account that instead of excessive speed it might just as well be insufficient visibility distance that causes accidents).

The severity of accidents is yet another problem. 25.2% of accidents occur in the dark although the traffic volume at nighttime is considerably smaller. But the number of fatalities lies at just under 40% and that of seriously injured persons at 30%. For this reason, physiological factors regarding perception and behaviour at night must be treated with more attention.

Any visual information includes three stages, i.e. seeing, perception and recognition. Recognition, the highest level of visual information, makes perception prerequisite. But perceptible are only those things which are visible. This ranking is not reversible at will.

Not everything that is visible is also perceived, and not everything that is perceived is also recognised.

This interrelationships play a far more important part in everyday-life than is generally assumed, and the play a particularly decisive part in road traffic. The processes that take places between "visibility" and "perception" have been clarified only insufficiently. The process taking place between perception and recognition shall be dealt with in more detail at this point as it practically represents the standard procedure of nighttime information absorption.

The decisive factor is that mere perception is not sufficient to cause a reaction from the driver. He must recognise the object.

In order to be able to perceive anything at all, it must be conspicuous. Consequently signs are only perceptible in the dark if they are conspicuous due to there brightness, contrast and size - it is only then that the process from recognition to reading can take its logical course.
In view of the already mentioned change in age structure by the year 2000 it is of special significance to consider visual capacity in context with age. In the case of people over 65, vision deteriorates rapidly. Only 48% have good vision. As regards night and dusk/dawn vision, it has been established that the visual capacities of over 65 years olds decrease dramatically. In fact, only 42% of this age group achieve good night and dusk/dawn vision.

Dependance of dazzle sensitivity on age is particularly apparent and shows a reduction in vision even with young drivers. This reduction becomes even more apparent in the group of 56 to 65-year olds, but takes on dramatic proportions over those 65 years of age, i.e. 67.5%. Taking mean values, a 60-year old driver is 3 to 4 times more sensitive to dazzle than a 20-year old one.

Apart from visual capacity there are also other factors that may reduce the processing of information (illness, fatigue, medication and lack of motivation).

For this reason the psycho-physiological performance capacity of drivers must be taken into account more seriously than ever before when we look at the driver, vehicle and road situation. The mentioned performance characteristics of man can be influenced only in a limited way. For this reason, any improved quality of the road environment with regard to visibility and orientation means considerable improvement in safety at night time.

As a consequence, anything possible must be done in order to shape the traffic environment in such a way that it becomes safer at night.

Maintenance of the road surface also means maintenance and optimisation of road equipment, particularly with regard to optical guidance. This very significantly includes traffic signs. It is their task to guide the motorist in such a way that traffic flow without friction is ensured. Traffic requires optical guidance particularly at night as the orientation aids available during the day fail in the dark. The development of retroreflective signs made it possible to provide visible guides in the dark in all those locations where there is no electrical power available. Uniformity during day and night and night visibility have become standard nowadays and their great significance for optical guidance at night only becomes recognisable if we have to drive in unknown territory, and optical guidance aids are less adequate or don't exist at all.
In order to ensure the functional performance of traffic signs it is necessary to maintain and replace them. It is particularly with regard to the target group 2000 that optical guidance in the dark presents a new challenge to traffic technology.

Perception, recognition and reading of a traffic sign are only ensured if the motorist is provided with the required brightness and, in particular, if old and no longer efficient traffic signs are replaced in time. Approximately 45% of all traffic signs in the former part of West-Germany are older than 10 years, 10% older than 15 years and 5% even older than 20 years. In the five new states of Germany the majority of traffic signs is 15 to 20 years old; consequently almost 100% of those signs have to be replaced, since it is particularly the group of signs older than 15 years which no longer guarantees sufficient recognisibility. Non-recognition of hazard or regulatory signs may have fatal effects, but illegible indications signs may also cause prolongation of reaction time which practically pre-programmes pile-up accident.

The problems mentioned can be summarised as follows:

In order to increase conspicuousness, brighter signs are often required in order to ensure information perception inspite of the complex road situation.

Brighter signs increase recognition time which may mean enormous time saving for the non-searching eye, particularly for carrying out any required action.

Approximately every 13 years the human eye requires twice the amount of light in order to see as much as a 20-year old.

The fact that a non-searching eye - due to visual noise (illuminated advertising, lights, shop windows) - requires longer orientation periods, may result in doubled reaction time.

The bright environment of a sign, for example, may require ten times higher brightness values; this applies especially if dazzle from oncoming traffic is to be expected.

More brightness also leads to better recognition of the colours which in turn means faster and better identification.

In difficult traffic situation an elderly person requires about 10 to 30 times brighter signs to read a directional sign in comparison with a younger driver. This is due to the fact that the eye sees logarithmically, i.e. a multiple of additional light is required in order to see twice as much, for example.
If we add up the factors that limit human visual performance, and if we take into account that approx. 90 % of all information is perceived by the eye, it becomes clear that it is absolutely necessary to use optical guide agents of supreme quality and to ensure that they are in good condition. Reflective sheeting on signs must fulfill the needs of the target group 2000, for example. This means: brighter efficient signs which can provide information to the motorist clearly, fast and at the right moment, and in the right manner.

Summary and recommendation

Due to the complexity of the future situation of driver, vehicle and road - particularly taking into account psycho-physiological capacity of elderly drivers - road equipment serving optical guidance takes on a decisive part.

Increasing mobility of our society and the high mileage driven at night require that necessary information is ensured even under unfavourable conditions such as darkness, wet surface and dusk/dawn. Additional maintenance requirements in order to fulfill the information tasks in road traffic are an urgent demand in order to maintain or desirably improve safety on our roads. Quality rather than quantity is the request regarding traffic signs and traffic equipment. In order to achieve this it is not only necessary to thin out the forest of signs, but to also systematically check the safety quality of traffic signs in the dark in conjunction with an effective strategy for maintaining and replacing all signs and equipment.

As a result, the following requests are posed to those responsible:

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- the fact that existing traffic signs are continuously becoming more and more obsolete.
Elderly People and Mobile Telephone Use
Effects on Driver Behaviour?

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The effects of a mobile telephone conversation on driving were studied in the advanced driving simulator at VTI. Twenty subjects, 10 men and 10 women, between 60 and 71 years and 20 subjects, also 10 men and 10 women, between 23 and 58 years participated in the study. The road the subjects drove could be characterized as "easy". It was straight and not expected to cause the subjects any problems with speed choice and steering strategy. The workload imposed on the subjects by the driving task was thus supposed to be very low. The telephone task included handling of the telephone and a conversation, containing a working memory part and a decision part. The handling task consisted of pushing the hands-free button to activate the telephone when it was calling. During the conversation the subjects were asked to listen to pre-recorded sentences and for each sentence to judge if they experienced it as "sensible" or "nonsense". After a number of sentences they were required to recall the last word in each sentence, in the order they were presented.

Effects will be discussed based on hypothesis like: When drivers' are solving the telephone task
- their ability to quickly detect and react on unexpected objects will deteriorate.
- their ability to control the vehicle, for example keep a consistent lateral position, will deteriorate.
- their workload will increase, due to the addition of the telephone task, and lead to a reduction in speed.
- The hypothetical effects are predicted to be stronger for elderly people.

Implications for traffic safety and for future in-car information systems will also be discussed.
ELDERLY PEOPLE AND MOBILE TELEPHONE USE: EFFECTS ON DRIVER BEHAVIOUR?
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1. INTRODUCTION

The proportion of elderly licenced drivers is anticipated to increase rapidly during the decades to come. Besides, the possibility to drive is assumed to be of growing importance in these people's lives. In some cases availability of a private car may be a critical factor for an individual's continued independence. The positive effects of mobility on social activity are of course of great importance. But, the problems associated with elderly drivers also merit attention, for instance their reported vulnerability and decline in physical and cognitive capacities relevant for driving (Kline, 1987; Planek and Overend, 1973).

Today, a lot of effort is focused on the development of RTI devices with the intention to improve traffic safety and efficiency. In principle RTI devices have a great potential to assist drivers with varying skills and capacities, and therefore make the traffic system suitable and useful to as many people as possible. However, to reach these goals a considerable amount of human factors research is needed in the MMI design.

When traffic safety is considered, drivers of different ages experience problems in different types of traffic situations i.e., in situations which impose different types of demand on them. Elderly drivers seem to experience problems mainly in intersections (crossing and turning) and when merging into traffic streams, and are also overrepresented and often responsible in such accidents (Matthews and Jones, 1989). Driver performance in these situations deteriorates rapidly after approximately 55 years, probably due to a decreased ability to gather and process information fast enough, and to coordinate the information processing with motoric actions (Planek, 1981). Also "improper lookout" errors seem to be frequent among elderly drivers (Treat, 1980).

Mobile telephones have high penetration in the Western world. They are relatively "old" RTI devices, and have passed several development stages relevant for the MMI design. Mobile telephone use have recently been reported to influence the behaviour of young drivers, 23 to 61 years (Alm and Nilsson, 1990). The most severe effects, with implications for traffic safety, were surprisingly enough found when the driving task was easy. The suggested explanation was that the drivers devoted so much attention to the telephone task that driving became the secondary task. As elderly drivers experience problems when they have to divide their attention, it is reasonable to believe that their safety related driving behaviour will be even more influenced when new RTI tasks (for example mobile telephone use) are added to the basic driving task (Warnes et al., 1991).

Problem. The purpose of the study was to investigate if and how the use of a handsfree mobile telephone influences the behaviour of drivers 60 years of age and older. The following questions were addressed: Will mobile telephone use influence elderly drivers' 1) ability to quickly react to an abruptly emerging object/event on the traffic scene, 2) steering ability? 3) workload? 4) choice of speed? 5) Also, will elderly drivers' performance of the telephone
task differ from young drivers' performance?

Predictions. Connected to the questions listed above, the following predictions were put forward and tested in the study:

Firstly, we predicted that activation of the handsfree function and engagement in a conversation over the mobile telephone while driving would increase elderly drivers' brake reaction time. Thus, that their ability to quickly react to a suddenly appearing stimulus in the driving environment would be negatively influenced. It was also predicted that elderly drivers would react slower than young drivers. Secondly, we predicted that elderly drivers' steering ability would be negatively influenced when they used the mobile telephone, and that the effect would be more pronounced than for young drivers. Thirdly, we predicted that elderly drivers' workload would increase when the telephone task was added to the ordinary driving task. It was expected that the workload level would be influenced by age. Forthly, we predicted that elderly drivers would lower their speed level as a result of the extra workload associated with the telephone task. That is, we predicted that the drivers would lower their speed to compensate for the increased task load due to the mobile telephone use. Fifthly, we predicted that elderly drivers' performance of the telephone task would be worse than young drivers' performance.

2. METHOD

2.1 Subjects

Twenty subjects, 10 men and 10 women, aged 60 to 71 years (mean age 65.9, SD 3.4 years) participated in the study. They all had a driving licence, and were experienced drivers meaning that they had had their driving licences for at least 5 years, and that they were driving at least 10,000 km per year. The subjects were recruited via advertisements at various public places, and via personal contacts. They were paid (250 SEK) for their participation in the experiment. The subjects were randomly assigned to two experimental conditions.

2.2 Apparatus

The VTI driving simulator was used in the study. It is an advanced simulator which consists of a moving base system, a wide angle visual system, a vibration-generating system, a sound system, and a temperature-regulating system (Nordmark et al., 1986; Nilsson, 1989; Nordmark 1990). The five subsystems can be controlled to operate in a way that gives the driver an impression which is very much alike the impression during real driving.

Vehicle. The car body in the simulator was an ordinary Volvo 740 with an automatic gearbox. The simulated physical environment in the "car" corresponded to that in modern passenger cars.

Mobile telephone. The mobile telephone used was an Ericsson Hot Line device with handsfree facility (Ericsson Radio Systems AB, Sweden). It was mounted on the instrument panel to the right of the steering wheel, over the ventilation controls at the height of the steering wheel. The mobile telephone communication was simulated with the help of the main simulator computer, a micro-controller and two tape recorders with remote controls. When a subject answered the mobile telephone, by pressing the handsfree button,
one of the tape recorders was activated and "read" the telephone task to the subject. Tasks for eight telephone calls were consecutively prerecorded on the tape. The presented telephone tasks were, together with the subjects' answers, recorded on the second tape recorder.

2.3 Driving task

Road. The road type that was presented to the subjects in the simulator was a two-lane, 7 meter wide asphalt road. It contained both horizontal and vertical curves. The road surface was characterized by high friction corresponding to dry summer roads, and the visibility condition was similar to a cloudy summer day. One practice route and one test route were used in the experiment. Both routes had the same general characteristics as described above. The practice route was 20 km long, rather straight and easy to drive. It was used to make the subjects familiar with simulator driving. The test route was 80 km long. It was also rather straight, and was not expected to cause the subjects any problems with speed choice and steering strategy. The workload imposed on the driver from road following was thus supposed to be very low.

Visual stimulus. A red square, with the size 4 x 4 cm, was used as visual stimulus. It always appeared in the same position, on the left shoulder of the road, and at a rather long distance in front of the "car". As the position was fixed relative to the road, the sight angle perceived from the driver's position varied a little according to the road curvature. The visual stimulus simulated an abruptly emerging event on the traffic scene.

2.4 Telephone task

The Working Memory Span Test (Baddeley et al., 1985) was chosen for the telephone task. It contains a working memory part and a decision part. The subjects performing the task were exposed to a number of sentences. Each sentence had the form "X does Y". For instance: "The boy brushed his teeth" and "The train bought a newspaper". After each sentence the subjects were supposed to answer "yes" if the sentence was regarded as sensible, and "no" if it was perceived as nonsense. The test contained 50% sensible and 50% nonsense sentences. When five sentences had been presented, the subjects had to recall the last word in each sentence, in the order of presentation. This completed the task of each telephone call. The procedure was repeated eight times with different sentences (eight telephone calls) during the experiment.

Presentation of the telephone task. Each telephone call started with an instruction, prerecorded on tape, telling the subjects how to perform the task. They were also told that they had to answer "yes" or "no" within three seconds, because then a new sentence would be read, and that they should repeat the last words when the command "Repeat" was given. Directly after the instruction the prerecorded Working Memory Span Test sentences were read. Each task presentation (telephone call) took roughly 60 seconds.

Relations between presentations of telephone calls and driving task stimuli. Eight telephone calls were presented to the subjects in the experimental group during the experiment. Therefore, eight specific positions along the test route were randomly selected. When the "car" passed these fixed points a telephone call was initiated. At four of the eight positions, also randomly chosen, the
visual stimulus appeared in connection with the telephone calls. For two of these four occasions, again randomly chosen, the visual stimulus appeared 1 second after the mobile telephone had rung, while for the remaining two occasions the visual stimulus appeared 30 seconds after the ring signal, when the subjects were concentrated on solving the telephone task. The random procedure was used to make it impossible for the subjects to correctly anticipate when the mobile telephone should ring, if the visual stimulus should appear in connection with the telephone call, and in case it did what the temporal relation between them should be.

2.5 Measures

Performance measures. Speed (km/h), lateral position on the road (m), variation in lateral position (m), brake reaction time (s), number of correct sentence judgments (sensible/nonsense), and number of correctly recalled last words (in the order of presentation) were used as performance measures.

Subjective measures. The subjects' workload were measured by the Task Load Index (NASA-TLX) developed by Hart and Staveland (1988).

2.6 Design

The design of the study was a classical experimental and control group study (single factor design). The subjects in the experimental group drove and performed the telephone task, while the subjects in the control group only drove the "car". The subjects were randomly assigned to the two groups, with the restriction that an equal number of men and women was assigned to each group.

When age was used as a variable in the analysis, data for young drivers were added from an earlier study (Alm and Nilsson, 1990), and the design became a two by two factorial design, with age (young versus elderly) as one factor and RTI system (mobile telephone versus control) as the other factor.

