RAC Foundation

Mobility • Safety • Economy • Environment

Road Collision Investigation Project

Development of taxonomies and meta-analysis

Professor Neville A Stanton
Human Factors Engineering, University of Southampton
June 2022

UNIVERSITY OF Southampton

The Royal Automobile Club Foundation for Motoring Ltd is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

Tel no: 020 7747 3445
www.racfoundation.org

Registered Charity No. 1002705
June 2022 © Copyright Royal Automobile Club Foundation for Motoring Ltd

ISBN: 978-1-9160527-2-7

RAC Foundation

Mobility • Safety • Economy • Environment

Road Collision Investigation Project

Development of taxonomies and meta-analysis

Professor Neville A Stanton

Human Factors Engineering, University of Southampton

May 2022

UNIVERSITY OF Southampton

About the Author

Neville A Stanton is Professor Emeritus of Human Factors Engineering in the Transportation Research Group at the University of Southampton. He has degrees in occupational psychology, applied psychology and human factors engineering, and has worked at the Universities of Aston, Brunel, Cornell and MIT. His research interests include modelling, predicting, analysing and evaluating human performance in systems as well as designing the interfaces and interaction between humans and technology.

Professor Stanton has worked on design of automobiles, aircraft, ships and control rooms for over 30 years, on a variety of automation projects. He has published 50 books and 400 journal papers on ergonomics and human factors. In 1998 he was presented with the Institution of Electrical Engineers Divisional Premium Award for research into system safety. The Chartered Institute of Ergonomics and Human Factors in the UK awarded him the Otto Edholm Award in 2001, the President's Award in 2008 (as part of the Human Factors Integration Defence Technology Centre) and 2018 (as the Director of the Human Factors Engineering team at the University of Southampton), the Sir Frederic Bartlett Award in 2012 and the William Floyd Award in 2019 for his contributions to basic and applied ergonomics research. The Royal Aeronautical Society awarded him and his colleagues the Hodgson Prize in 2006 for research on design-induced, flight-deck error published in The Aeronautical Journal. The University of Southampton awarded him a Doctor of Science in 2014 for his sustained contribution to the development and validation of human factors methods.

Acknowledgements

The author of this report would like to acknowledge the support and help received from Elizabeth Box (RCIP Project Manager), Winston Rasaiah (Principal RCIP Investigator) and the three RCIP Investigators: Matt Butler, Matthew Dale and Emma-Marie Tomlinson. Professor Neville Stanton's time on this research was part-funded by the National Institute for Health Research under the Sociotechnical Approach to Road Safety (STARS) project.

Disclaimer

This report has been prepared for the RAC Foundation by Professor Neville Stanton (University of Southampton). Reasonable efforts have been made to publish reliable data and information but the author, the University of Southampton and the RAC Foundation cannot assume responsibility for the validity of all materials or the consequences of their use. The report content reflects the views of the author and not necessarily those of the RAC Foundation.

Contents

List of Figures

List of Tables

List of Abbreviations

CG	*central government*
CM&LAG	*company management and local area government*
DfT	Department for Transport
DP	*driving processes*
DVLA	Driver and Vehicle Licensing Agency
E&E	*equipment and environment*
Euro NCAP	European New Car Assessment Programme
HGV	heavy goods vehicle
II	*international influences*
KSI	killed or seriously injured
NI	*national influences*
PACTS	Parliamentary Advisory Council for Transport Safety
PPE	personal protective equipment
RB&A	*regulatory bodies and associations*
RCIP	Road Collision Investigation Project
TOM	*technical and operational management*

Note: *Italics* denote AcciMap levels.

Foreword

From the outset we have sought to ensure that all the work we have undertaken and commissioned as part of our Road Collision Investigation Project (RCIP) has drawn on the best-quality evidence available. Nowhere has this approach been more important than in the in-depth collision investigation work completed by the RCIP investigators embedded within their respective police force areas. At the start of their work, the investigators were trained by Professor Stanton on how to take a 'systems' approach to their analysis, using validated approaches and techniques.

