

# HUMAN FACTORS IN AUTOMOTIVE ENGINEERING AND TECHNOLOGY



Guy H. Walker,  
Neville A. Stanton  
and Paul M. Salmon

HUMAN FACTORS IN ROAD AND RAIL TRANSPORT



CRC Press  
Taylor & Francis Group

# Human Factors in Automotive Engineering and Technology

GUY H. WALKER

*Heriot-Watt University, UK*

NEVILLE A. STANTON

*University of Southampton, UK*

and

PAUL M. SALMON

*University of the Sunshine Coast, Australia*



**CRC Press**

Taylor & Francis Group

Boca Raton London New York

---

CRC Press is an imprint of the  
Taylor & Francis Group, an **informa** business

CRC Press  
Taylor & Francis Group  
6000 Broken Sound Parkway NW, Suite 300  
Boca Raton, FL 33487-2742

First issued in paperback 2017

© 2015 by Guy H. Walker, Neville A. Stanton and Paul M. Salmon  
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

ISBN-13: 978-1-4094-4757-3 (hbk)  
ISBN-13: 978-1-138-74725-8 (pbk)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

**Trademark Notice:** Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

**Visit the Taylor & Francis Web site at**  
**<http://www.taylorandfrancis.com>**

**and the CRC Press Web site at**  
**<http://www.crcpress.com>**

# HUMAN FACTORS IN AUTOMOTIVE ENGINEERING AND TECHNOLOGY

# Human Factors in Road and Rail Transport

Series Editors

**Dr Lisa Dorn**

*Director of the Driving Research Group, Department of Human Factors,  
Cranfield University*

**Dr Gerald Matthews**

*Associate Research Professor, Institute for Simulation and Training,  
University of Central Florida*

**Dr Ian Glendon**

*Associate Professor, School of Psychology, Griffith University*

Today's society confronts major land transport problems. Human and financial costs of road vehicle crashes and rail incidents are increasing, with road vehicle crashes predicted to become the third largest cause of death and injury globally by 2020. Several social trends pose threats to safety, including increasing vehicle ownership and traffic congestion, advancing technological complexity at the human-vehicle interface, population ageing in the developed world, and ever greater numbers of younger vehicle drivers in the developing world.

Ashgate's Human Factors in Road and Rail Transport series makes a timely contribution to these issues by focusing on human and organisational aspects of road and rail safety. The series responds to increasing demands for safe, efficient, economical and environmentally-friendly land-based transport. It does this by reporting on state-of-the-art science that may be applied to reduce vehicle collisions and improve vehicle usability as well as enhancing driver wellbeing and satisfaction. It achieves this by disseminating new theoretical and empirical research generated by specialists in the behavioural and allied disciplines, including traffic and transportation psychology, human factors and ergonomics.

The series addresses such topics as driver behaviour and training, in-vehicle technology, driver health and driver assessment. Specially commissioned works from internationally recognised experts provide authoritative accounts of leading approaches to real-world problems in this important field.

## About the Authors

**Dr Guy H. Walker** is an Associate Professor within the Institute for Infrastructure and Environment at Heriot-Watt University in Edinburgh. He lectures on transportation engineering and human factors, and is the author/co-author of over 90 peer-reviewed journal articles and 12 books. He and his co-authors have been awarded the Institute for Ergonomics and Human Factors (IEHF) President's Medal for the practical application of ergonomics theory, the Peter Vulcan prize for best research paper, and Heriot-Watt's Graduate's Prize for inspirational teaching. Dr Walker has a BSc (Hons) degree in Psychology from the University of Southampton, a PhD in Human Factors from Brunel University, is a Fellow of the Higher Education Academy and is a member of the Royal Society of Edinburgh's Young Academy of Scotland. His research interests are wide-ranging, spanning driver behaviour and the role of feedback in vehicles, using human factors methods to analyse black-box data recordings, the application of sociotechnical systems theory to the design and evaluation of transportation systems through to self-explaining roads and driver behaviour in road works. His research has featured in the popular media, from national newspapers, TV and radio through to an appearance on the Discovery Channel.