2.7 Procedure

Instruction phase. The subjects had to fill in a questionnaire about background variables (sex, age, driver licence, distance driven each year, experience of car driving, and of mobile telephones). After that each subject was randomly assigned to one of the two conditions (experimental and control), and given a written instruction, describing the experimental task. The subjects in the experimental group were told that they were supposed to drive an 80 km long route in the simulator. They were asked to "drive" the simulator in the way they normally drive a car, and to avoid to "play" with it. They were told to brake with their right foot. Furthermore, they were informed that two things would happen when they were driving, the mobile telephone would ring, and a red square would appear on the screen. The subjects were instructed to answer the ring signal from the mobile telephone by pushing the handsfree button. After doing so they should listen to the instructions that followed, and solve the task presented over the mobile telephone. The subjects were told to brake as fast as possible when the red square appeared. After reading and asking questions about the instructions, they had some practice on the telephone task. The subjects in the control group were exposed to
an identical instruction, but without the parts containing the mobile telephone.

Training phase. All subjects were introduced to the driving simulator. For the subjects in the experimental group the handling aspects of the mobile telephone were repeated, and they could practice to locate and push the handsfree button. Thereafter, all subjects drove the 20 km long practice route. The red square appeared three times, and the subjects could practice to brake as fast as possible, and hard enough to put out the square. For the subjects in the experimental group the mobile telephone also rang three times, and they were asked to solve the same telephone tasks they practiced on, but now via the mobile telephone while driving. When the training phase was over, all subjects had a short brake during which they were offered coffee, tea, or juice.

Test phase. The subjects performed the telephone (experimental group) and driving tasks. For the experimental group the subjects' answers to the telephone task were recorded on tape. Speed, lateral position and brake reaction time were recorded via the main simulator computer. After completing the 80 km long test route each subject had to rate his/her workload using NASA-TLX. Finally, the subjects were thanked for their participation, and paid 250 SEK. The running of a subject took 2-2.5 hours in total.

3. RESULTS

The resulting effects of mobile telephone use on elderly drivers' behaviour, including comparisons to young drivers' behaviour (data from Alm and Nilsson, 1990), will be presented in terms of: 1) brake reaction time to the simulated danger situation (the red square), 2) lateral position, and variation in lateral position on the road, 3) workload, 4) speed level, and 5) correct answers to the telephone task.

3.1 Brake reaction time

For each subject the mean reaction time, for the four visual stimuli (simulated danger situations), was calculated. Group means were then calculated from these subject related values. The results are shown in Figure 1. A two-way ANOVA showed significant main effects of both mobile telephone \( F (1;36) = 10.13, p< .01 \) and of age \( F (1;36) = 9.89, p< .01 \).

Effect of mobile telephone. The main effect of mobile telephone means that, independent of the age of the subjects, use of the mobile telephone while driving resulted in longer reaction times compared to driving without using the mobile telephone. Thus, a negative effect of mobile telephone use was found on both the elderly and the young subjects' ability to quickly react to an unexpected event. The differences in mean reaction time, between experimental and control groups, were 0.385 and 0.439 seconds for the groups of young and elderly subjects, respectively.

Effect of age. The main effect of age means that there was a difference in reaction time between young and elderly subjects, which was independent of mobile telephone use. The absence of an interaction effect (mobile telephone x age) tells us that the size of the difference, between experimental and control groups, did not vary with age. It was noted that the difference in mean reaction time, between the control group of young subjects and the
experimental group of elderly subjects, was as big as 0.818 seconds.

![Graph showing simple reaction time (mean for 4 visual stimuli) as a function of experimental condition and age.](image)

**Figure 1.** Simple reaction time (mean for 4 visual stimuli) as a function of experimental condition and age.

### 3.2 Lateral position

For each subject in the experimental group we calculated the mean lateral position, for 0-500 and 0-2500 metres after initiation of each telephone call. The 500 metres cover the distance during which the subjects had to activate the mobile telephone by pressing the handsfree button, while the 2500 metres cover the period during which the entire telephone task was completed. For the subjects in the control group mean lateral positions were calculated for corresponding sections of the test route. Mean lateral positions for elderly subjects are shown in Figure 2 (for 0-500 metres) and Figure 3 (for 0-2500 metres), for each of the eight telephone calls.

**Effect of mobile telephone.** Figure 2 shows that the lateral position on the road differed very little, between elderly subjects who activated the mobile telephone while driving and elderly subjects who only drove. The small differences remained also when the analyzed distance was extended to cover the performance of the entire telephone task (Figure 3). Performed two-way ANOVAs showed no significant effects of either mobile telephone or telephone call (calls 1 to 8).

**Effect of age.** When the 0-500 metre distance was considered, the "no effect" result obtained for elderly subjects (Figure 2) was in agreement with the result for young subjects driving the same route. On the other hand, when the 0-2500 metre distance was considered the results for elderly (Figure 3) and young subjects were not in agreement, as the young subjects drove significantly more to the right while performing the telephone task, compared to when they only drove. When the lateral position data for young and elderly subjects were combined and tested by a two-way ANOVA, no significant effects were found for the two analyzed distances after each telephone call.
3.3 Variation in lateral position

When the subjects' steering ability was analyzed, not only the absolute value but also the variation (SD) in lateral position on the road was of interest, because it may have implications for traffic safety. For each subject in the experimental group, the SDs were calculated for 0-500 and 0-2500 metres after initiation of each telephone call. For the subjects in the control group, SDs were calculated for the corresponding sections of the test route. The resulting variations (SDs) in lateral position for elderly subjects are shown in Figure 4 (0-500 metres) and Figure 5 (0-2500 metres).
metres), for each of the eight telephone calls.

Effect of mobile telephone. Figure 4 shows that elderly subjects varied their lateral position more when they activated the handsfree function while driving compared to when they only drove. The result persisted over all telephone calls. A two-way ANOVA showed significant main effects both of mobile telephone \( F(1;144) = 32.89, p = .0001 \) and of telephone call (calls 1 to 8) \( F(7;144) = 3.22, p = .0034 \). Besides, there was a significant interaction between mobile telephone and telephone call \( F(7;144) = 2.28, p = .0315 \). The effects of telephone call are less relevant, since they probably only reflect the fact that the different telephone calls occurred at positions with different curvatures.

![Variation in lateral position](image)

Figure 4. Elderly subjects' mean variation in lateral position 0-500 metres after initiation of the 8 telephone calls, for the 2 experimental conditions.

![Variation in lateral position](image)

Figure 5. Elderly subjects' mean variation in lateral position 0-2500 metres after initiation of the 8 telephone calls, for the 2 experimental conditions.
Figure 5 shows that, also when the distance covering completion of the entire telephone task was considered, the variation in lateral position was larger for elderly subjects who used the mobile telephone while driving than for elderly subjects who only drove. The difference is not obvious for all telephone calls. However, the performed two-way ANOVA again showed significant main effects both of mobile telephone [$F (1;144) = 6.09, p= .0147$] and of telephone call [$F (7;144) = 2.97, p= .0062$].

Effect of age. The effects of mobile telephone use on the elderly subjects' variation in lateral position were not in agreement with the results for young subjects. The differences between young and elderly subjects were analyzed for all telephone calls together. The results are shown in Figure 6 (0-500 metres) and Figure 7 (0-2500 metres).

![Figure 6. Variation in lateral position 0-500 metres after initiation of the telephone calls (means for 8 calls), as a function of experimental condition and age.](image)

For young subjects, there was no difference in in lateral position variation between the experimental and control groups (Figure 6). But, for elderly subjects there was a difference due to experimental condition. A two-way also ANOVA showed a significant interaction effect between mobile telephone and age [$F (1;36)= 10.65, p= .0024$]. Thus, during the phase when the handsfree function had to be activated, the effect of mobile telephone was influenced by age, i.e. elderly subjects varied their lateral position more than the young subjects.

The young subjects in the control group varied their lateral position more than the young subjects in the experimental group (Figure 7). For the elderly subjects the effect was in the opposite direction. A two-way ANOVA showed a significant interaction between mobile telephone and age [$F (1;36)=7.23, p= .0108$]. Thus, the effect of mobile telephone was influenced by age also during performance of the entire telephone task, i.e. the variation in lateral position increased for the elderly subjects while it decreased for the young subjects.
Figure 7. Variation in lateral position 0–2500 metres after initiation of telephone calls (means for 8 calls), as a function of experimental condition and age.

3.4 Workload

By NASA-TLX it is possible to obtain subjective ratings of six different aspects of workload and their respective weights. The test is rather demanding and despite considerable efforts we could not collect complete data from all the elderly subjects. However, nine subjects in each group (experimental and control) performed the ratings of mental demand, physical demand, time pressure, performance, effort, and frustration level satisfactorily. But, they could not weigh the different aspects in relation to each other. As Byers et al. (1989) have shown that NASA-TLX ratings without weights can be used to assess workload, we used the ratings of the separate workload aspects in our analysis.

Table 1. Results of ANOVAs performed on the NASA-TLX subscale ratings for young and elderly drivers.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
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<tr>
<td>Mental demand</td>
<td>RTI</td>
<td>1,34</td>
<td>25.94</td>
<td>0.0001</td>
</tr>
<tr>
<td>Physical demand</td>
<td>--</td>
<td></td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Time pressure</td>
<td>--</td>
<td></td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td>RTI</td>
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<td>4.86</td>
<td>0.0343</td>
</tr>
<tr>
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<td>RTI</td>
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<tr>
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<td>6.22</td>
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<tr>
<td>Frustration</td>
<td>RTI*AGE</td>
<td>1,34</td>
<td>5.46</td>
<td>0.0255</td>
</tr>
</tbody>
</table>

Effect of mobile telephone. When we analyzed the differences, in the ratings of separate workload aspects, between the experimental and control groups of elderly subjects, only mental demand differed significantly. Elderly subjects, who performed the telephone task while driving rated mental demand higher than elderly subjects who only drove \( t (16) = 2.34, \ p < .05 \). When ratings for
young subjects were added, and a number of two-way ANOVAs performed the results shown in Table 1 were found. It can be seen that four of the six workload aspects were influenced by mobile telephone use. Independent of their age, subjects engaged in the telephone task rated mental demand and effort higher, were less pleased with their performance, and were more frustrated than subjects in the control groups.

**Effect of age.** Interestingly enough, we can note that no main effect of age was obtained. The only age related effect was an interaction between age and frustration level. Young subjects were more frustrated than elderly subjects when they used the mobile telephone while driving.

### 3.5 Speed level

For each subject in the experimental group a mean value of the speed, from initiation of the handsfree function and 80 seconds forward, was calculated for each telephone call. The 80 seconds covered completion of the entire telephone task. The subject means were used to calculate group means for each telephone call. Corresponding calculations were made for the subjects in the control group. Resulting speeds are shown in Figure 8.

![Figure 8](image)

**Figure 8.** Elderly subjects' speed level 0-80 seconds after initiation of the 8 telephone calls, for the 2 experimental conditions.

**Effect of mobile telephone.** Figure 8 shows that the mean speed for elderly subjects using the mobile telephone was lower than the mean speed for elderly subjects who only drove. The effect appeared for every telephone call. The average speed difference, between the experimental and control groups of elderly subjects, was 9.5 km/h, and statistically significant \( F (1;144) = 17.94, p = .0001 \). When mean values over all telephone calls together were calculated, and the corresponding data for young subjects added the speed levels in Figure 9 were obtained. A two-way ANOVA showed a main effect of mobile telephone \( F (1;28) = 172.55, p = .0001 \). Thus, independent of age, subjects drove slower (9.2 km/h on average) while using the mobile telephone compared to when they were only driving.
Effect of age. Figure 9 shows that the elderly subjects drove faster than the young subjects. The two-way ANOVA showed a main effect of age [$F(1;28) = 45.60$, $p = .0001$]. Thus, independent of mobile telephone use, the elderly subjects drove on the average 4.7 km/h faster than the young subjects.

![Figure 9](image)

Figure 9. Speed level (mean for the 8 telephone calls) as a function of experimental condition and age.

3.6 Performance of the telephone task

The Working Memory Span Test (Baddeley et al., 1985) was used as the telephone task.

Effect of age. The performance of both the decision part (number of correct sensible/nonsense judgments) and the working memory part (number of correctly recalled last words in the order of presentation) was in favour of the young subjects. The results were statistically tested using t-test. The young subjects made significantly more correct judgments [$t(18) = 2.59$, $p = .02$] and more correct recalls [$t(18) = 2.97$, $p = .01$] compared to the elderly subjects.

4. DISCUSSION

It was predicted that engagement in a conversation over the mobile telephone while driving would have a negative impact upon elderly drivers' ability to react quickly to a suddenly appearing event. Elderly drivers were also expected to react slower than young drivers. The predictions were fully supported by the results of this study. The elderly drivers' brake reaction time of 1.332 seconds (control) was prolonged by 0.439 seconds when they used the mobile telephone. Earlier (Alm and Nilsson, 1990), a corresponding prolongation has been reported for young drivers, but at a significantly lower level ($0.953 \pm 0.385$ seconds). Thus, both mobile telephone use and age influence drivers' reaction time negatively. Figure 1 shows that the level of performance (brake reaction) for young experienced drivers, driving on an "easy road" and being engaged in a mobile telephone conversation, coincides with that for elderly experienced drivers, driving on the same
road but without using a mobile telephone.

Elderly drivers have a number of possibilities to compensate for their somewhat longer reaction time. They can, for example, drive slower, or try to avoid traffic situations with frequently occurring unexpected events (intersections without traffic lights, roads with short sight distances, school environments, etc). If speed is considered, the distances driven during the obtained reaction times were 50 and 36 metres for elderly and young experimental groups, respectively, and 42 and 28 metres for elderly and young control groups, respectively. Obviously the elderly drivers did not reduce their speed enough to fully compensate for their longer reaction time. This has implications for traffic safety. Thus, elderly drivers’ risk of an accident, caused by a suddenly appearing event, is higher than the corresponding risk for young drivers. Long reaction times may be one reason for the "improper lookout errors", which according to Treat (1980) are frequent among elderly drivers.

It was also predicted that the demands, from using the mobile telephone, would have a negative impact on elderly drivers’ ability to monitor and adjust the lateral position of the car and, that the steering effect would be more pronounced with increasing age. Therefore, both the "absolute" lateral position on the road and its variation were studied. The results show that the elderly drivers varied their lateral position more when they used the mobile telephone, compared to when they did not. The effect was obtained for both 0-500 and 0-2500 metres after the initiation of telephone calls. A realistic interpretation is that both the physical activity to locate and press the correct (handsfree) button, and the mental activity to carry out a conversation, have a negative effect upon elderly drivers’ steering ability. For young drivers, only the mental activity seems to influence the variation in lateral position, but in the opposite direction compared to elderly drivers (Alm and Nilsson, 1990). The young drivers followed the road even more carefully (with less variation) when they were talking in the mobile telephone. Independent of driver age, the "absolute" lateral position on the road seems to be uninfluenced by the mobile telephone use. There was, however, a tendency (not significant effect) for the young drivers to move more to the right, when they were engaged in the telephone conversation.

Consequently, a mobile telephone conversation seems to have a more severe effect on elderly drivers’ tracking ability than on young drivers’ tracking ability. While young drivers move to the right on the road and keep a more steady course, elderly drivers increase their variation in lateral position. Also this result has implications for traffic safety. Thus, elderly drivers, using a mobile telephone while driving, run a greater risk to intrude into the wrong lane, or to unintentionally leave the road.