The depth and quality of the investigations completed have, as a result, yielded a rich understanding of the causal factors related to the collisions investigated, as well as recommendations for action, many of which would not have come to light without applying such an approach. This has been the real purpose of the exercise – not to focus on the actual cases investigated per se, but to determine the likelihood of such investigations successfully deriving safety learnings, were a road collision investigation branch to be established. This report essentially documents why we believe that case to have been made.

Whilst it has not been possible to publish each of the 37 in-depth investigations conducted, given the confidential and highly sensitive nature of the material, we are pleased to be able to publish this meta-analysis of what those investigations found and, most importantly, what they signal for what a road collision investigation branch might set out to establish as part of its investigatory duties.

Our view, though there is clearly much detail still to be addressed, is that a road collision investigation branch would benefit from adopting an operating model that maximises learning from the many incidents that occur on the road network, achieving this by means of conducting largely thematic reviews which aggregate the findings from multiple cases, across police force areas, adopting a deep-dive approach on some – but not all – cases. For many years, a key argument against establishing a unit to pursue a 'no-blame' look at road collision causation has been that the sheer number of collisions occurring on the road network would make the task undoable owing to its scale. Whilst some individual cases would merit detailed investigation because of their scale or novelty – for example where they involve vehicles operating under high levels of automation – others could usefully be aggregated to reveal patterns of causality, as has been done here using the AcciMap approach.

We hope also that the taxonomy and resulting meta-analysis findings presented in this report will help inform the development of the protocols and approaches that a road collision investigation branch would need to identify learning points and recommend actions which will ultimately make our roads safer for all of us.

Steve Gooding

Director, RAC Foundation

Executive Summary

The aim of this report is to present the development of taxonomies (classification schemes) for Actor Maps (identification of the main actors contributing to a collision) and AcciMaps (the main events, decisions and actions (or lack thereof) contributing to a collision), as well as the subsequent meta-analyses, as part of the Road Collision Investigation Project (RCIP), which is being led by the RAC Foundation. RCIP investigators were trained to apply Actor Map and AcciMap frameworks to 37 road collisions from three police force areas:

- Dorset, Devon and Cornwall (combining two police force areas);
- Humberside; and
- West Midlands.

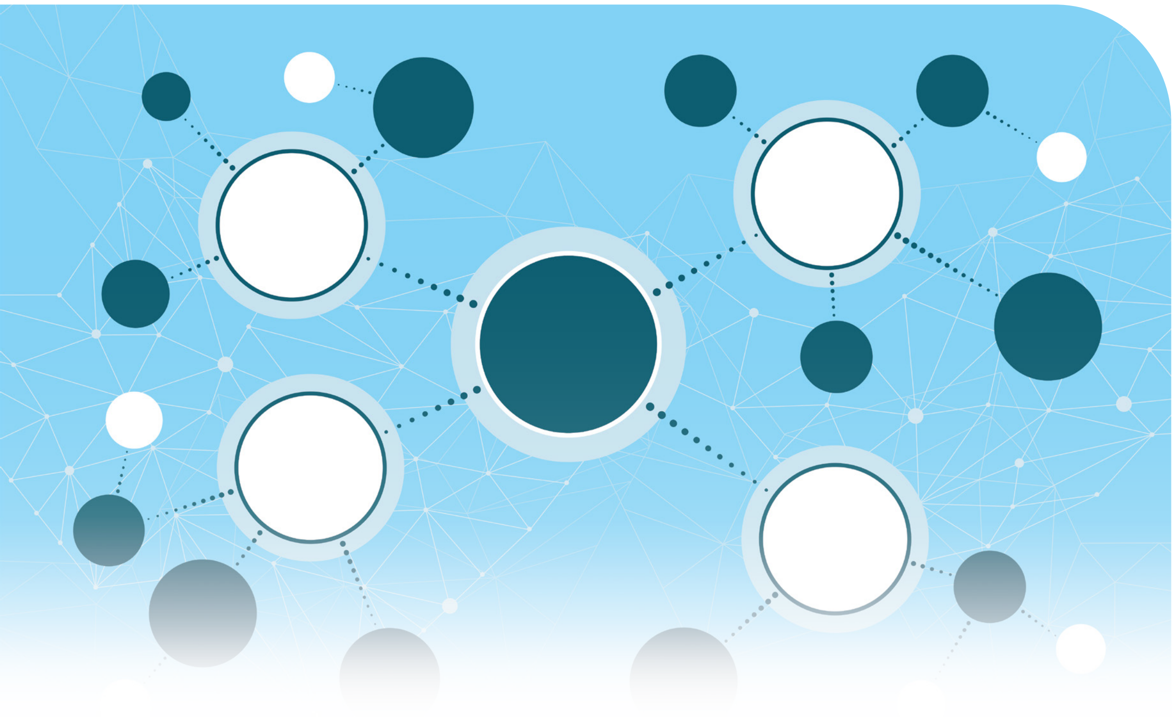
These collision reports were then used to develop Actor Map and AcciMap taxonomies. The Actor Map taxonomy comprised 256 categories from 1,195 actors (e.g. people, organisations and artefacts), and an AcciMap taxonomy comprised 19 factors from 1,656 actions, events and decisions (or lack thereof).