**Professor Neville A. Stanton** is both a Chartered Psychologist and Chartered Engineer, and holds a Chair in Human Factors Engineering in the Faculty of Engineering and the Environment at the University of Southampton. He has published over 200 peer-reviewed journal papers and 25 books on human factors and ergonomics. In 1998, he was awarded the Institution of Electrical Engineers Divisional Premium Award for a co-authored paper on engineering psychology and system safety. The Institute for Ergonomics and Human Factors awarded him the Sir Frederic Bartlett medal in 2012, the President's Medal in 2008 and the Otto Edholm medal in 2001 for his original contribution to basic and applied ergonomics research. In 2007, the Royal Aeronautical Society awarded him and his colleagues the Hodgson Medal and Bronze Award for their work on flight-deck safety. He is also the recipient of the Vice Chancellor's Award for best postgraduate research supervisor in the Faculty of Engineering and the Environment at the University of Southampton. He is an editor of the journal *Ergonomics* and is on the editorial board of *Theoretical Issues in Ergonomics Science*. He is also a Fellow and Chartered Occupational Psychologist registered with the British Psychological Society, a Fellow of the Institute of Ergonomics and Human Factors Society, and a Chartered Engineer registered with the Institution of Engineering and Technology. He has a BSc (Hons) in Occupational Psychology from the University of Hull, an

MPhil in Applied Psychology, a PhD in Human Factors Engineering from Aston University in Birmingham and a DSc awarded by the University of Southampton.

**Paul M. Salmon** is a Professor in Human Factors and leader of the USCAR (University of the Sunshine Coast Accident Research) team at the University of the Sunshine Coast. He holds an Australian Research Council Future Fellowship in the area of road safety and has over 13 years' experience in applied human factors research in a number of domains, including military, aviation, and road and rail transport. He has co-authored 10 books, over 90 peer-reviewed journal articles, and numerous conference articles and book chapters. He has received various accolades for his research to date, including the 2007 Royal Aeronautical Society Hodgson Prize for best paper and the 2008 Ergonomics Society's President's Medal. He was also named as one of three finalists in the 2011 Scopus Young Australian Researcher of the Year Award.

# Acknowledgements

This book describes the authors' work which, over the past 20 years, has taken place in various institutions and under various funded projects. We would like to acknowledge the support of Heriot-Watt University, the University of Southampton, the University of the Sunshine Coast, Brunel University and Monash University. We would also like to acknowledge the important role of our sponsors, which have included Jaguar Cars, Ford Motor Company, the UK Engineering and Physical Sciences Research Council (EPSRC), the Australian Research Council (ARC) and the Carnegie Trust. Some of the research reported here has also been undertaken via a current ARC Discovery grant and another provided by the Australian National Health and Medical Research Council, and a joint EPSRC and industry funded project called the Centre for Sustainable Road Freight. Over these past 20 years, we have worked with many friends and colleagues who have advanced their own research agendas using some of the same facilities and equipment. We will leave it to them to tell their own equally fascinating research stories, but nonetheless would like to particularly acknowledge: Dr Dan Jenkins, Dr Mark Young, Dr Tara Kazi, Professor Mike Lenne, Dr Kristie Young, Dr Ashleigh Filtness, Dr Catherine Harvey, Alain Dunoyer, Adam Leatherland, Dr Melanie Ashleigh, Ben McCaulder, Dr Philip Marsden, Amy Williamson, Natalie Taylor, Melissa Bedinger and of course all our many hundreds of experimental participants, most of whom were not compelled to nausea in the driving simulator.