The third prediction stated that elderly drivers’ workload would increase when the telephone task was added to the driving task. The workload level was assumed to be influenced by age. Only one of the workload aspects were found to be differently estimated by the experimental and control groups of elderly drivers. Mental demand was rated higher in the group using the mobile telephone. When young drivers’ workload estimations (Alm and Nilsson, 1990) were added a number of effects were found. Independent of age, drivers who used the mobile telephone rated their mental demand, their effort, and their frustration level higher than did drivers who did not use the mobile telephone. The mobile telephone users
also rated their performance lower. Furthermore, an interaction effect between age and frustration level was found. Young drivers were more frustrated than elderly drivers, maybe because they put more effort to the performance of the telephone task. At least, the analysis of the performance of the telephone task showed that young drivers performed significantly better than their older colleagues. Despite that, they rated their frustration level higher than the elderly drivers. No effect of age on workload was found.

An important conclusion, that can be drawn from the results, is that drivers do not try to keep a constant level of workload. Instead of reducing the demands from the driving (primary) task in proportion to the demands added from the new (secondary) task, they seem to work harder to cope with the new situation.

The elderly drivers using the mobile telephone was also expected to lower their speed level (partly reduce the demands from the driving task), as a result of the extra workload imposed by the telephone task. The prediction was confirmed, as the elderly drivers lowered their speed level with 9.5 km/h on average, when they performed the telephone task. An advantage of a lower speed is that the stopping distance becomes somewhat shorter. On the other hand, when some drivers (mobile telephone users) lower their speed this may lead to an increased variation in the speed level of the traffic flow, which in turn may have negative consequences for traffic safety. The result for elderly drivers is in agreement with that found for young drivers (Alm and Nilsson, 1990).

An unpredicted result was that the elderly drivers drove somewhat faster than the young drivers. The difference may be a consequence of the driving environment in the simulator. Generally, a large part of speed sensation is said to be due to the "streaming" of the peripheral visual field. Since the driving environment in the simulator is rather poor, the speed sensation during the experiment probably was different from the sensation during real driving. The possibility to use other drivers' speed level as a reference was also eliminated, because the driver was alone on the road. Thus, available cues for speed estimation were restricted to the speedometer, the sound level in the car, and the frequency of road markings. Because the time to accommodate the eyes from infinity to near distance increases with age, it is possible that the elderly drivers had more problems than the young drivers to use the speedometer. The sound level may also have been more difficult to perceive and use as a speed cue, due to age related hearing losses. Taken together these factors may have resulted in a less effective speed control, leading to "speed blindness".

The obtained effects probably have implications for traffic safety, because they may increase the accident risk. As elderly drivers usually are well aware of their reduced capacities, and receptive to procedures and devices that would make them safer and better drivers, it may be worthwhile to inform them about obtained behavioural effects and suggest strategical solutions. For instance, they can use the mobile telephone only when the car is parked. If it is used while driving they can avoid to drive in situations where unexpected events are frequent, and when the traffic intensity is high. In a longer perspective, it may be possible to develop intelligent driver support systems to assist elderly drivers while using the mobile telephone. Already available are "letter-box" and "please wait functions", that can notify the calling person that the driver is there, but that s/he can not speak for the moment due to the traffic situation. The driver have
to activate these functions. More advanced future systems, for lane keeping, speed control, obstacle (danger) detection etc., can be beneficial to compensate for elderly drivers' deteriorating skill and cognitive capacity, given that these systems do not introduce other negative effects. An ideal system shall also have enough knowledge about the traffic situation, to automatically prevent mobile telephone use, in order to avoid extra risks.

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5. REFERENCES


VTI RAPPORT 372A
Dementia and Road Test Performance

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Dementia and Road Test Performance
Linda A. Hunt
Occupational Therapist
Washington University School of Medicine

Introduction
Despite increasing awareness of the problems associated with driving and dementia, there have been very few studies on the actual driving performance of persons with Senile Dementia of the Alzheimer’s Type (SDAT) nor how performance relates to dementia severity. Cross sectional studies are currently being conducted, but presently there is not conclusive data that one international group is more affected than another by SDAT. Hence the incidence rate in the United States of 12% for those age 65 to 85 and 47.2% for those over age 85 may also be characteristic of populations in other countries. Therefore, driving and dementia may be an international concern. The current study examined the driving skills of persons in the questionable and mild stages of dementia using an in-car, on-the-road assessment. This study had 3 goals: 1) to study the difference for in-car, on-the-road driving performance for persons with questionable or mild Alzheimer’s disease compared with healthy elderly controls, 2) to assess whether those with SDAT lack insight into their driving deficits, 3) to compare performance on a pre-driving cognitive assessment with actual in-car, on-the-road driving to determine if there is a relationship between the two for SDAT persons.

Methods
Subjects were recruited from the Washington University Memory and Aging Project. The clinical dementia rating scale (CDR) [1] rates cognitive performance on 6 categories: memory, orientation, judgement, problem solving, community affairs, home management including hobbies, and personal care. A score of 0 = no dementia, .5 = questionable dementia, and 1 = mild dementia (moderate and severe demented subjects were not selected). Thirty-nine subjects were selected based on the following criteria: 1) currently driving, 2) a driving history of at least 10 years, 3) no physical
impairment, 4) a collateral source familiar with their driving history. The subjects with a score of 0 indicating no dementia served as the controls, and were matched with the mild and questionably demented subjects for age, education, gender and driving experience. There were no significant differences on the characteristics across the three groups (Table 1).

The procedures consisted of: 1) a predriving component including the subject’s self-rated assessment of his driving skills and brief clinical tests, 2) a one hour in-car, on-the-road driving trial, 3) a caregiver’s 16-item questionnaire regarding the demented person’s driving ability.

All evaluations were conducted by a single investigator. For the in-car, on-the-road test, an experienced driving instructor was also present.

The self assessment of driving skills included true/false questions about present driving skills and a self rating of driving ability.

The clinical tests were drawn from the occupational therapy clinical assessment battery developed by the Irene Walter Johnson Rehabilitation Institute for the assessment of disabled drivers. These tests were selected to briefly screen cognitive, physical, sensory and visuoperceptual function, and included measures of attention switching, problem solving in common driving situations and traffic sign recognition.

In-car driving skills were assessed during a one hour trial. A car with dual brakes was used. An experienced driving instructor who was unaware of the dementia status of each subject sat in the front passenger seat and provided the subject with the directions to drive a pre-designed route using urban streets and highways. The instructor also attended to safety issues, such as applying the dual brake and handling the steering wheel when necessary. The investigator sat in the back seat.

All subjects drove the identical route. One mildly demented, a CDR 1, subject independently and unexpectedly drove to her
nearby home to "prove" her driving skills to the evaluators by driving in her actual environment. Subjects drove in low volume traffic under good road conditions, the exception occurred when it rained during the test of one subject.

While the subjects were being evaluated, their caregivers completed a questionnaire regarding the subjects' driving ability and their ability to perform activities of daily living. Collateral sources of control subjects, who invariably came alone to the testing site, were asked these questions over the telephone.

Results

The evaluation results showed that all 13 control subjects passed the driving exam. All 12 subjects with questionable dementia passed the driving exam. But 7 out of 14 subjects (50%) with mild dementia did not pass the exam.

Table 2 shows the results of the subjects' self-ratings of driving ability. The "no problem" category was assigned to subjects who indicated no difficulty in driving on all types of roads, during day and night, and in all weather conditions. If they reported limiting their driving either by time of day, road type, mileage, or weather conditions, then they were assigned to the "problem" category.

Three (23%) of the controls recognized problems in their driving performance, stating that they were "fair" drivers and that they limited their driving generally by the time of day and by weather conditions. All questionably demented subjects rated themselves as "good" drivers and did not report restriction of their driving. Two (14%) mildly demented subjects reported that they were "fair" drivers. In general, the demented subjects perception of their driving ability did not correspond to either that of their caregivers nor their actual driving performance (Table 3).

Table 2 also shows that self reported occurrence of getting lost. Again, these reports do not match the caregivers' reports (Table 3).
The road test results showed that: 1) for following directions, impaired subjects required repeated step-by-step directions such that even mildly demented subjects driving with a spouse giving directions was not considered a safe recommendation to prolong driving ability; 2) signaling when changing lanes—the impaired driver needed verbal cues to signal throughout the driving task whereas the unimpaired driver, while forgetting initially, would remember subsequently throughout the task; 3) interpreting traffic signs and lights—two impaired subjects stopped at green lights and one subject stopped at a light to see what other drivers were doing; and 4) judgement was assessed by the subject’s awareness of the driving environment, how their driving impacted others, the occurrence of environmental demands for safety and the subject’s problem-solving abilities. Impaired judgement was noted by subjects coasting to near stop in traffic, drifting into other lanes, sudden stops for no apparent reason, driving while pressing the brake and the accelerator simultaneously, and inability to understand why other drivers honked at them, which may be related to the inability to understand the significance of their actions.

The pre-driving clinical tests that seem to relate to driving ability were:

1) traffic sign and light recognition (Table 6)
2) short term memory
3) attention switching

The traffic sign test substantiated the recommendation to stop driving because the subjects that did not pass the driving test could not identify traffic signs. As the degree of dementia increases, the ability to identify traffic signs seems to decline.

Also, all subjects that did not pass the driving exam did poorly on the attention switching task. Whereas all control and questionably demented subjects passed this test.

In regards to auditory short term memory as the CDR rating increases in severity of dementia, auditory short term memory declines.
Summary

There is little data regarding the incidence of driving problems in persons with SDAT. The 1988 Friedland [2] study compared reports of first degree relatives about the driving performance of 30 patients with dementia of the Alzheimer type (DAT) and 20 healthy age matched control subjects. Forty seven percent of the DAT patients incurred at least one crash, whereas only 10% of the controls had had a crash in the previous 5 years. The occurrence of crashes was not significantly correlated with dementia severity or disease duration. Similar findings were reported by the Lucas-Blaustein study [3] also in 1988 based on a questionnaire given to caregivers of 72 dementia patients. 30% of the patients had at least one automobile accident since the onset of symptoms of dementia. Both of these studies concluded that the actual diagnosis of the disease is sufficient to withdraw the driver’s license privileges. However, an editorial by Drachman [4] argues rather than basing the right to drive only on a diagnosis that instead an evaluation of those functions necessary for competent driving must first be determined. Drachman states that the limitation of driving privileges should be based on demonstration of impaired driving competence rather than a stigmatizing label, such as Alzheimer’s disease.

Conclusions were as follows: 1) 50% of those with mild dementia did not pass the driving assessment while all of the controls and all of the questionably demented subjects passed the test; 2) SDAT subjects are less likely to report driving ability problems than control subjects and hence, in-car, on-the-road assessment may be essential in determining driving fitness; 3) caregivers are not always reliable in monitoring driving fitness; 4) driving ability in SDAT may be stage-dependent with mild SDAT subjects worse than questionably impaired subjects. Hence recommended public policy should incorporate measures of dementia severity rather than using the diagnosis of SDAT alone inasmuch as some persons with mild dementia still demonstrate driving fitness; 5) the issue of dementia progression mandates that retesting be a component of public policy; and 6) although sample sizes were limited, this study found that a predriving test of traffic
sign recognition, auditory memory ability and attention switching correlated with in-car, on-the-road performance. Therefore, tests of this nature for the SDAT population merit further study as a predictive measure of driving performance.

References


### TABLE 1
Demographic Characteristics of Subjects

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control (N=13)</th>
<th>Questionable (N=12)</th>
<th>Mild (N=14)</th>
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<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
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<tr>
<td>Male/female</td>
<td>6/7</td>
<td>3/9</td>
<td>9/5</td>
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<tr>
<td>Mean age in years (+ SD)</td>
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<tr>
<td>Mean years of driving (+ SD)</td>
<td>47.7±11.4</td>
<td>52.6±12.1</td>
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TABLE 2
Self-Rated Driving Problems Shown by Group

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<tr>
<td>Self-rated driving ability</td>
<td>%</td>
<td>%</td>
<td>%</td>
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<tr>
<td>No problem</td>
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<td>Problems</td>
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<tr>
<td>Intersection bothered me</td>
<td>%</td>
<td>%</td>
<td>%</td>
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<td>No problem</td>
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<td>Problem</td>
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<tr>
<td>My reactions to dangerous situations are slower than they used to be</td>
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<td>%</td>
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<td>My thoughts wander when I drive</td>
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<tr>
<td>No</td>
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<td>Yes</td>
<td>31</td>
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<tr>
<td>Traffic situations make me angry</td>
<td>%</td>
<td>%</td>
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<td>No</td>
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<td>I've gotten lost while driving</td>
<td>%</td>
<td>%</td>
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<td>My family is concerned about my driving</td>
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+p< .05 by X² analysis across Dementia Groups
### TABLE 3
Caregivers' Survey of SDAT Driving Performance Shown by Group

<table>
<thead>
<tr>
<th>Question</th>
<th>Control (N=13)</th>
<th>Questionable (N=12)</th>
<th>Mild (N=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% E</td>
<td>% E</td>
<td>% E</td>
<td></td>
</tr>
<tr>
<td>Is subject now a safe driver?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>92</td>
<td>83</td>
<td>50+</td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>Are you concerned about the subject's driving ability?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td>25</td>
<td>71++</td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>75</td>
<td>29</td>
</tr>
<tr>
<td>Does the subject get lost on familiar routes?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>17</td>
<td>8</td>
<td>71++</td>
</tr>
<tr>
<td>No</td>
<td>83</td>
<td>92</td>
<td>29</td>
</tr>
<tr>
<td>Is subject easily distracted while driving?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>83</td>
<td>86</td>
</tr>
<tr>
<td>Does subject become frustrated or angry while driving?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td>17</td>
<td>36</td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>83</td>
<td>64</td>
</tr>
<tr>
<td>Is subject slower in reacting to driving situations?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>25</td>
<td>33</td>
<td>79++</td>
</tr>
<tr>
<td>No</td>
<td>75</td>
<td>67</td>
<td>21</td>
</tr>
<tr>
<td>Does subject finds it difficult to join traffic?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td>8</td>
<td>64++</td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>92</td>
<td>36</td>
</tr>
</tbody>
</table>

+<.05 by X² analysis across Dementia Groups
++<.01 by X² analysis across Dementia Groups
### TABLE 4

Driving Performance Differences Between Controls and Subjects with Questionable and Mild SDAT

<table>
<thead>
<tr>
<th>Driving Behaviors</th>
<th>Group</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control (N=13)</td>
<td>Questionable (N=12)</td>
<td>Mild (N=14)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Distracted by talking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>100</td>
<td>100</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Distracted by environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>100</td>
<td>100</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Acted impulsively</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>100</td>
<td>100</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Follows directions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>100</td>
<td>100</td>
<td>36*</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Upset other drivers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>83</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td>17</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Disagreed with instructor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>100</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Poor judgment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>100</td>
<td>50*</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td></td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

*p<.01 by X² analysis across Dementia Groups
### TABLE 5
Driving Performance Differences Between Controls and Subjects with Questionable and Mild SDAT