These taxonomies were then used to undertake meta-analyses of the 37 road collision investigation reports. The meta-analysis of the Actor Maps showed that relatively few categories of actors (35 out of 256) are associated with the majority of collisions. Similarly, the meta-analysis of the AcciMaps showed that all of the 1,656 actions, events and decisions (or lack thereof) could be placed into just 19 factor categories. Across the eight AcciMap levels there were just 11 factors that appeared far more frequently than any others. Both of these taxonomies, together with the meta-analysis, enabled a summary of the analysis and derivation of interventions at a national level. The study also points toward the existence of a common contributory (and protective) network for road collisions. This shows that there are a common set of recurring factors that play a part in the majority of road collisions, regardless of the nature of the collision or what actors are involved at the 'sharp end' (i.e. the lower system levels of 'driving processes' and 'equipment and environment').

There were relatively few factors at each of the eight levels of the AcciMap that appear significantly more frequently than all the rest: 'international influences' (4), 'national influences' (3), 'central government' (5), 'regulatory bodies and associations' (4), 'company management and local area government' (4), 'technical and operational management' (1), 'driving processes' (5) and 'equipment and environment' (8). These comprise topics that are typically thought as 'blunt-end factors' (i.e. legislation and regulation; information for the public, industry and government; budget and finance; standards; campaigns, communication and co-ordination) and 'sharp-end factors' (i.e. road design, signage and monitoring; personal protective equipment; substances (i.e. drugs and alcohol); vehicle control; vehicle design; vehicle maintenance and condition; and road conditions). To take into consideration both the sharp-end factors (accounting for 40% of all factors) and blunt-end factors (accounting for 60% of them) together is to take a truly sociotechnical systems approach. On the basis of the study reported here, it is recommended that future effort and resources should be focused on:

1. training road safety investigators in the sociotechnical systems approach using the Actor Map and AcciMap frameworks;
2. undertaking continuous adherence training to ensure that road safety investigators are using the methods appropriately;
3. undertaking a national roll-out of Actor Map and AcciMap frameworks, together with the taxonomies for road safety investigations;
4. prioritising road safety investigations so as to maximise the benefits from the available resources (for example by focusing on: major incidents, indicative incidents that occur frequently, incidents that involve vulnerable road users, incidents involving new technologies such as electric/automated vehicles, and so on);
5. developing a national sociotechnical road safety plan from meta-analysis of Actor Map and AcciMap road safety investigations that increase the protective factors and reduce the contributory factors;
6. continuing to develop and refine the Actor Map and AcciMap taxonomies; and
7. gathering evidence to support the effectiveness of the road safety interventions from the national sociotechnical road safety plan.