# Glossary

ABS	Anti-Lock Braking System
ACC	Adaptive Cruise Control
ANOVA	Analysis of Variance
AS	Active Steering
CC	(Conventional) Cruise Control
DSA	Distributed Situational Awareness
DSQ	Driving Style Questionnaire
GIDS	Generic Intelligent Driver Support
HTAoD	Hierarchical Task Analysis of Driving
HUD	Head-Up Display
I-E Scale	Internality-Externality Scale
KR	Knowledge of Results
LoC	Locus of Control
MDIE	Driving Internality and Externality scale
NASA-TLX	NASA Task Load Index
ns	not significant
RHT	Risk Homeostasis Theory
SA	Situational Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique
SD	Standard Deviation
S&G-ACC	Stop & Go Adaptive Cruise Control



# Contents

<i>List of Figures</i>	<i>vii</i>
<i>List of Tables</i>	<i>ix</i>
<i>About the Authors</i>	<i>xi</i>
<i>Acknowledgements</i>	<i>xiii</i>
<i>Glossary</i>	<i>xv</i>
1 The Car of the Future, Here Today	1
2 A Technology Timeline	13
3 Lessons from Aviation	27
4 Defining Driving	39
5 Describing Driver Error	49
6 Examining Driver Error and its Causes	75
7 A Psychological Model of Driving	95
8 Vehicle Feedback and Driver Situational Awareness	111
9 Vehicle Automation and Driver Workload	131
10 Automation Displays	141
11 Trust in Vehicle Technology	159
12 A Systems View of Vehicle Automation	179
13 Conclusions	193
<i>Appendix</i>	<i>203</i>
<i>Further Reading</i>	<i>273</i>
<i>References</i>	<i>275</i>
<i>Bibliography</i>	<i>295</i>
<i>Index</i>	<i>303</i>



# List of Figures

1.1	The driving simulator laboratory has been through several iterations in its 20-year history: This is the first, dating from 1995 and based around the front portion of a Ford Orion	2
1.2	The Brunel University Driving Simulator (BUDS) in 2000	2
1.3	The current iteration (2013): The Southampton University Driving Simulator (SUDS)	3
1.4	Sadly, the all-too-common experience is that human factors insights are discovered to be needed too late: Too late to be cheap and too late to be as effective as they could be	11
1.5	By far the best place to employ human factors insights is early in the design process	11
2.1	One of the first implementations of solid-state electronics in vehicles was electronic ignition, which replaced the mechanical distributor and its troublesome contact breaker points	14
2.2	Collision warning with brake support system	21
2.3	Handling management system	22
2.4	Adaptive Cruise Control	23
3.1	Allocation of function (adapted from Singleton, 1989)	35
3.2	Allocation of function matrix	36
4.1	Top level of the HTAoD	45
5.1	The perceptual cycle in driving	52
5.2	Illustration of the multi-modality of a typical infotainment system	56
5.3	Levels of cognitive control (adapted from Rasmussen, 1986)	57
5.4	Percentage of errors implicated in crashes (from Treat et al., 1979)	60
5.5	Contributing factors taxonomy (from Wierwille et al., 2002)	67
6.1	On-road study methodology	76
6.2	The instrumented vehicle (ORTeV)	77
6.3	Frequency of different error types made during on-road study	83
6.4	Participant's head rotation, gaze and the lateral position of the vehicle during speeding violation event	85
6.5	Participant midway through right-hand turn on the red arrow: Overlaid circles show the straight on green traffic signal (left-hand side of the driver view window) and the red right-hand turn traffic signal (right-hand side of the driver window view)	88
6.6	Head rotation, gaze angle and lateral position during 'perceptual failure' error event	90