<table>
<thead>
<tr>
<th>Driving Skills</th>
<th>Control (N=13)</th>
<th>Questionable (N=12)</th>
<th>Mild (N=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signals when changing lanes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>54</td>
<td>36</td>
<td>52</td>
</tr>
<tr>
<td>Yes</td>
<td>15</td>
<td>33</td>
<td>71**</td>
</tr>
<tr>
<td>Signals too late</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>85</td>
<td>83</td>
<td>50**</td>
</tr>
<tr>
<td>Yes</td>
<td>15</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>Interprets traffic lights and signs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>23</td>
<td>100</td>
<td>38</td>
</tr>
<tr>
<td>Yes</td>
<td>77</td>
<td>25</td>
<td>38</td>
</tr>
<tr>
<td>Ignores signs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>92</td>
<td>75</td>
<td>64</td>
</tr>
<tr>
<td>Yes</td>
<td>8</td>
<td>25</td>
<td>36</td>
</tr>
<tr>
<td>Stays in appropriate lane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td>Yes</td>
<td>92</td>
<td>83</td>
<td>79</td>
</tr>
<tr>
<td>Maintains speed while changing lanes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>23</td>
<td>17</td>
<td>43</td>
</tr>
<tr>
<td>Yes</td>
<td>77</td>
<td>83</td>
<td>57</td>
</tr>
<tr>
<td>Maintains speed in general</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>17</td>
<td>43</td>
</tr>
<tr>
<td>Yes</td>
<td>92</td>
<td>83</td>
<td>57</td>
</tr>
<tr>
<td>Checks blind spot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>8</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>Yes</td>
<td>92</td>
<td>75</td>
<td>57</td>
</tr>
<tr>
<td>Cuts in front of cars</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>85</td>
<td>75</td>
<td>71</td>
</tr>
<tr>
<td>Yes</td>
<td>15</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>Parallel Parking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>8^</td>
<td>100^</td>
<td>70^**</td>
</tr>
<tr>
<td>Yes</td>
<td>92^</td>
<td>90^</td>
<td>30^**</td>
</tr>
<tr>
<td>Back up 100 feet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>100^</td>
<td>20^</td>
<td>40^**</td>
</tr>
<tr>
<td>Yes</td>
<td>80^</td>
<td>60^</td>
<td>60^**</td>
</tr>
<tr>
<td>Instructor Hit Brake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>85</td>
<td>75</td>
<td>43^*</td>
</tr>
<tr>
<td>Yes</td>
<td>15</td>
<td>25</td>
<td>57</td>
</tr>
<tr>
<td>Instructor took wheel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>86</td>
<td>67</td>
<td>57</td>
</tr>
<tr>
<td>Yes</td>
<td>15</td>
<td>33</td>
<td>43</td>
</tr>
<tr>
<td>Driving recommendation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continue Driving</td>
<td>100</td>
<td>100</td>
<td>50^**</td>
</tr>
<tr>
<td>Stop Driving</td>
<td></td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

*p<.05 by $X^2$ analysis across Dementia Groups

**p<.01 by $X^2$ analysis across Dementia Groups

^1 subject was not tested

^^3 subjects were not tested
TABLE 6
Traffic Sign and Traffic Light Recognition Among Subject Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Control (N=13)</th>
<th>Questionable (N=12)</th>
<th>Mild (N=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Traffic Signs for meaning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Right Turn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>100</td>
<td>100</td>
<td>50*</td>
</tr>
<tr>
<td>Impaired</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>No Left Turn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>100</td>
<td>100</td>
<td>57*</td>
</tr>
<tr>
<td>Impaired</td>
<td></td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>No U Turn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>100</td>
<td>100</td>
<td>36*</td>
</tr>
<tr>
<td>Impaired</td>
<td></td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>Merging Traffic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>92</td>
<td>75</td>
<td>36*</td>
</tr>
<tr>
<td>Impaired</td>
<td>8</td>
<td>25</td>
<td>64</td>
</tr>
<tr>
<td>Traffic Lights for meaning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Impaired</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>100</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>Impaired</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not impaired</td>
<td>100</td>
<td>100</td>
<td>86</td>
</tr>
<tr>
<td>Impaired</td>
<td></td>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

*p<.01 by X^2 analysis between groups
Predicting Accident Frequency from Older Driver Capabilities: 
Developing a Testable Model

Cynthia Owsley
PhD, Associate Professor of Ophthalmology
School of Medicine/Eye Foundation Hospital
University of Alabama at Birmingham
USA

Also published as:
Visual/cognitive correlates of vehicle accidents in older drivers
Psychology and Aging 6: 403-415

and

Ball K, Owsley C (1991)
Identifying correlates of accident involvement for the older driver
Human Factors 33: 583-595
Predicting Accident Frequency from Older Driver Capabilities: Developing a Testable Model

Cynthia Owsley, Ph.D., Associate Professor of Ophthalmology, School of Medicine/Eye Foundation Hospital, University of Alabama at Birmingham, Birmingham, AL 35294.

In Symposium on "Visual and Cognitive Capabilities in Older Drivers: Predicting Accident Risk".

Over the past two years we have been developing a testable model of how vision and cognitive problems relate to crash frequency in older drivers. This model is based on the idea that visual sensory tests alone are most likely insufficient for identifying older drivers who are at risk for vehicle crashes. A more comprehensive approach to predicting crash involvement is to assess a number of different aspects of vision and visual information processing. Two studies performed in our laboratory have led to the development of a model which includes several components: eye health of the driver (e.g., presence of ophthalmic disease; visual sensory function (e.g., acuity, visual field sensitivity, contrast sensitivity); visual attention; and cognitive status (e.g., memory, comprehension). The outcome measure in the model is accident frequency. We will discuss how this model was developed and how it will be further evaluated, and will also consider alternative measures of driving performance such as performance in a simulator or road test, and how they might be incorporated into the model.
Visual Function and Eye Health: Their Relationship to Older Driver Problems

Michael E Sloane
Associate Professor of Psychology
University of Alabama at Birmingham
USA

Also published as:
Visual/cognitive correlates of vehicle accidents in older drivers
Psychology and Aging 6: 403-415
Visual Function and Eye Health: Their Relationship to Older Driver Problems

Michael E. Sloane, Associate Professor of Psychology, University of Alabama at Birmingham, Birmingham, AL 35294.

In Symposium on "Visual and Cognitive Capabilities in Older Drivers: Predicting Accident Risk".

This presentation will focus on how eye health variables and visual sensory function relate to crash frequency in older drivers. Driving is a highly visual task, and thus it might be expected that the higher incidence of visual problems and eye disease in the elderly is a primary cause of their driving difficulty. Despite the intuition that vision and driving ability should be related, earlier studies have found only weak correlations between visual deficits and vehicle crashes. In two recent studies we have taken a renewed look at predicting crash frequency in older drivers, by combining assessments of eye health/visual sensory function with the assessment of visual attention and cognitive status. Our studies indicate that: (1) Eye health and visual sensory status are not strongly predictive of crash frequency, agreeing with earlier studies. However, these variables are strongly related to visual attentional skills which is the strongest correlate to crash frequency. (2) Visual field sensitivity, which is a measure of the integrity of sensory processing throughout the visual field, is crucial for following events in peripheral vision. However, an older driver can have excellent visual field sensitivity, yet still have difficulty using information in peripheral vision, because of a visual attentional problem. (3) Simply being made aware by an eye-care specialist that one has an ocular disease that affects vision was associated with older adults avoiding challenging driving situations (e.g., heavy traffic). These results will be discussed within the context of the model described in Dr. Owsley's presentation.
Attentional and Cognitive Factors in Predicting Older Driver Problems

Karlene Ball
Ph D, Professor of Psychology
Western Kentucky University
USA

Also published as:
Visual/cognitive correlates of vehicle accidents in older drivers
Psychology and Aging 6: 403-415

and

Ball K, Owsley C (1991)
Identifying correlates of accident involvement for the older driver
Human Factors 33: 583-595
Attentional and Cognitive Factors in Predicting Older Driver Problems

Karlene Ball, Ph.D., Professor of Psychology, Western Kentucky University, Bowling Green, KY 42101.

In Symposium on "Visual and Cognitive Capabilities in Older Drivers: Predicting Accident Risks."

This presentation will further expand on research results from a study aimed at identifying the factors which place some older drivers at risk for crash involvement. Specifically, attentional and cognitive factors will be discussed within the context of the model presented by Dr. Owsley. By assessing a large sample of older drivers at several levels in the visual information processing system, we have identified a test of visual attention, the useful field of view, that has both high sensitivity (89%) and specificity (85%) in predicting which older drivers have crash problems. The useful field of view test measures the spatial area within which an individual can be rapidly alerted to visual stimuli. Restrictions in the useful field of view can co-occur with normal visual field sensitivity, normal acuity, and normal contrast sensitivity suggesting that the field reduction is frequently not due to a visual dysfunction. Recent work has indicated that shrinkage in the field is based rather on three other problems: slowing in the processing of visual information; an increased susceptibility to visual distractors; and difficulty with dividing attention. By adopting a criterion cutoff in the continuous function between accident frequency and UFOV restriction, we were able to compute an odds ratio which indicated that older adults with a greater degree of shrinkage in the useful field of view were six times more likely to have had one or more accidents in the previous five year period than those with a lesser reduction. With respect to the model, we noted that eye health, central and peripheral vision, and mental status were more highly related to UFOV than to crash frequency per se. We thus hypothesized that visual attention may serve as a mediating variable between these other variables and accident frequency. This finding will be explained more fully as it relates to the relationships between cognitive status variables, as assessed by the Mattis Organic Mental Status Syndrome Examination (MOMSSE) and the useful field of view. In this case again, while poor mental status and useful field of view are moderately related, restrictions in the useful field of view can co-occur with normal mental status as well as poor. These results have interesting implications with respect to licensing restrictions and Alzheimer's disease.
Attention and Driving Performance in Alzheimer's Dementia

Raja Parasuraman
Department of Psychology
The Catholic University of America
U S A
Attention and Driving Performance in Alzheimer's Dementia

RAJA PARASURAMAN
Department of Psychology, The Catholic University of America, Washington DC

With the aging of the adult population, the number of drivers aged 60 and over has risen markedly throughout the world. A proportion of these older drivers may suffer from Alzheimer's disease (AD), from other progressive degenerative dementias, or from undetected, "incipient" dementia. A growing public health issue has arisen due to concerns about the motor-vehicle accident risk posed by drivers with dementia. Assessment of this risk requires a better understanding of how the specific perceptual and cognitive deficits caused by AD contribute to impaired driving performance in this population. We demonstrate the need for systematic investigations of attentional skills in relation to driving performance in older drivers with and without dementia. Such investigations should focus on normal older adults and persons in the mild, early stages of dementia, because the latter are the most likely among the dementia population to be still driving. Evidence from a variety of diverse empirical studies is presented to indicate that: (1) Motor-vehicle accident rates per mile are higher in drivers with dementia than in normal older drivers. (2) Accident rates in normal young and older drivers are related to performance on information-processing measures of different components of attention. (3) This relationship is greatest for measures of the switching of selective attention, and less so for divided and sustained attention (vigilance). (4) Many of these same attentional functions, and particularly the switching of visual selective attention, are impaired in the early stages of Alzheimer's dementia and thus may contribute to increased accident risk. Further studies of cognitive and driving performance in older drivers are necessary to establish that the attentional impairments found in mild DAT contribute to increased accident risk. Implications of these findings for driver assessment, education, and training are discussed.
Attention and Driving Performance in Alzheimer's Dementia

RAJA PARASURAMAN
Department of Psychology, The Catholic University of America, Washington DC

ABSTRACT

With the aging of the adult population, the number of drivers aged 60 and over has risen markedly throughout the world. A proportion of these older drivers may suffer from Alzheimer's disease (AD), from other progressive degenerative dementias, or from undetected, "incipient" dementia. A growing public health issue has arisen due to concerns about the motor-vehicle accident risk posed by drivers with dementia. Assessment of this risk requires a better understanding of how the specific perceptual and cognitive deficits caused by AD contribute to impaired driving performance in this population. We demonstrate the need for systematic investigations of attentional skills in relation to driving performance in older drivers with and without dementia. Such investigations should focus on normal older adults and persons in the mild, early stages of dementia, because the latter are the most likely among the dementia population to be still driving. Evidence from a variety of diverse empirical studies is presented to indicate that: (1) Motor-vehicle accident rates per mile are higher in drivers with dementia than in normal older drivers. (2) Accident rates in normal young and older drivers are related to performance on information-processing measures of different components of attention. (3) This relationship is greatest for measures of the switching of selective attention. (4) Many of these same attentional functions, and particularly the switching of visual selective attention, are impaired in the early stages of Alzheimer's dementia and thus may contribute to increased accident risk. Further studies of cognitive and driving performance in older drivers are necessary to establish that the attentional impairments found in mild DAT contribute to increased accident risk. Implications of these findings for driver assessment, education, and training are discussed.

INTRODUCTION

A growing public health issue has arisen due to concerns about the motor-vehicle accident risk posed by drivers with dementia. Alzheimer's disease (AD), the leading cause of dementia, is variously estimated to affect, at a conservative estimate, between 1.5 and 2.5 million persons in the U.S. (Office of Technology Assessment, 1988). Many more individuals may be affected but go undiagnosed. The early diagnosis of dementia of the Alzheimer type (DAT) is difficult to make because age-related cognitive decline cannot be easily distinguished from incipient or very mild dementia (Storandt and Hill, 1989). As a result, many persons in the early stages of the disease may not be seen by physicians.

Dementia clearly poses a serious public health problem, one that will become worse as the dementia population grows into the millions. What proportion of these persons drive? Furthermore, how many continue to drive once they receive a diagnosis of dementia? Unfortunately, accurate, nationwide statistics are not available on the proportion of drivers with dementing illnesses, and among those drivers with DAT, whether DAT is a factor in accident causation. The progressive nature of Alzheimer's disease is such that in time all persons with DAT become incapable of driving safely and eventually stop driving. But many may continue to drive after they are initially diagnosed. Two recent studies reported that the majority of DAT patients continue to drive for up to four years following their diagnosis (Friedland et al., 1988; Lucas-Blaustein et al., 1988). The experience of dementia clinics also tends to be that some affected individuals continue to drive even when their impairment is moderate to severe.

Persons diagnosed with DAT have a variety of abnormalities in memory, attention, visuospatial skills, decision making, and other cognitive functions (McKhann et al., 1984; Rosen & Mohs, 1982). Many of these functions, and particularly attention and decision making, are also important for safe driving performance (McKenna, 1982; Panek et al., 1977). As reviewed in this paper, several studies have found that information-processing measures of selective attention are related to safety during driving (Kahneman et al., 1973). Recent information-processing studies, also reviewed in this paper, indicate that impairments in different attentional functions occur very early in the course of Alzheimer's dementia (e.g., Parasuraman and Nestor, 1986). Therefore, there is a strong need to examine attention in relation to driving in DAT. A theoretical and empirical rationale is presented for examining attentional skills in DAT and their relation to driving performance and accident risk. Although several aspects of attention are important, it is argued that selective attention, and the ability to shift selective attention, are critically related to accident risk, particularly in older drivers. These same
attentional functions, and notably the switching of visual selective attention, decline in efficiency in the early stages of DAT and hence may contribute to reduced and/or impaired driving performance in individuals with DAT.

ATTENTIONAL SKILLS AND DRIVING PERFORMANCE

Cognitive studies suggest that at least three forms of attention should be distinguished—selective, divided, and sustained attention (Parasuraman and Davies, 1984; Posner and Boies, 1971). Selective attention involves the focusing and shifting of attention between stimulus locations, features, or categories. Divided attention refers to the need to monitor two or more stimulus sources simultaneously, or more generally, the combination of any two tasks that have to be performed simultaneously, so-called dual tasks. Finally, sustained attention refers to the ability to maintain vigilance for an infrequent, unpredictable event over a prolonged period of time.

Each of these attentional functions may form an important component of driving skill. Analyses of accident reports that are attributed to "driver inattention" suggest that many types of attention failure may be involved in motor-vehicle accidents (Shinar, 1978; Sussman et al., 1982). The bulk of the research has examined selective attention, with fewer studies on divided and sustained attention. The present paper reviews studies of selective attention. For a broader review, see Parasuraman and Nestor (1991).

SELECTIVE ATTENTION AND DRIVING

Driving involves continuous monitoring of the outside environment and of the internal controls and status of the automobile. As such it is a task requiring both a focusing of attention (and conversely, freedom from distraction) as well as efficient switching of attention to task-relevant sources of information. There are some plausible a priori grounds for supposing that differences in the skill of focusing and switching attention might be related to driving performance.