1. Introduction to Actor Maps and AcciMaps



The aim of this report is to present the development of taxonomies (classification schemes) for Actor Maps and AcciMaps (Svedung & Rasmussen, 2002), as well as the subsequent meta-analyses, as part of the Road Collision Investigation Project (RCIP), led by the RAC Foundation. The purpose of this research is to demonstrate how Actor Maps and AcciMaps could be used by analysts within a national Road Collision Investigation Branch (similar to those in air, maritime and rail). This report follows two previous RCIP reports, the first of which identified the need for a sociotechnical systems-based approach (Gooding, 2017) and the second of which compared methods for road collision investigation to select the most appropriate one (Stanton, 2019). The Actor Maps and AcciMaps framework (Svedung & Rasmussen, 2002) has been adopted against a background of plateauing road collision statistics over the past decade in the UK, which have remained at around 1,700 deaths a year (DfT, 2020). It should be noted however, that over the past year (2020/21), road deaths have reduced by an estimated 300, which is likely to be due to the effects of COVID-19 reducing road transport (DfT, 2021). Nevertheless, and rather frustratingly for road safety analysts, many of the collisions are repetitions of previous ones except that different road users and different roads are involved (Das et al., 2021). It is proposed that a national investigation body could disseminate road safety interventions nationwide (Gooding, 2017; Stanton, 2019). The desire to tackle road collision investigation more broadly has led to the adoption of a sociotechnical systems thinking approach in general (which combines the analysis of social systems with technical systems (Waterson et al., 2015; Salmon et al., 2012)), and to the Actor Maps and AcciMaps frameworks in particular (Newnam & Goode, 2015; Newnam et al., 2017; Salmon et al., 2020; Stanton et al., 2019).

The iceberg metaphor is often used in sociotechnical systems research (Blokland & Reniers, 2020), to reflect the fact that just as the tip of the iceberg above the surface of the water belies the bulkier mass that lurks beneath the surface, the lower-order system factors which are close to the road environment are more self-evident than the underlying higher-order system factors. For the purposes of the sociotechnical systems analysis, it is vital that the higher-order system factors are identified and addressed if there is to be a reduction in near misses, collisions, serious injuries and deaths. Another way of thinking about the active failures by drivers – often called 'human error', but wrongly, as they are within normal performance variability, in other words within the limits of how people will normally behave (Read et al., 2021) – is to think of them as 'sharp-end' system factors (the tip of the iceberg). These are often much easier to identify in an investigation, as they are close to the event itself, in terms of both time and physical proximity (Salmon et al., 2012; Newnam & Goode, 2015; Newnam et al., 2017; Salmon et al., 2020; Stanton et al., 2019). However, it is argued that they are symptoms of deeper, 'blunt-end', underlying system problems (the bulkier mass of ice beneath the surface of the water (Salmon et al., 2020; Stanton et al., 2019; Blokland & Reniers, 2020; Grant et al., 2018; Grant et al., 2019; Hulme et al., 2019; Salmon et al., 2019)). Actor Maps and AcciMaps are explicit in the representation of both kinds of factors. Whilst the sharp-end factors are normally self-evident, to discover the blunt-end factors requires much more investigation (McIlroy et al., 2021). The Actor Map and AcciMap approach is helpful here, in that it provides a framework for conducting the investigation, by providing the systems levels at which the search for actions, decisions and events (or the lack thereof) should take place. The factors at the blunt end create the preconditions that make road collision events at the sharp end possible (Salmon et al., 2020; Stanton et al., 2019; McIlroy et al., 2021). For the purposes of sociotechnical systems analysis, it is vital that these higher-order factors are identified and addressed if road collisions are to be reduced.

This analysis makes it clear that there is a tension between the need for strong evidence that a particular factor had a role to play in the road collision on the one hand, and, on the other hand, the uncovering of broader systemic factors which are at play higher up in the system, and are often hidden from plain sight (McIlroy et al., 2021). The former are typically immediately connected with the collision (and are often completely obvious) whereas the latter require much deeper investigation, and definitive proof of their influence is far harder to ascertain (McIlroy et al., 2021; RoSPA, 2017). If there is a focus solely on the immediate causes at the levels of 'equipment and environment' and 'driving processes' (which has traditionally been the case for road collision investigations), this could mean that the consideration of safety improvements is missed (McIlroy et al., 2021). A truly systemic approach requires identification of all of the factors and also of strategic, joined-up, interventions (Stanton et al., 2019; Salmon et al., 2019).