7.1	Information flow between driver, automatics and vehicle sub-systems (from Stanton and Marsden, 1996)	96
7.2	A group of 29 drivers were asked 'what do you think the oil warning light means?' (The correct answer is low oil pressure)	106
7.3	Hypothesised relationship between psychological factors	108
8.1	Quantity of knowledge extracted by the drivers of high and low feedback vehicles across the four encoding categories (n=12)	120
8.2	Median values of $d_a$ characterising probe recall performance in each of the vehicle feedback conditions	127
9.1	The driver's view of the road, instruments and secondary task (see bottom-left of picture)	134
9.2	Correct responses to the secondary task in the manual and ACC conditions	136
9.3	Driver reactions to ACC failure	137
10.1	Functional diagram of S&G-ACC	142
10.2	Display types	143
10.3	Change detection rates with the three interfaces	150
10.4	Self-reported workload with the three displays	151
11.1	The TPB can be used as a simplified behavioural model within which to situate trust and its effects on behaviour	160
11.2	Trust curves and the relationship between objective system reliability and driver trust: The dotted line is a theoretical trust continuum, whereas the solid curved line is an approximate one based on empirical studies (e.g., Kantowitz, Hanowski and Kantowitz, 1997; and Kazi et al., 2007)	166
11.3	Indicative trust calibration curve overlain across sampling behaviour curve to reveal an important intermediate region where sampling and trust changes rapidly	170
11.4	Different methods of assessing driver trust can be applied at different points in the system design lifecycle	175
12.1	Results for vehicle speed	184
12.2	Results for lateral position	185
12.3	Results for workload/frustration	186
12.4	Results for overall situational awareness	187
13.1	Hollnagel and Woods' (2005) self-reinforcing complexity cycle	195

# List of Tables

3.1	Types of driver error and their (potential) technological solution	29
3.2	Degrees of automation for driver tasks	37
4.1	Comparison of two-litre saloon cars since 1966	40
5.1	The SHERPA method provides a simple way to systematically and exhaustively identify credible error types based on a task analysis and external error modes	51
5.2	Three types of schema-based errors	53
5.3	Reason's error taxonomy	54
5.4	Example error types for Reason's errors and violations taxonomy (adapted from Reason, 1990)	59
5.5	Classification of driver errors (from Reason et al., 1990)	59
5.6	Driver error and incident causation factors (adapted from Wierwille et al., 2002)	61
5.7	Principal causal-factor taxonomy for accident analysis (adapted from Najm et al., 1995)	62
5.8	Contribution of vehicle manoeuvres to road accidents in the UK (adapted from Brown, 1990)	63
5.9	Drivers' errors as contributing to accidents (adapted from Sabey and Staughton, 1975)	64
5.10	Human error and causal factors taxonomy (from Sabey and Taylor, 1980)	65
5.11	Errors associated with accident scenarios (adapted from Verway et al., 1993)	65
5.12	Generic driver error taxonomy with underlying psychological mechanisms: Action errors	68
5.13	Driver error causal factors	70
5.14	Potential technological solutions for driver errors	71
6.1	CDM probes used during on-road study	78
6.2	Different error types (frequency and proportion of all errors) made by drivers during the on-road study	81
6.3	CDM extract for unintentional speeding violation	84
6.4	CDM extract for intentional speeding violation	86
6.5	Extracts from CDM transcript for 'perceptual failure' error	88
8.1	Sample vehicles	115
8.2	Descriptive analysis of the control measures	118
8.3	Inferential and effect size analysis of the control measures	119



8.4	Summary of multiple comparisons for SA profile of high and low feedback vehicle drivers	121
8.5	Results of comparisons between vehicle types across the four encoding categories	122
8.6	Eight levels of the independent variable of vehicle feedback	123
8.7	Number of signal and noise trials per vehicle feedback condition (n=35)	126
10.1	Mapping interface design and the SA elements	143
10.2	Demographic profile of participants	146
10.3	Independent and dependent variables	146
10.4	Descriptions of driving tasks	148
10.5	Calculation of driver response times for each of the task types	148
10.6	Response time percentiles for S&G-ACC	150
10.7	Points at which participants noticed their own vehicle braking	152
10.8	Comments on the three interface designs (where 'x' indicates the number of times the comment was made)	152
11.1	Revenge types and their manifestation	172
12.1	Assignment of participants to experimental conditions	182
12.2	Summary results	188