A number of studies have examined the correlation between laboratory-based measures of the efficiency of focusing and switching attention, generally using dichotic-listening tasks, and real-world driving performance, typically accident rate (Table 1). Kahneman, Ben-Ishai, and Lotan (1973) reported the first such study, following a related earlier study examining pilots undergoing flight training (Gopher and Kahneman, 1971). In both studies a dichotic listening test was used in which words and digits were presented to each ear simultaneously. Subjects were required to focus attention on one ear and report digit targets occurring in that ear only. In a
<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Age</th>
<th>Driving index</th>
<th>Sampling period (years)</th>
<th>Attention task</th>
<th>Performance measure</th>
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<td>117</td>
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<td>Omissions</td>
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<td>SAT (V) ¹</td>
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<td>index</td>
<td></td>
<td>SAT (V)</td>
<td>Switching errors</td>
<td>-0.09</td>
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</table>

¹ Dichotic Listening Test (Auditory); ² Includes severity of accident; ³ NS=not significant, S=significant, correlation coefficients not given; ⁴ Selective Attention Test (Visual), an analogue of the DLT (A); ⁵ Driving index was positively related to driving competency, hence a negative r between the index and errors on the SAT(V) is expected.

* p < .05  
** p < .01  
*** p < .001
second condition they were required to switch attention from one ear to the other upon receiving a
cue. This test assesses three types of error in selective attention: omissions of targets from the
relevant channel (failure of focused attention); intrusions (false target reports) from the irrelevant
channel (distraction); and errors in shifting attention from one channel to the other (attention
switching failure). Kahneman et al. (1973) administered the test to 117 professional bus drivers
aged 22-32 years. The numbers of omissions and intrusions in the focused-attention part of the
test correlated 0.29 and 0.31, respectively, with vehicle accident rate over a one-year period, while
the correlation between the number of errors in the switching part of the test and accident rate
was 0.37.

Subsequent studies have, with one exception, replicated this basic finding of a moderate
correlation between selective attention performance and accident rate or driving performance.
Table 1 gives the results of these studies and shows that with the exception of the McKenna et al.
(1986) study, significant correlations in the range of 0.3 to 0.4 were obtained for at least one
measure of selective attention. Four additional aspects of these studies deserve comment.

Attention or General Intelligence? First, the relation between selective attention and
accident rate is not a function of general intellectual functioning. Using a dichotic listening task,
Gopher and Kahneman (1971) found a correlation of 0.2 between intelligence test scores and
flight training success of Air Force pilots, a value lower than the correlations for the selective
attention measures but nevertheless significant. However, in a subsequent large sample (N=2000)
study Gopher (1982) found that the abilities required by the dichotic listening test were not
tapped by tests of general intelligence. Moreover, the attention measures enhanced the predictive
value of the test battery used for pilot selection. Furthermore, in a study conducted in our
laboratory in which young and older drivers were compared, correlations of accident rate and
WAIS-IQ were small and nonsignificant. Kahneman et al. (1973) also reported that "the validity of
the selective attention test was not due to differences in intelligence; the short intelligence test
(Raven's matrices) did not discriminate significantly between criterion groups, and its correlation
with the attention test was low" (page 115).

Attention Switching. An important feature of the selective attention/driving studies is that
the largest correlations were obtained for the "switching" measure of selective attention. This was
originally noted by Kahneman et al. (1973), who suggested that the ability to reorient attention to
another channel from a prior state of attention is more difficult than the initial adoption of a
focused attention state. Posner, Walker, Friedrich, and Rafal (1984) have more recently referred
to these attentional operations as the disengagement and engagement of attention, respectively. It
is therefore of interest to note that recent studies from our laboratory have shown that both mild (Greenwood, Parasuraman, and Haxby, 1989) and moderate DAT patients (Greenwood, Parasuraman, and Haxby, 1991) are particularly impaired in the ability to disengage or reorient attention, although their ability to focus attention is not markedly impaired.

Relation to other Selective Attention Skills. Recently some visual selective attention measures have been linked to motor vehicle accident risk (Ball et al., 1990; Owsley et al., 1991). It is not clear whether these measures are closely related to the measures used in the selective attention studies shown in Table 1. Both auditory and visual selective attention tasks were used in these studies, with broadly similar results. This suggests that the relationship between selective attention and accident rate applies generally across sensory modalities. However, while processing of auditory information is necessary while driving, visual processing requirements tend to dominate (e.g., particularly at intersections, where most accidents involving older drivers occur), so that one could argue that primarily visual attention skills contribute to safe driving performance. A selective attention measure known as the "useful field of view" (UFOV) has been related to accident risk in older drivers (Ball et al., 1990; Owsley et al., 1991). The UFOV measures the effective visual field for efficient localization or identification of peripheral targets while subjects are engaged in a "same-different" discrimination task presented at the center of the display. Targets are presented briefly to prevent saccadic eye movements to the periphery. Owsley et al. (1991) reported a correlation of .36 between the UFOV measure and state-recorded accidents in a sample of 53 older drivers.

Age. A fourth aspect of the results of the attention and driving studies listed in Table 1 is that higher correlations were generally found in studies in which the subjects included older drivers. McKenna et al. (1986) suggested that if attentional performance declines with age then the correlation between attention and accident rate could be spurious if the age range of subjects is very wide (see also Salthouse, 1985). An alternative hypothesis is simply that attentional performance is more predictive of driving performance in older than in younger subjects. For example, in a study in our laboratory moderately high correlations were found between selective attention (dichotic listening) and self-reported accident rate in a sample of 65-75 year old adults, with the highest correlation being obtained for the switching measure. In contrast, the correlations for a younger group aged 30-45 years were smaller.

Summary. Selective attention, as evaluated in information-processing paradigms, is related to the accident rate of drivers. Correlations between both visual and auditory selective attention measures and accident rate have been reported. The most reliable association occur for
attention-switching measures and the strength of the association appears stronger in older than in younger drivers.

ATTENTION AND DRIVING IN ALZHEIMER'S DEMENTIA

A variety of perceptual and cognitive abilities are relevant to driving performance. Moreover, DAT is associated with deficits in some of the same cognitive functions. However, a number of other factors must also be taken into account in attempting to understand how cognitive impairment affects the driving performance of demented drivers. First, DAT is not associated with a unitary cognitive profile; several distinct patterns of cognitive deficit have been identified (Becker et al., 1988; Martin et al., 1986). Moreover, the duration of DAT varies greatly and the factors that influence the rate at which the disease progresses are not well known (Corkin, 1982).

Driving performance in DAT should thus be examined within the context of a disease marked by both variable rate of cognitive deterioration and a heterogeneous pattern of cognitive symptoms. In the very early stages of the disease, cognitive changes, though present, are often not measurably different from those in normal older adults. Thus at this point in the development of Alzheimer's disease, some cognitive abilities related to driving may be relatively intact. Similarly, driving abilities may not be substantially compromised in persons with mild DAT whose initial symptoms are primarily language related (Kirshner et al., 1984). Likewise, for mild DAT patients with well-developed premorbid cognitive abilities, scores on standardized tests of memory and other cognitive functions may still fall well within normal range, even though they may represent a significant decline for a given individual (Grady et al., 1988; Martin et al., 1986). These persons would also appear to have sufficiently preserved cognitive abilities to continue driving.

Studies using standard clinical neuropsychological tests that tap aspects of selective attention, such as the Trail Making and Stroop Tests, have found that these tests are sensitive to the mild, early stages of dementia. Grady et al. (1988) carried out a longitudinal analysis of neuropsychological functioning in DAT and found that impairments on these tests often represent the first nonmnestic cognitive impairment in mild DAT. Based on these findings, Grady et al. concluded that a general deficit of attentional capacity characterizes the early stages of DAT. More recently, Grady et al. (1989) used monaural and dichotic listening tasks to investigate selective attention processes in persons with mild and moderate dementia. They found that DAT subjects did poorly on both the monaural and dichotic tasks relative to age-matched controls, but did significantly worse on the dichotic task, presumably because of difficulties with selecting a target in the presence of distractors.
Two important aspects of these studies should be noted. First, many of the DAT subjects in these investigations were in the early stages of the disease with most intellectual abilities retained at average to above average levels. Although no driving statistics were given for these subjects, many were probably still driving automobiles at the time of testing. Second, these studies do not elucidate the specific selective mechanisms that are impaired in mild DAT; it is not clear, for example, whether impaired performance is related to problems in attentional switching, to attentional focusing, or both. Nevertheless, the results of Grady et al. (1989) indicate that persons with mild to moderate DAT show impairments on a dichotic listening task similar to the one that has been shown to be related to accident risk during driving, particularly in the older driver.

The driving studies reviewed earlier suggest that the switching/shifting operation of selective attention, rather than selective attention per se, may be most predictive of accident risk, particularly in older drivers. Cue-driven shifts of attention (such as in the switching condition of the dichotic listening test) have also been examined in simpler visual tests of attention that are appropriate for use with dementia patients. People normally select visual information by making overt eye and head movements towards a stimulus source at a particular spatial location. Hence an eye movement also generally (but not always) represents a shift of attention. However, it has been shown that information from a non-fixated location can be selected and responded to without overt eye movements to that location. Such covert attention shifts facilitate the processing of stimuli at attended locations (in terms of RT or accuracy) compared to unattended locations (Eriksen and Hoffman, 1972; Posner, 1980). Posner et al. (1984) provided evidence from brain-damaged patients indicating that the posterior parietal lobe plays an important role in covert attention, particularly in the disengagement of attention from a spatial location. Abnormalities in the posterior parietal lobe are also observed in persons with DAT (Haxby et al., 1985).

In order to investigate whether covert attention shifts are impaired in early DAT, Greenwood et al. (1989) used a task in which letter targets were presented to the left or right of a central fixation point. Subjects were required to respond to the occurrence of a single letter (detection task) or decide whether the presented letter was a vowel or consonant (discrimination task). A location cue (a central arrow) preceded the presentation of each letter (by a variable interval). On 62.5% of the trials, the cue was "valid" and correctly pointed to the location of the subsequent target, while on 18.75% of the trials the cue pointed to the wrong location and thus was "invalid." On the remaining 18.75% of trials, the cue pointed to both locations and thus was characterized as "neutral." Both DAT subjects and age-matched controls were faster to respond
to the target when a valid cue was presented than when the cue was neutral or invalid, suggesting that the ability to focus attention on the target was not substantially compromised in DAT. However, compared to age-matched controls, DAT subjects showed markedly increased RT to targets for invalid cues. The magnitude of this increase was also greater for the discrimination task than for the detection task. Posner et al. (1984) have shown that the costs associated with invalid cues primarily reflect the operation of disengagement or reorienting of attention. The results of this study therefore indicate a deficit in the ability to disengage attention in older persons with DAT. Moreover, RT costs were correlated with metabolic hypometabolism in the right hemisphere parietal lobe (as measured by positron emission tomography), which has been linked to the shifting of visuospatial attention (Posner et al., 1984). These results were confirmed in a later study in which both mild and moderately demented patients were tested (Greenwood et al., 1991).

These results have several implications for driving performance in mild DAT. First, the operation of disengagement of attention as measured in the cue-directed paradigm is similar to the measure of switching/shifting attention in the dichotic listening task. DAT patients in the early stages of the disease have difficulties with shifting, disengaging, or switching attention; these very same attentional operations have been shown to play a role in safe driving. Second, DAT patients have difficulties with switching attention even though their ability to engage and focus attention remains relatively intact (at least for the simple visual stimuli that been have studied thus far). Third, the disengagement operation is necessary for unexpected events (invalid cues) that occur within the visual modality -- conditions which a driver is likely to face.

RELATION OF ATTENTION TO DRIVING PERFORMANCE IN DAT

The studies discussed thus far have demonstrated that: (1) selective attention (and in particular, the shifting of selective attention and the UFOV measure of visual selective attention) is related to accident risk during driving; (2) the shifting of selective attention is impaired in efficiency in the early stages of DAT; and (3) other aspects of attention, for example divided and sustained attention, while impaired in DAT, have not been reliably related to driving performance or accident risk. Pursuing the logic of results (1) and (2) would lead to the conclusion that impairments in selective attention in persons with DAT contribute to increased accident risk among drivers with DAT. However, that conclusion cannot yet be reached firmly because no study has directly examined both selective attention and driving performance in the same group of DAT subjects. Moreover, before such a relationship can be established, more needs to be known of
the actual driving performance of persons with DAT. To date the literature consists of one study carried out in the 1960s (J. A. Waller, 1967) and a few very recent studies (Coyne et al., 1990; Friedland et al., 1988; Kaszniak, Nussbaum, and Allender, 1990; Lucas-Blaustein et al., 1988). Although characterized by some methodological problems, the studies generally point to increased risk of motor vehicle crashes for older drivers with Alzheimer's disease and other dementias.

J. A. Waller (1967) reported that whereas there was no statistical difference in accident rate (adjusted for mileage driven) between drivers over 60 and drivers aged 30-59 years, the accident rate was twice as high in persons with dementia (of unspecified type), and four times as high in persons with combined dementia and cardiovascular disease. This study was conducted at a time when the diagnosis of Alzheimer's disease was not frequently made, and the diagnostic category Waller used for dementia ("senility") was imprecise and vaguely defined. Nevertheless, it is likely that the subject sample tested included many individuals with DAT. Furthermore, this pioneering study has two positive features not shared by subsequent studies. First, Waller used a relatively large sample (two to three times that of later studies), randomly selected from a retirement community in California. Second, he made use of objective accident statistics (DMV reports) as opposed to caregiver reports of accidents, as used in subsequent studies.

**IMPLICATIONS FOR DRIVER LICENSING AND TRAINING**

Older drivers with dementia are involved in more accidents than healthy older drivers. Should a diagnosis of dementia (DAT or other type), therefore, lead to a revocation of a driver's license? Friedland et al. (1988) proposed that it should, given that drivers with DAT are involved in more accidents per mile driven than normal older adults. In our view, however, renewal of licensing should be based on criteria related to driving competence (Drachman, 1988; P. F. Waller, 1988), rather than solely on chronological age or a medical diagnosis. If diagnosis of disease was used as a sole criterion, many older drivers with other medical conditions would also have to be excluded, because increased accident rates have also been reported for older drivers with cardiovascular disease (J. A. Waller, 1965) and Parkinson's disease (Dubinsky et al., 1991).

Licensing procedures have changed little since the early 1950s. Currently, they consist of a short assessment of knowledge of traffic regulations and basic driving skills, and cursory evaluations of static visual acuity. None of these procedures (even with a road test) adequately evaluate the attentional factors discussed in this paper that have been found to be important for safe driving. The recent National Research Council (1988b) report on transportation needs of older
persons recommended further research in developing skill-based tests that are predictive of accident involvement. There is also a growing need for improving renewal licensing procedures to cope with the increased number of older drivers and drivers with dementia. In fact, however, some state regulators may be moving in the opposite direction by allowing longer renewal periods and experimenting with mail-in renewals (P. F. Waller, 1988). Nevertheless, at least one state, California, now requires physicians to report diagnoses of dementing illness to the DMV so that driving competence can be assessed. The problem remains, however, of the limited validity of existing competency procedures for predicting accident risk.

As the studies reviewed in this paper reveal, there is good evidence that a skill test that predicts accident involvement in older drivers should incorporate attentional measures. The measures that appear promising to date are the UFOV measure and measures of attention shifting based on dichotic listening and related tests. There is also evidence that attention shifting measures are diagnostic of attention impairment in the early stages of Alzheimer-type dementia (Greenwood et al., 1989). Further research is needed to determine whether these two aspects of attention are the only components of attention related to driving, or whether other attentional skills, such as sustained and divided attention, also need to be assessed. Additional work is also needed to refine the selective attention tests for ease of use in the clinical setting.

While these attention measures account for only some of the variance contributing to accident involvement, they may allow for better predictive capability when combined with measures of other skills involved in driving. Gopher (1982) carried out a large-scale (N = 2000) study of the effectiveness of selective attention and other measures in predicting success in flight training among pilots. He found that prediction of successful completion of training was bolstered when traditional psychometric measures were combined with the same selective-attention task used in the driving studies. A comparable prospective study is needed to establish whether similar predictive efficiency can be obtained for driving performance, particularly with older drivers.