Traditionally, active (typically lower-order and sharp-end) and latent (typically higher-order and blunt-end) contributory analyses have identified the lower-level system factors ('equipment and environment' and 'driving processes', just mentioned, being obvious examples) in the event of a collision, but the conditions under which the collision occurred are created by the higher system levels and are often ignored (Salmon et al., 2020; Stanton et al., 2019; McIlroy et al., 2021). This will include factors such as:

- international standards and regulations;
- national standards and regulations;
- governmental policy and legislation;
- national priorities for road safety;
- audits and statistics;
- compliance with regulations and standards as undertaken by regulatory bodies;
- risk assessments; and
- communications and planning undertaken by organisations and local road planning authorities.

If there is a failure to identify all of the potential active and latent failures in the AcciMap, together with the appropriate mitigating strategies identified at each level, then the transport system is unlikely to change. The sociotechnical systems approach is intended to be holistic, especially as it aids in the identification of the higher system-level factors that create the preconditions for collisions. Only by addressing these preconditions will any significant reduction in road collisions occur. In short, road safety is shared across system levels and actors (McIlroy et al., 2019).

As originally conceived, the Actor Map and AcciMap frameworks had six levels (Svedung & Rasmussen, 2002; Salmon et al., 2020), ranging from 'equipment and environment' (at the lowest level) up to 'national government' (at the highest level). More recently this has been extended to include 'national influences' and 'international influences' that operate above the government level (Parnell et al., 2017), to acknowledge that there are higher factors that may be influencing government and the lower levels (such as international standards adopted by national governments). Both of these 'maps' help to show that the factors associated with collisions are both multicausal and, as often as not, non-linear (Stanton et al., 2019). The maps provide a structure for road collision investigations, and encourage the search for potential underlying causes and influences – beyond those which are immediately apparent at the scene of the road collision.

The use of the Actor Map and AcciMap frameworks is growing in acceptance across a broad range of applications, including: aviation (Branford, 2011), disease outbreaks (Waterson, 2009), emergency response (Salmon et al., 2014a), led outdoor activities (Salmon et al., 2014b), rail collisions (Salmon et al., 2013), road collisions (Das et al., 2021; Stanton et al., 2019; McIlroy et al., 2021) and security response to potential terror events (Jenkins et al., 2010). This demonstrates the domain independence of the approach. AcciMaps enable incidents and collisions to be viewed as a framework of relationships between factors; this offers the analyst a significant supplement to the standard narrative reports (McIlroy et al., 2021). Despite this, the construction of Actor Maps and AcciMaps would benefit from a guiding taxonomy of actors (for the Actor Maps (McIlroy et al., 2019)) and contributory factors (for the AcciMaps (Newname & Goode, 2015; Newnam et al., 2017; Salmon et al., 2020; Stanton et al., 2019)). An **Actor Map taxonomy for the UK** has already been developed, derived through a series of workshops with experts (McIlroy et al., 2019) and identifying main actors at the levels of *international influences* (10 actor map categories), *national influences* (12), *central government* (15), *regulatory bodies and associations* (26), *company management and local area government* (29), *technical and operational management* (31), *driving processes* (14) and *equipment and environment* (30).[1] This is a good starting point for deeper exploration of the actors with a series of case studies into road collisions.