Driver training programs can complement driver testing procedures in serving the dual requirement for reducing accident risk among drivers with dementia while continuing to be responsive to their mobility needs. Information on the role of attention and other cognitive skills in safe driving should be made available, so that drivers (or their family members) who think they may have declining skills can seek further evaluation. This may take the form of completing a self-assessment inventory that can be provided by organizations such as automobile associations and retired persons groups (e.g., Malfetti and Winter, 1986) or referral for medical and neuropsychological evaluation. Whether drivers with dementia are aware of their attentional
deficit and of its impact on their driving must also be considered in implementing educational or counseling programs. Many neuropsychological disorders, including dementia, are associated with impaired awareness of the cognitive deficits resulting from the disorder (McGlynn and Schacter, 1989). Rebok, Bylsma, and Keyl (1990) reported that although a group of older drivers with DAT performed more poorly than normal controls on a driving simulator test, the DAT drivers reported themselves to be as highly capable of driving as the controls.

Can driving performance in older drivers with dementia, particularly those with mild or incipient dementia, be improved through training programs? It is probably the case that training can improve aspects of driving that depend upon general knowledge or upon basic driving procedures (cf., Knopman and Nissen, 1987). It is less certain that cognitive skills related to safe driving can be retrained. Unfortunately very little is known about the best methods for training cognitive skills in relation to driving. Moreover, only some cognitive skills may be retrainable. Older drivers use a number of compensatory strategies in driving, for example, driving only familiar routes, driving slowly, or not driving at night. Driver strategies for reducing attentional demands might include not using the radio, avoiding busy intersections, not driving with a distracting companion, and so on. For drivers with dementia, however, some of these strategies may not be effective. For example, reduced efficiency in switching selective attention cannot be easily compensated for by simply driving more slowly or by paying closer attention to the road. Whether training techniques can be developed to overcome attention limitations in drivers with DAT remains a topic for further investigation.

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Older Drivers Handling Road Traffic Informatics: Divided Attention in a Dynamic Driving Simulator

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OLDER DRIVERS HANDLING ROAD TRAFFIC INFORMATICS: DIVIDED ATTENTION IN A DYNAMIC DRIVING SIMULATOR (*). Drs. Peter C. Van Wolffeelaar, Dr. W.H.Brouwer and Dr. J.A. Rothengatter.

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1. INTRODUCTION

Older drivers face specific problems and limitations when participating in road traffic due to the effects of the ageing processes that result in diminishing psycho—motor and cognitive capabilities. Results from accident statistics and observation studies suggest that elderly traffic participants are particularly hindered by situations requiring divided attention and/or rapid decision making. An example is turning left (right in the U.K.) on an intersection, where they more often tend to miss (perceive too late) traffic coming from the crossing or opposite direction. In this situation they may also fail to perceive relevant traffic signs (McFarland et al., 1964; Transportation in an aging society, 1988). Both sensory (Keltner and Johnson, 1987) and higher order, perceptual and decisional, impairments play a role in this situation (Salthouse, 1982; Brouwer et al, 1990). Motor requirements for visual orientation, like moving the eyes, head and shoulders can also be a limiting factor (Hauer, 1988).

While driving several subtasks may be in progress in parallel so that drivers have to be able to divide attention and switch to other subtasks when necessary. Drivers may perform other tasks that are not intrinsically related to driving itself such as telephoning, manipulating and listening at audio—equipment and talking to passengers. These non—driving tasks also have to be integrated adequately into the pattern of activity. Modern information technology in the car will change the nature of the driving task. Research as carried out in the DRIVE-program (*) is concerned with the requirements for Road Traffic Informatics (RTI) systems, aimed at improving the efficiency and safety of the road traffic system. The introduction of RTI technology will bring new equipment and control panels in cars, warning and assisting the driver while participating in traffic. However, particular attention has to be given to the ergonomic design of these newly created tasks in relation to the questions wether they will facilitate, or at least not interfere with, safe driving behaviour. In principle, this implies that such a new task should be performable in parallel with "basic" driving tasks (critical tasks with regard to safety and efficiency of transportation) with minimal interference.

This study is particularly aimed at the age related abilities to divide attention between different sources of information and at the investigation of performance in relation to different modalities of RTI—information and response modalities. It is obvious that this is highly relevant to the introduction of possible RTI implementations as these will create an extra source of information to the driver while he is already engaged in the task of driving.

2. EXPERIMENTAL SETUP.

A task environment was created that simulated both the fundamental characteristics of the basic driving task and the characteristics of RTI information presentation. RTI tasks were simulated in different modalities of stimulus presentation and response modality. The choice of the dimensions on which the RTI tasks were changed are based on Wickens' (1984) hypotheses concerning attentional resources, and on previous findings described in the gerontopsychological and traffic safety literature, in as far
fig.1: Schematic overview of the experimental task environment showing the central and peripheral video screens, the experimental computer and the response devices.

fig.2: The central video screen showing the road geometry and the central location of the RTI-stimuli with examples of the RTI-stimulus modalities.
as these may be relevant to RTI applications. The task consisted of a basic 'driving'-task and additional 'RTI'-tasks.

The 'driving-task' was simulated by the combination of two subtasks, reflecting basic activities while driving: steering and attending to events in the visual periphery. The first subtask (the 'steering task') consisted of steering a simulated car on a two lane road, projected on a central 50 cm video screen about 1 meter in front of the subject (van Wolffelaar, 1991). The display showed a moving road, projected in a perspective as perceived through the windscreen of an automobile (fig. 1). At the same time a continuously varying 'sidewind' was diverting the driver from a straight course giving the steering task functional characteristics of a compensatory tracking task. The strength of this 'sidewind' was adapted to the individual capacity for each subject at the beginning of each experimental session. In this way the basic steering task was made equally difficult for all subjects.

The second 'driving'-subtask (the 'peripheral detection task') consisted of monitoring the appearance of traffic signs on two 30 cm video screens, located 30 degrees to the left and right of the main screen in the visual periphery, and responding to the appearance of these signs by pressing one of the horn buttons on the steering wheel. The signs were little arrows projected in the centre of a red triangle, pointing at one of four directions (left, right, up, down) in an unpredictable sequence. Only if an arrow pointed into the direction of the steering wheel the corresponding (left, right) horn button on the wheel should be pushed. In this way this task required not only detection of the peripheral signs but also sign identification and response choice. The rate of appearance of the arrows varied at random between 4 and 6 seconds. The size of the arrows was such that they were large enough to evoke detection when appearing on one of the two screens but also small enough to require eye movements for foveal identification after detection. The integrated performance of these two subtasks was referred to as the basic 'driving task', analogue to maintaining a straight course on the road while attending and responding to relevant occurrences in the periphery of the visual field.

In the simulated 'RTI-tasks', stimuli were projected in the centre of the video screen in a small rectangle area, located in the centre of the visual fixation point on the road display (fig. 2). This location of presentation required minimum additional eye-movements for the RTI tasks while driving. The high pace rate of stimuli however required practically continuous attention and response actions. The RTI-tasks simulated the activities using electronic in-car devices while driving. The investment of additional attention was expected to cause interference with the basic driving task activities.

The RTI-tasks were presented in different stimulus modalities (machine-paced vs self-paced presentation, verbal vs spatial coding, short vs long stimulus duration) and required two different response modalities (vocal vs manual). Each modality was administered in a separate experimental task block. For the RTI-tasks that were administered in the machine paced modality it's presentation rate was initially adapted to a correct response rate of 95%, assuring that each subject had an equal starting level of performance. The adapted pace rates varied between 0.5 and 2.0 stimuli per second depending on individual capacities and task modality. The different modalities of the simulated RTI-tasks were realised in two types of tasks: a 'dot counting task' and a 'serial addition task'.

The dot counting task, required quick and accurate counting of a group of dots appearing in random patterns. Responses were either vocal by saying loud the number of counted dots (vocal response condition) or manual by pushing the button with the corresponding digit on a telephone keypad that was mounted beside the steering wheel (manual response condition). The projected number of dots varied at random between 5 and 9 and were presented either in a machine paced or in a self paced rate (machine paced vs self paced condition).

The second type of RTI task was a 'serial addition' task that required the mental addition of single digits ranging from 1 to 5 (verbal coding condition) that were
fig. 3: Average course deviation in the steering task in the three main task conditions for the two age groups.

% increase in track deviation (SDLP) for modalities of additional RTI-tasks

fig. 4: Average percentage increase in course deviation (SDLP) in the two age groups for different modalities of RTI-tasks when these RTI-tasks are added to the primary driving task.
sequentially presented, the next one appearing after the previous one had disappeared, in the central RTI-rectangle. Another modality (spatial coding modality), required analyzing the number of spatial displacements, also one to five, of one of the borders in a hexagonal figure between successive stimuli. Both verbal and spatial serial addition stimuli modalities were projected at different presentation durations: 'short' (500 msec), 'long' (pace interval minus 500 msec) and 'both' (both stimuli projected simultaneously), resulting in different memory loads (memory requirements conditions).

In this way the RTI task was varied according to the following dimensions:
- verbal vs. spatial coding of stimuli;
- vocal or manual response;
- memory requirements;
- machine-paced or self-paced presentation.

Performance decrements in the dual (actually triple) task situation could be evaluated both in terms of performance on the RTI task itself and in terms of the interference of the RTI task with the driving task. An essential element in this task environment is that steering task difficulty and speed of RTI-presentation is individually adapted before the integrated presentation of these subtasks. This allows for direct comparison of young and older drivers with regard to effects of dividing attention that occur on top of performance differences already evident in single task performance, e.g. as a consequence of aging.

2.1 METHOD

Subjects.
Two main groups of subjects, 24 young (25-40 years) and 24 elderly (60-80) drivers participated in this experiment. All selected subjects were experienced and currently active drivers (total driving experience > 75,000 km), reported to be in good health, with no history of recent major illness and had normal or corrected to normal static visual acuity. They were asked not to take alcohol or medication the night before they performed the task.

Procedure.
The simulator task was partitioned into 39 sequential taskblocks, lasting 1 to 4 minutes each. The complete experimental task has the following main segments:

1. In the familiarization blocks the subjects should become accustomed and get the 'feel' for the reactivity of the simulator system.
2. In the sidewind adaptation blocks the difficulty (amplitude of a noise signal) of the tracking task was individually adjusted by an adaptive task procedure until a SD of lateral position of '40 cm' had stabilised.
3. The RTI-dot counting tasks were performed as a single task and in combination with the 'driving task' in machine paced vs self-paced stimulus modality and manual vs vocal response modality.
4. Both verbal and spatial RTI-serial addition task modalities were assessed in paced stimulus modality and vocal response modality only. Stimulus duration was varied in three sequential task block conditions: 'short', 'long' and 'both'.

Half of the subjects received inverted sequences of task blocks within the main task segments, to balance out task sequence effects. As the complete task consisted of several main segments with different RTI-task modalities, an assessment of the 'reference' driving task was accomplished between the successive RTI task modality segments to obtain reference scores and to control for vigilance, fatigue and/or learning effects in the course of the complete task period.
non-response to peripheral stimuli

![Graph showing non-response to peripheral stimuli](image)

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Single Task</th>
<th>'Driving' Task</th>
<th>'Driving' + RTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-80 yr</td>
<td>0.17</td>
<td>0.5</td>
<td>7.2</td>
</tr>
<tr>
<td>25-40 yr</td>
<td>0.22</td>
<td>0.24</td>
<td>2.2</td>
</tr>
</tbody>
</table>

fig. 5: Average percentage of non-response (no response at valid stimuli) to peripheral stimuli in the three main task conditions for the two age groups.

% increase in missed peripheral signs for modalities of additional RTI-tasks

![Bar chart showing increase in missed peripheral signs](image)

fig. 6: Average percentage increase in non-response to peripheral stimuli in the two age groups for different modalities of RTI-tasks when these RTI-tasks are added to the primary driving task.
2.2 RESULTS

steering task
The steering task was assessed in three different conditions: as a single task, as one component of the 'driving task' and in the combined RTI/driving task. Before the actual assessment in multiple task conditions the individual level of task difficulty was determined by adaptation of the 'sidewind factor'. The average group sidewind factor of the elderly is lower compared to the younger drivers (mean sidewind factor = 4.4 vs 5.5, p<0.05).

In the single task condition no difference in course deviation was found between the agegroups, as expected, considering the individually adapted sidewind forces (fig. 3). In the driving task (steering + peripheral detection) the course deviation increased for both age groups, but to a larger extent for the elderly (p<0.005). In the combined RTI/driving tasks this trend magnified substantially, indicating disproportionally growing problems in maintaining a straight course for the elderly subjects in conditions of increasing task complexity (p<0.001).

Fig. 4 indicates the relative interaction of RTI-task modalities with steering performance for the two age groups, i.e. the relative contribution of RTI-task modality conditions to decrease in steering performance. Elderly show a larger increase in course deviation in the manual RTI—response modality (pushing the keypad instead of vocal response) of the dot counting task (p<0.05).

peripheral detection task
In the single task condition of the peripheral detection task (just responding to peripheral events, no sidewind on the steering wheel), older drivers responded slightly slower than younger subjects, but no age—differences were found in the detection of the stimuli nor in the quality of responses (fig. 5). This state continued when sidewind was added in the 'driving task' conditions, indicating no specific age—dependent problems in normal driving in this simulator. But age—differences do appear however when the RTI tasks are added to the driving task. The proportion of non—responses to peripheral stimuli now increases significantly stronger for elderly than for younger subjects (p<0.005). In this complex and highly demanding RTI/driving task condition, combining basic driving activities with fast RTI—handling, the elderly, on average, disproportionally fail to detect relevant peripheral signs. This result closely resembles findings in traffic accident analyses, indicating disproportional increase of attentional problems and related accidents of elderly in complex and time pressured traffic situations.

Fig. 6 indicates the relative interaction of RTI-task modalities with peripheral detection task performance for the two age groups. The manual response mode to RTI—stimuli appears to be relatively more unfavourable to older drivers (p<0.10). Notice the lack of performance decrease for both age groups in peripheral detection in the 'both' memory requirement RTI task condition. Here the RTI task appears to be so easy perform that no increase in misses to peripheral signs occurs.

RTI tasks
The results of the simulated RTI—tasks indicate that they are performed equally well by our elderly subjects when performed as single tasks (fig. 7). Not only do our elderly respond as fast as younger subjects but also the proportions of non—responses and response errors are at the same level for both age groups. Performance in combination with the 'driving task' however, again leads to a disproportional increase of non—response (p<0.01) and response errors (p<0.001, not shown in the fig. 7) in combined RTI/driving tasks for the elderly.

Fig. 8 indicates the relative decrease in RTI performance while 'driving' between age groups. Elderly tend to miss relatively more RTI—signals in the manual response mode (p=0.068) as well as in the paced stimulus mode (p=0.079) compared to younger subjects.

For a full description of the simulator study see Van Wolffelaar et al. (1990).
fig. 7: Average percentage of non-response (no response at valid stimuli) to RTI-stimuli in the two main task conditions for the two age groups.

fig. 8: Average percentage increase in non-response to RTI-stimuli in the two age groups for different modalities of RTI-tasks when these RTI-tasks are performed in parallel to the primary driving task.
3. CONCLUSIONS

Even though the performance results have been obtained in the laboratory and thus require verification in actual traffic it should be noted that the tasks used represent both elementary driving task and RTI interaction tasks in the sense that they appeal to the cognitive processes that are likely to be involved in driving and RTI interaction. The very substantial deterioration found in the basic driving tasks and, in particular, in course control as measured with the standard deviation of lateral position, indicates that elderly have severe problems with coping with RTI information presentation and responding to the presented information.