There have also been reports of a generic taxonomy for AcciMaps (Salmon et al., 2020) as well as a specific one for road freight collisions (Newnam & Goode, 2015). The **generic taxonomy** was developed from the analysis of 23 incidents occurring in a wide range of domains, including aerospace, led outdoor recreation, maritime, oil and gas, public health, and rail (Salmon et al., 2020). A total of 5,587 contributory factors were classified into 79 thematic codes. The most frequently occurring factors associated with incidents included: policy, legislation and regulation; communication and co-ordination; preparation and planning; supervision and leadership; and equipment, technology and resources. The authors report that the classification scheme needs to be appropriate for the domain to which it is applied (Salmon et al., 2020), therefore a taxonomy specific to road collision may need to be developed. The **road freight transportation taxonomy** was developed from a thematic analysis of reports from the US National Transportation Safety Board (Newnam & Goode, 2015). The taxonomy identified factors at each of the six AcciMap levels: 'government' (e.g. decisions, actions and legislation relating to road transport), 'regulatory bodies' (e.g. activities, decisions and actions, as well as policies and guidelines), 'other organisations and clients' (e.g. activities, decisions and actions), 'road freight transportation company' (e.g. activities, decisions, actions, as well as company policies, planning and budgeting), 'drivers' (e.g. driver, co-drivers, passengers, law enforcement officer, road and rail work crews) and 'equipment and environment' (e.g. in-vehicle telemetry, road surface conditions, ambient and meteorological conditions). It was anticipated at the outset that some of these classifications would be shared with the current project, as the focus is on the general transport system, but might need extending for all road users (Stanton et al., 2019).

Only three meta-analyses of AcciMaps have been reported in the open, peer-reviewed, literature (Newnam & Goode, 2015; Newnam et al., 2017; Salmon et al., 2020). The generic meta-analysis showed that contributory factors traditionally associated with the sharp end of the system (i.e. physical processes and actor activities as well as *equipment and environment*) were also found at the blunt end (all the other system levels) (Salmon et al., 2020). These factors included: violations, unsafe acts, judgment, decision-making, qualifications, training, experience, competence, communication, co-ordination, risk assessment, management, policy, legislation and regulation. The road freight meta-analyses cover the analysis of 27 National Transportation Safety Board reports over the period

1 Note that when any of these eight levels are named in the text from this point onwards, italics are used to aid their easy identification.

1996–2013 (Newnam & Goode, 2015) and 21 Australian coronial investigations over the period 2004–14 (Newnam et al., 2017). Whilst there are obviously some differences in the frequencies in the factors, the similarities are striking. To cite an example, both studies report the presence of contributory factors including: policies and procedures (at the *central government* level), policies and procedures (at the *regulatory bodies and associations* level), training, fatigue management programmes and work scheduling (at the *company management and local area government* level), fatigue, alcohol/drugs, competence and work schedule (at the *driving processes* level) and road design, road furniture, time of day and traffic conditions (at the *equipment and environment* level) (Newnam & Goode, 2015; Newnam et al., 2017). Because the previous meta-analysis research did not focus specifically on road collisions for all road users (the latter two studies being focused solely on road freight collisions), there is a gap in current understanding that will, to some extent at least, be fulfilled by the meta-analysis presented in the current report.

2. Method Part 1: Development of Actor and AcciMaps

The first method section covers the approach taken to train the investigators in the Actor Map and AcciMap frameworks, and a summary of the 37 collisions which they investigated.

2.1 Road Collision Investigation Project Investigators

The Road Collision Investigation Project (RCIP) investigators were recruited by the police force in the three police force areas identified for the study: Dorset, Devon and Cornwall; Humberside; and West Midlands. The RAC Foundation and the Department for Transport (UK) provided the job description and person specification for the role, and the relevant police forces interviewed and appointed three road collision analysts. There were five people involved in the study, aged between 20 and 56 years (mean age = 36 years), with previous length of experience in collision investigation ranging from 0 to 25 years (mean length = 9.5 years). One RCIP analyst was assigned to each of the three police forces. In addition, there was one principal RCIP Analyst (who reviewed the work of the RCIP analysts) and the RCIP project manager. Technical support on the Actor Map and AcciMap processes was provided by the author of this report.

2.2 Training of Road Collision Investigation Project Investigators

The RCIP investigators were trained by the author of this report in August and November 2019. The initial training comprised an introduction to the role of Actor Maps and AcciMaps in road collision investigation, with a demonstration based on the collision between an Uber automated vehicle and a pedestrian (Stanton et al., 2019). The process for analysing collisions in which the RCIP analysts were trained has four main steps:

A. Identify the actors who could have played a role in the collision, at all of the system levels in the Actor Map (McIlroy et al., 2019).
B. Associate the actions, events and decisions (or lack thereof) pertaining to those actors leading up to the collision in the AcciMap (Newnam & Goode, 2015; Newnam et al., 2017; Salmon et al., 2020).
C. Identify the active and latent failures on the AcciMap.
D. For each failure identified in the AcciMap, identify at least one recommendation to mitigate that failure, using the systems levels from the AcciMap framework.