Moreover, it should be taken into consideration that the results discussed concern the relative deterioration compared to baseline performance levels and that these baseline levels are partly already lower in elderly than in young adults (e.g. steering). If the effects found in the laboratory are replicated on the road, it will be necessary to conclude that due to their age-specific functional limitations elderly are not able to cope with RTI equipment while driving, and hence special provisions will have to be made to allow them to use the equipment.

As the effects of interaction in RTI-related tasks depend to a large degree on age-specific capacities of the driver, it will be necessary to evaluate all RTI implementations, that require some form of interaction during the execution of the driving task, with drivers of different age groups. Moreover, since some modes of presentation and response seem to be more favourable for young drivers and others more favourable to older drivers, it is recommended that RTI implementations are developed such that their functioning can be adapted to the specific pattern of capacities of the user.

4. SUMMARY

Older drivers may face specific problems and limitations when participating in traffic, due to effects of ageing on perceptual-motor capacities. With regard to attention, the ability to divide attention between tasks appears to pose specific problems, as is evident on the basis of both accident data and laboratory studies. It seems obvious that this problem is highly relevant to the introduction of Road Traffic Informatics (RTI). When it is not taken into account, RTI may create additional problems for older drivers. On the other hand, when developed properly, RTI might help in compensating for ageing related impairment.

To study divided attention while driving, a task environment was created that simulated both fundamental driving tasks (lane-tracking and reacting to peripheral visual information) and RTI. Modalities of RTI that were varied were: Low to high memory requirement; Self-paced or machine-paced presentation; Numerical or spatial presentation; Vocal or manual responding. An essential element in the study is that the difficulty of lane-tracking and the RTI tasks is adapted to individual capacity in single task conditions. This allows for direct comparison of young and older drivers with regard to effects of dividing attention.

The simulator tasks were presented to 24 young (25-40) and 24 older (60-80) experienced drivers, who each participated in a session of approx. 2 hours' duration. Both young and older drivers performed well on the basic driving tasks when no RTI was present as well as on the RTI tasks when no driving was required. When the RTI tasks were combined with driving, performance of older drivers in both types of tasks dropped significantly more than performance of the young. From a safety point of view, the increased number of misses of peripheral stimuli and increased course deviation are particularly important. With regard to RTI modalities it appears that high memory requirements, machine-paced presentation and manual responding (as opposed to vocal) have particularly strong negative effects on older drivers' performance.
This study is part of the project V1006 'Factors in elderly people's driving abilities' within the DRIVE programme of the Commission of European Communities.

5. LITERATURE


Older Driver: Emergent Trends in The European Policy Environment

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and

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Imperial College
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'Older people are more numerous, more active and more mobile than ever before. But older people are more vulnerable on the roads, as is shown by the fact that half of all pedestrians killed are over 60 years old. We are therefore paying special attention to the older road user as we work towards achieving a one third reduction in road accident casualties by the year 2000.' (Christopher Chope, Minister for Roads and Traffic, 1991)

1 INTRODUCTION

Global concern about the driving performance of the elderly, as shown by today's sessions, coupled with recent in-vehicle information technology developments mean that the prospect of international standards for driver competence and ability is now on the policy agenda (DREAM, 1990). From the outset, we frame our discussion in terms of performance rather than competence standards as we believe there is a necessary distinction to be made between competence standards and performance standards; by competence we mean the measured knowledge and abilities of the individual driver through testing at specified intervals for limited time periods, by performance we mean actual continuous in-vehicle behaviour. From this perspective much of the literature which believes itself to be talking to the issue of performance standards is indeed talking to the parallel issue of competence. New technologies open up for the first time the prospect of monitoring performance continuously in the vehicle on a day-to-day basis as opposed to the measuring of competence. The development of in-vehicle monitoring of driver performance technologies reduces the administrative complexities in ensuring adequate levels of driver performance and opens up the further prospect of international standards of driver performance.

Whilst the prospect of one universal international driving standard must still be viewed as remote given different national attitudes in Europe towards driving, mobility and the elderly, and whilst there is not yet any specific move concerned with standardising ability and competence standards in respect of the elderly, there are clear and important moves towards a common ability and competence standard for the total population. One very first concrete moves in this direction have been the EC driving licence directives of 1980 and 1991. Such institutional change contains the potential for extension into adjacent and wider area of traffic safety and into more defined categories such as the elderly.

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1 Press release of 25. 6. 1991 of the UK Department of Transport.

2 The ability of driving simulators to deliver such continuous observation has always been their attraction, but their field of applications is restricted by the costs involved in operating and setting them up.
Currently there are a number of important European transport technology programmes3 concerned with road safety which may in time feed such a policy initiative. These programmes have focused on the recording of accident data (Fincham, Fowkes and Willson, 1991), upon the support of driver processing capabilities (e.g. route guidance systems, distance and overtaking warning systems), upon the development of automatic systems to alert the driver to danger and more importantly upon the development of systems which take over from the driver in dangerous circumstances4. One, at least, of these European projects, DRIVAGE has focused specifically on the benefits that new transport information technology can bestow upon the road safety of the elderly (Wames, Frazer and Rothengatter, 1991)5. This paper will discuss why focus has fallen upon road safety and the elderly in Europe, using mostly UK and German evidence, discuss the technical and political problems involved in resolving the dilemma of providing adequate accessibility for the elderly whilst at the same time ensuring the safety of all user groups and suggest some possible solutions.

2 DEMOGRAPHIC CHANGES: AGEING POPULATION AND GROWING SAFETY CONSCIOUSNESS

Globally, there is a general policy recognition that demographic changes mean that society has increasingly to be designed for the presence of the elderly (Kline, 1987 or Department of Transport, 1991). There is a recognized need for expansion and modification of current social services for the elderly and for wider social changes in attitudes towards the elderly population. In this paper we will concentrate on possible technological solutions. Within the United Kingdom (Department of Transport, 1991), at least, part of this policy focus has fallen upon the social issue of accessibility and the elderly.

The predicted rise of the absolute and relative number of elderly in the population is a concern both in the U.K. and within Europe generally:

‘By the year 2001 the number of people in the U.K. who are over 55 years of age will almost have reached 15 million and there will be nearly 6.5 million over 70 years of age. By 2031 there are expected to be almost 19.5 million people over 55 and 8.4 million over 70 years of age. ...Currently there are only some 10 million driving licence holders over the age of 55. By

3 Examples are DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) and PROMETHEUS (Programme for an European Traffic with Highest Efficiency and Unprecedented Safety), both sponsored by the European Community.

4 The PROMETHEUS project is supporting ‘Common European Demonstrators’ in the these areas.

5 This project also examines potential problems of information overload.
2001 there will be almost 12 million people over 55 who hold or have held driving licences and this will rise to close to 17 million by 2031. Many will live in suburban or rural areas where there is little alternative to the car for regular travel.’

(Report MCAP/ AA Working Group. Helping the older driver.1990)

An impression of the scale of these changes in the U.K is given by Figure 1.

Figure 1
Predicted growth of the older population in the UK

![Predicted growth of the older population in the UK](image)

Source: Department of Transport, 1991, Figure 1.

Comparative data on the ageing of populations in the various EC member states have been cited by Warnes et al. (1991) and are presented here as Table 1.

Independent of these demographic trends, trends in the residential location of elderly households give rise to further constraints. The choice of retirement locations in either rural areas or in retirement enclaves confronts the policy maker with difficulties. The dynamics of the housing market render the surrendering of the large family home and movement to a cheaper and smaller location an important individual saving strategy for the elderly. Such strategies of ‘cashing in’ the family home are likely to accelerate the movement to retirement locations. The respective, but different difficulties inherent in either widely scattered or unduly concentrated locations are obvious, and do not need to be discussed here, but should be kept in mind. However, it should be pointed out, that in
Table 1
The ageing of EEC national populations 1980-2000

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<tr>
<td></td>
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* East and West Germany


scattered locations especially the elderly have come to rely on private car-borne travel in the face of decreasing rural public transport services across the community.

Paradoxically, increased age heightens the dependence on technology for mobility (AA Foundation for Road Safety Research, 1988), whilst the dependence on technological mobility heightens the degree of risk precisely because of the degree of physiological impairment. Those most in need of mobility technologies are at the most risk. The UK road accident experience is a good example. While in 1989 only 11% of recorded road accident casualties involved people over 60 years of age, 28% of the number of road fatalities were over 60 of age (Department of Transport, 1990).

For the elderly, this dilemma between safety and mobility has been present in an individual form⁶, given the ageing of the population, this individual dilemma will increasingly take a societal form. In this context, there is a growing policy recognition that the transport arrangements of modern society need rethinking.

⁶ See the report of the Medical Commission on Accident Prevention and Automobile Association (1990) which poses this dilemma in individualist terms 'For the older driver a time comes when there is a conflict between safety and mobility'.

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Awareness of the need to rethink mobility arrangements for demographic reasons has been accompanied by an awareness of the need to rethink mobility arrangements in the light of growing evidence of increasing and imminent environmental constraints. A parallel feature of the policy environment has been the emergence of considerable concern around safety and liveability in the urban environment for the population as a whole. This latter development has raised awareness of vehicle speeds and thus raised the prospect of, and in many places led to, the tighter regulation in respect of speed (See for example the German experience with ‘Tempo 30’ (FGSV, 1989)). New technologies offer the prospect of improving safety, partially through the improving of performance and partially through the strengthening of enforcement (Rothengatter and Harper, 1991).

The prospect, development and existence of new technologies capable of providing higher levels of safety can be expected to result in more detailed research into the relationship between safety and age, not least because such new technologies are frequently capable of automatically collecting data which previously would have been difficult to gather. Because it is recognised that the new in-vehicle information technologies require careful designing in order to permit the human-machine interfaces able to address the needs of all age groups, research into the relationship between age and response to information systems is currently under way (See also Godthelp and op de Beek, 1991, for warning and information filtering systems). The increasing policy awareness of the relationship between age and road accidents, whether as pedestrian, cyclist or driver has been accompanied by stronger and more detailed scientific evidence on the ageing process and physiological impairment. The demography of accidents is an area of increasing policy and research concern. It has been found, that there is an increase with age in the occurrence of accidents under the following circumstances: failure to yield right of way; right turns; U-turns; reversing; rural junctions (MCAP and AA, 1990).

Whilst some new technologies will certainly permit readier recording and attribution of culpability in respect of accidents, other technologies, however, can also make the environment safer and thus reduce the occurrence of accidents. Currently, new technologies are under development which can compensate for or alert to the impairment which accompanies age. Whilst some of these new forms locate technology in-vehicle, other forms require installation within the roadside infrastructure. Whether compensatory technology is designed to operate solely within the private domain, or in private-public cooperation, the imperative to develop and implement safety technologies given the

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7 Dynamic route guidance systems would fall within this category, as would improved junction control systems (though it should be noted that improvements in this field can be accomplished by tailoring facilities either at the level of publicly owned infrastructure or at level of privately owned mobile equipment).
ageing of the population is of necessity a general policy issue.

These concerns are made more important by growing traffic levels across Europe. Again the UK forecast should rather typical. In 1989 the UK Department of Transport predicted an increase by between 23% and 40% in miles travelled by all traffic by the end of the century and between 75% and 129% by 2025 (Department of Transport, 1990). Increasingly, the elderly driver will interact with other elderly drivers on the road. The consequences of this shift in the composition of the driving population on traffic safety are still unknown. It is, therefore, now prudent to consider ways of lessening the burden of risk for the elderly driver. New technology can at the minimum lessen the information burden involved in driving. The next section discusses the mechanisms and advantages of so doing.

3 LESSENING THE INFORMATION BURDEN: NEW TRANSPORT INFORMATION TECHNOLOGIES AND THE ELDERLY

The well-documented deterioration of the physiological and mental abilities of elder drivers makes technologies which reduce the information burden of the driver a useful instrument for improving road safety (See for German examples Haas, 1990, and Herberg, 1990). Figure 2 shows as an example East German measurements of the loss of driving ability as a function of age:

The reduction in information processing speeds places the older driver particularly at risk in complex situations which require the extensive use of such capabilities; junctions, merging and overtaking situations are obvious cases where diminished speed of information processing can have highly negative consequences. The impact of this handicap is compounded by a number of other handicaps which are frequently associated with old age such as a reduction in the ability to judge own speed and the speed of other vehicles, and the loss of agility necessary for the various head movements involved in the safe manoeuving of the conventional vehicle.

Although some older car drivers try to compensate for these losses, in particular the loss in the speed of information processing, by avoiding stressful driving situations in the peak hours on major roads or at night or in unfamiliar areas, others are not be aware of or underestimate their problems by relying on their accumulated experience. There is some evidence from West Germany about the number of drivers that stop driving completely (Hartenstein and Schulz-Heising, 1989) as a permanent adjustment to physiological deterioration.

In spite of the adjustments, which the driving elderly undertake, evidence from both the US
Figure 2  
Loss of driving ability as a function of age

![Bar chart showing loss of driving ability by age group.]


and the UK shows that accident rates ‘per distance driven’ increases with age (Broughton, 1988, and IIHS, 1989). This experience creates the need for technologies to support the elderly driver in his or her task.

The main road transport informatics (RTI) technologies currently proposed to form part of the new integrated road transport informatics environment, which could be brought to bare upon this task, are:

- **Dynamic and static route guidance systems** relieve the drivers from some of their planning and monitoring tasks, which can be especially stressful in areas unknown to the driver. These technologies can only be fully useful for older drivers, if they permit the route choice to be tailored to the driving needs of the older driver, e.g. minimization of turning and merging manoeuvres, rather than travel time minimization.

- **Parking guidance and reservation systems** can reduce the need for the older driver to search extended periods of time in densely used urban areas under stressful conditions.

- **Trip planning systems** can advise the older driver about routes, necessary rest periods and rest facilities and modal alternatives on longer journeys. A basic example is the EUROTRIP system developed within the DRIVE programme (DRIVE, 1991).
• **Distance keeping and platoon driving systems** are intended to relieve the driver of the need to continuously monitor relative distance and speed to the vehicles in front. For the elderly this would be welcome as it would reduce the mental work involved in routine driving.

• **Overtaking warning system** are envisaged in the first instance to advise the driver of the presence of cars in his/her overtaking path. The elderly would benefit from such technologies given their reduced ability to judge speeds and distances of following and oncoming vehicles.

• **Performance monitoring systems** are intended to provide non-intrusive monitoring of the driving abilities of the driver, in particular of their alertness. These systems have the immediate potential to be expanded to advise drivers on the need for rest periods.

The combination of driver support technologies with artificial intelligence techniques and environmental and traffic sensors will allow to tailor the system responses to the particular needs of the driver and especially the elderly. The system proposed by the GIDS project within DRIVE falls into this category (Michon and McLoughlin, 1991).

Significant new developments have happened within the DRIVE programme project DREAM, DREAM's European experiments have made substantial progress towards, what can usefully be termed, an in-vehicle screening technology:

> "... it can be said that not only will it be possible to monitor driver status in the vehicle, but the .. consortium is also in a good position to build a device for this purpose' (DREAM, 1990, p. 75).

The DREAM project does not itself consider the policy implication of the availability of such a technology, however, the increasing availability of such technologies will heighten the need for all levels of government to advise the public, and the elderly public in particular, on the use and usefulness of such technologies. This work would be an extension of already suggested government work on advising elderly drivers with respect to safety precautions (MCAP and AA, 1990). The effectiveness of such non-technological advice was shown by research by Holland (1991)\(^8\). Her research found that 'within two months of filling in a self rating questionnaire and having had eye and hearing tests, 68% of elderly drivers and pedestrians had made changes to their driving behaviour'. She concluded that these changes were 'a result of the feedback from the sensory tests and of thinking extensively about their own behaviour while filling in the questionnaire.' Some of the most important changes noted were:

- starting to wear prescribed spectacles for driving

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\^8\ For other experiences with voluntary counselling and training see Seaton, 1990.
visiting the optician and having their prescription updated
- avoiding driving in the dark
- planning routes beforehand - it was occasionally specified that this was to avoid complex junctions.

Potentially, further developments of the new information technologies outlined above could substantially increase the performance of the elderly drivers. However, there may be limitations to the improvements offered by such technologies, where their use is purely discretionary. The next section examines the arguments regarding the voluntary versus regulatory implementation of these technologies.

4 SAFETY TECHNOLOGY OR RESTRICTIONS ON THE MOBILITY OF THE ELDERLY? CONSTRAINTS ON THE POLICY CHOICE

Just as the awareness of the growing numbers of elderly fuels research and policy thinking into making the necessary adjustments in mobility arrangements, so this very same growth rules out the possibility of simply reducing the road safety problems of the elderly by simple cut-off age legislation. The categorical and simple exclusion of the elderly from car use on grounds of safety is not possible given the electoral dynamics of the situation. Larger numbers of elderly mean greater senior citizen power and transport policy and legislation must necessarily reflect this change in political demography. Electoral power enables the elderly to protect themselves against legislation discriminating on age alone and to ensure their accessibility needs are met either privately or publicly. Thus the functional pressure to resolve problems between the risks involved in movement and accessibility at the level of technology therefore increase.

The consequence of this expansion in the elderly constituency within many developed societies, combined with general societal needs for road safety and protection and with the wish to facilitate the mobility of the elderly, has the clear potential for generating a major market for RTI solutions. Whilst simply restricting the auto-mobility of the elderly may not be electorally acceptable as a transport policy, insisting on the vehicles of the elderly being furnished with highest level of safety technology is likely to receive more substantial support. Indeed, there has been a general recognition that there are particular conventional vehicle design needs of the elderly which are currently not met by the market and the use of regulatory instruments may go some way to ensuring manufacturers meet this latent demand ( Förster, 1990). Improved vehicle design and construction can make a major contribution to saving lives and injuries for all age groups but is especially important to the older road user. Improved primary safety features such as effective lighting, brakes and all round
vision are particularly helpful to the older driver. Improved secondary safety features, such as side impact protection, safer steering wheels and car fronts offer some measure of protection to pedestrians.

Furthermore, in combination the current drive towards transport informatics and the accompanying considerations of vehicle redesign, there are general market developments emerging out of the concern with congestion and parking which are capable of hosting the development of a vehicle more suited to the elderly (Appel, 1990). Equally, the growth in the numbers of elderly driver will make its own contribution to generating a market for vehicle designs stressing safety even further than currently.

In the present, there is considerable Europe-wide, as well as global discussion of the problems faced in gaining public acceptability for Road Transport Informatic developments (See Jones, 1991, Scott and Martin, 1990, Underwood, Chen and Ervin, 1990, and SIRIUS, 1990, for British, Australian, American and European perspectives on this issue). In this context where RTI implementation is seen a problematic, providing safety technologies for the growing market of the elderly driver may offer an important first step towards the public acceptance and correspondingly wide-scale implementation of RTI.

The considerable variability in physiological deterioration with age generates a good natural justice case as to why no simple categorical age barrier can be placed upon the entitlement of the elderly to drive a car. Such variability accompanied by the need to ensure justice has, however, the consequence of generating considerable potential economic costs, as it necessitates, in order to be comprehensive and under conventional technologies, person by person screening as to physiological/driving competence on a regular basis. In practice, and because of their costs, such policies are not followed or proposed. Historically, the organisational requirements and costs of such a policy were prohibitive. However, there is now a general policy recognition of the need for a more careful screening as to the driving capabilities of the elderly and the pressure for such screening is likely to grow with the increasing numbers of elderly. The cheapest option of course, in screening terms, would be that of applying a categorical age rule, however, as we have indicated considerations of natural justice and electoral power mean that, given the variability in the rate of physiological decay, no categorical rule can be operated.

This combination of factors is likely to push technology and policy developments in the direction of in vehicle screening of driver performance. In vehicle screening would reduce the administrative complexities and costs of personal screening by qualified staff and has the advantage
that screening can take place within short time intervals during the actual driving. Variability in driving competence and performance exists within the same individual as a consequence of variability in health and this variability is likely to be accentuated by increasing age. The vehicle is the natural location for providing the driver with information on her or his current 'entitlement' to drive. Where health factors would make driving unsafe, the in-vehicle equipment can either advise against driving or enforce the 'temporary' ban. In essence, such an arrangement is no different to those already proposed technologies which overrule, through in-vehicle equipment, drivers' wish to overtake or approach a vehicle in front in unsafe conditions.

An important benefit of in-vehicle screening i.e. temporary surrender of licence to drive, as opposed to age barriers and permanent surrender of licences is that it provides for greater flexibility of mobility arrangements amongst the elderly and contains the prospect of associated lower social costs. Were politicians to enforce simple categorical rules on entitlement to drive and age, the cost of providing traditional solutions to the mobility needs of the elderly would be very large indeed. Such traditional solutions would have to involve both public transport and para-transit provision to considerably higher and more extensive service standards than currently and simultaneously involve various forms of at-home service delivery, for example, meal-on-wheels, or community nursing schemes. The costs would be accentuated by the ageing of the population and this dimension alone is likely to make such an option prohibitive.

Much of the discussion on mobility entitlements and the elderly has concerned itself with the respective benefits of voluntary versus regulatory control on the permanent surrendering of driving entitlements. Whilst this discussion, which finds primarily in favour of voluntary surrender through counselling, is likely to continue for some time, the instruments involved are blunt compared with the more finely tuned instrument of in-vehicle screening. Even if the strongest option of enforcement of adequate level of physiological ability through in-vehicle monitoring is not adopted, in-vehicle technologies can usefully be harnessed as a counselling tool. Currently, in the U.K., there is no official procedure for counselling the elderly on when to reduce either their volume of driving or to cease altogether. Although, as mentioned earlier, there is the beginning of a more systematic rethinking of such arrangements.

For the first time, through new technology, a comprehensive performance standard can be considered, which focuses on the continuous performance of the driver in the vehicle. This contrasts with existing driving tests, which only provide snapshots of the abilities and competence of the driver involved. This contrasts also with the performance monitoring implied in the requirement to install
tachographs in heavy goods vehicles and busses, as their records are only used after the event to inform enforcement.

It is necessary to maintain the difference between safety monitoring and legal enforcement. The in-vehicle screening technologies envisaged here do not imply any monitoring with the intention of providing evidence against the driver in a legal sense, even if the technology could provide for 'driver overrule' procedures. The possibility that insurance rules might enforce the use of such technologies, such as happened in the case of seat-belt wearing, is a different matter, although the public regulation of insurance rules in many countries creates ambiguities in this area.

In-vehicle technologies are capable of providing drivers with record of their diminishing performance but equally importantly they are capable of advising the driver on how to improve upon performance. Variability in driving performance and driver health can be coupled to in-vehicle driving counselling in order to generate higher levels of safety for the elderly while driving. It is conceivable that recent developments in computerised medical diagnostics will contribute substantially to transport technologies in the not to distant future.

5 INFRASTRUCTURAL AND ORGANISATIONAL CONSEQUENCES OF IN-VEHICLE SCREENING

The single most important question is probably that of whether vehicles should be designed to advise the driver or to determine whether the driver obtains command of the vehicle in a particular state of health. Similarly, there are questions to be considered as to whether in certain circumstances command of the vehicle is surrendered to the infrastructure external to the vehicle where interrogation of the vehicle suggests that the driver is not competent. Whilst, at this point, such a discussion may appear exceedingly futuristic, it is the case that these questions are already being raised in respect of other RTI technologies such overtaking and distance warning systems. Safety, as opposed to the simple convenience of traffic managers, is a ground on which radical new technology developments are likely to receive greater levels of political and social acceptability. The option of customised screening versus categorical ban has clear benefits at the level of social justice, customised counselling and the prospect of special training through in-vehicle equipment have clear behavioural benefits for the elderly driver. The combination of this set of benefits may very well be that regulatory surrender of the licence becomes more acceptable provided it is on the very short term basis which only in vehicle screening will allow.
New technologies thus, in general, provide the basis for the new organisation and administration of road safety procedures. What precisely would the infrastructural and organisational consequences of in-vehicle screening be?

Firstly, in-vehicle screening of the type we have described would generate the possibility that the individual would be permitted by the vehicle to make an outward journey without being permitted to make the return journey in the same vehicle. There would be a need to develop both person pick up arrangements and vehicle recovery arrangements in order to reduce the inconvenience of such 'temporary bans' for the elderly. Such arrangements would be highly dependent upon appropriate communication technologies being present in the vehicle or at appropriate intervals along the road sides. Although, this may seem at first sight to be a highly complicated procedure, there are already organisational precedents and recovery for reasons of safety should not be considered essentially different to recovery for reasons of accident.

Secondly, whilst it is the case that such technologies have general applicability to the whole driving population, as the excessive alcohol example suggests, it is unlikely that the adoption of such a technology for the total population would receive immediate acceptance. However, it is possible that the use of such a technology could be made a condition of driving above a certain age. Such a regulation would encourage the manufacture of safer vehicles. The manufacture of safer vehicles, in its turn, may induce greater demand for safer vehicles. The existence of safer vehicles and their increasing use may permit the gradual inclusion of different categories of drivers, commencing with those at greatest risk, until the whole population is covered by the regulation.

Finally, it is likely that the increasing volume of evidence on the special needs of the elderly will find itself reflected in the standards for other elements of the road system, e.g. highway design, traffic signs and control or road markings. Furthermore, an interaction is to be expected between highway design and operation and the new information technologies. Examples for such interaction are the standards for overtaking sight distance versus overtaking warning systems, intergreen times versus vehicle/signal control communication, road signing versus road guidance technologies.

6 Conclusion: New European directions?

This paper has discussed the social and political problems of mobility versus safety in an ageing society where the elderly possess corresponding political power and face intensifying traffic
in their environment. It has noted that new technologies are under development concerned with safety and that these technologies are explicitly being developed as European technologies. Similarly, there are a suite of European policies currently under development in the transport policy and in the general social policy area. Standardisation is a distinctive contemporary European concern. Inside this frame, the standardisation of driver ability and competence tests is already receiving attention.

Similarly, there is action on part of member governments to push common improvements in vehicle design. The UK Department of Transport has initiated such a course of action within the European community with a view:

‘to obtaining agreement on directives which would enable the introduction of domestic legislation to require improvements to all cars. This is proving to be a lengthy process but considerable progress has been made towards establishing the technical bases for such Directives. Meanwhile the Department is urging manufacturers to take voluntary action to incorporate safety features as an integral part of new vehicle designs. Some manufacturers have responded to this and are now advertising the safety features of their new models.’

(Department of Transport, 1991)

On the one hand, Europe is currently in the business of overcoming old national sensitivities in its process of integration, in this context of overall change there is a possibility of smuggling in such a change, and on the other hand, the political sensitivity and the potential cost implications may be so great as to be prohibitive of implementing an international performance standard for elderly driver. Given these political problems, it may prove to be the case that the mid course of providing technological assistance and counselling to the elderly driver generates the effective circumstance of international performance standards. Action to persuade manufacturers and users should be undertaken now.

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Older Drivers - A Problem for Whom?

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OLDER DRIVERS - A PROBLEM FOR WHOM?


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Abstract. In 1991, a Swedish Parliamentary Committee studied road safety problems in relation to older drivers (65+ years). The Committee concluded that older drivers in general fully compensate for the increased risks associated with old age by adapting their driving habits to their own particular infirmities. The Committee therefore found no reason to impose general, age-related restrictions on the right to drive a motor vehicle. General fitness and practical driving tests have not either shown themselves to be of any significance for road safety in reasonable proportion to the resources which would be required if medical examinations or retaking of the driving test were to be made obligatory at a certain age.

High risk per kilometer driven

Compared to the average automobile driver, older drivers have higher risks per mileage of being involved in accidents. This has been demonstrated in a great number of

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studies from various countries over a long period of time (OECD 1985).

Recent Swedish data is shown in figure 1. The well-known U-shape emerges. It can be observed that the accident risks of older drivers do not substantially increase until the age of 75. The increase is an overall effect of the ageing process which decreases the capability of the driver to

Figure 1 Drivers involved in personal injury accidents — with and without own injuries — per 10 million kilometers driven and year. Annual Swedish average for the period 1987-891.

1 The figure is based on the total number of accidents reported by the police to Statistics Sweden, i.e. 62,000 car drivers involved in 43,000 accidents with personal injuries during 1987-89. The exposure data is taken from the annual road user survey for the same years, conducted by the Road Safety Office by means of postal questionnaires mailed to representative samples of road users.
avoid accidents, and increases the vulnerability to personal injuries resulting from accidents. The latter aspect is observable when accidents resulting in severe injuries only are studied, for example fatalities.

Risks, exposure, and accident consequences

Based on data such as these shown in figure 1, various safety measures are constantly under discussion. In the international arena, some of them have been implemented. In Sweden, recent discussions have concerned measures such as general medical examinations for ageing drivers, compulsory safety courses, retaking of the driving test, and so on. The purpose of such measures would be to decrease the average risk level in population of older drivers by compulsory selections leading to that only those with low accident risks are allowed to keep their licenses.

However, this point of view could be questioned. Accident risk is a concept used to explain variations in accident and injury numbers. The overall objective for road safety efforts is to reduce the number of injuries among the road users in general or in a specific group. However, the number of injuries in a specific group is a function not only of the accident risk but also of the amount of exposure and the accident consequences. So, the number of injuries can be effected by decreasing the exposure, the accident risks, or the accident consequences. Therefore, when considering road safety measures directed towards older drivers one have to reflect upon their exposure and how they manage it.
Low involvement rates

When we look at the number of car drivers involved in accidents - relative to the number of license holders - a totally different picture emerges (figure 2).

Figure 2 shows that over the age of approximately 25, the involvement rate remains on the same level for all ages. This means that the older drivers have succeeded in keeping their accident involvement rate at the same low level as the normal driver in spite of their increased accident risks. The explanations are well known. First, the license holders still active have decreased their exposure by more
than halving their annual mileage. Second, the number of licence holders who stop driving for good increases with age, of course. All this contributes to keeping involvement rates on a low level in spite of high age\textsuperscript{2}.

Based on these data, the Swedish Parliamentary Committee "Driving License Year 2000" concluded in their final report that older license holders have shown themselves able to adapt their driving habits to the ageing process (SOU 1991:39). Therefore there is no specific need for general safety measures dealing the older drivers as a group.

The number of older drivers is increasing. By the year 2000, they will have increased by one-third in Sweden. Naturally, the number of accidents with older drivers will increase as a consequence. The increment, however, will not be larger than the increase in the population of older license holders, provided that they do not change their driving habits.

A system-oriented policy

The Swedish Committee has proposed new principles in handling drivers who break traffic rules. In principal, any person convicted of a motoring offence should not be allo-

\textsuperscript{2} The accident and injury risk (accidents per mileage) would be much higher if the older drivers retained their driving style from younger days. Older drivers to some extent change their driving habits from high to low risk conditions by avoiding risky weather and night driving, by making better trip plans and preparation, by taking more rests when driving, getting better glasses, using seat belts more regularly, etc.
wed back on the road without retaking a driving test. Drivers convicted of serious offences would also be required to obtain a new provisional licence and undergo a personal fitness inquiry including medical examinations.

By means of these general rules, individual older drivers with deficiencies in their driving skills will be taken care of.

However, as the population of older drivers grows, it becomes more and more evident that the older driver should be the main consideration when designing the traffic system. The older driver should be taken into account when determining various properties of the system, such as speed levels. In regulating the traffic and modifying the traffic environment, characteristics of the older drivers could be used as standards. Such a general policy would benefit all road users regardless of age.

References


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Motorists found guilty of less serious offences would be given a limited licence, according to the proposals; they would be allowed to continue to drive for a given period of time, say half a year. During this period they must have their driving competence tested. If they fail, their license will be revoked.

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