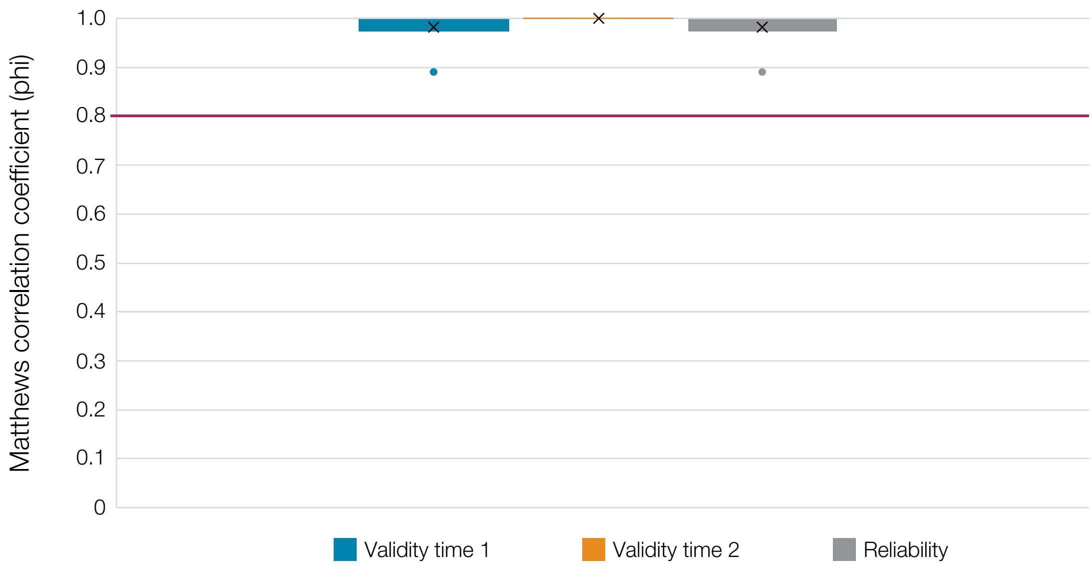
All of these steps are crucial to the systems approach advocated in the RCIP (Svedung & Rasmussen, 2022; Gooding, 2017; Stanton, 2019), as they are necessary for providing the breadth of recommendations needed to reduce collisions. This was followed by two further case studies in which the RCIP analysts were required to construct the Actor Map and AcciMap based on information provided by the trainer. The first of the case studies was based on a collision between a car and a cyclist, in which the car driver was distracted (Parnell et al., 2017). The second case study was based on a collision between a car and a motorcycle, where the motorcycle was speeding (McIlroy et al., 2021). After the initial training, there was a gap of approximately two months during which the RCIP analysts began investigating historical collisions in their own area. Telephone and online support for these investigations was provided by the trainer. In the second training session, the Actor Map and AcciMap frameworks were revisited and a refresher of the case studies was given. In addition, the RCIP analysts brought case studies from their own investigations to share with each other. These were discussed amongst the trainer and analysts, and corrections made where appropriate.

2.3 Reliability and validity

Testing of reliability and validity is a necessary precursor of using any method (Stanton, 2016), including those for collision investigation. A formal study of both reliability and validity was undertaken for the Actor Map and AcciMap classifications made by the RCIP analysts as part of the training sessions. Concurrent validity was assessed by comparing the RCIP analysts' classifications with those made by an expert (the trainer). Test–retest reliability was assessed by comparing the classifications made in the first training sessions with those made at the session two months later. From this data the Matthews Correlation Coefficient, phi (Matthews, 1975) was computed. This approach has been used for numerous investigations into reliability and validity of human factors methods (Stanton & Young, 1999;

Stanton & Young, 2003; Stanton et al., 2021). For the Actor Map, both validity and reliability performed well, as shown in Figure 2.1, where above the red line indicates an acceptable level of performance.

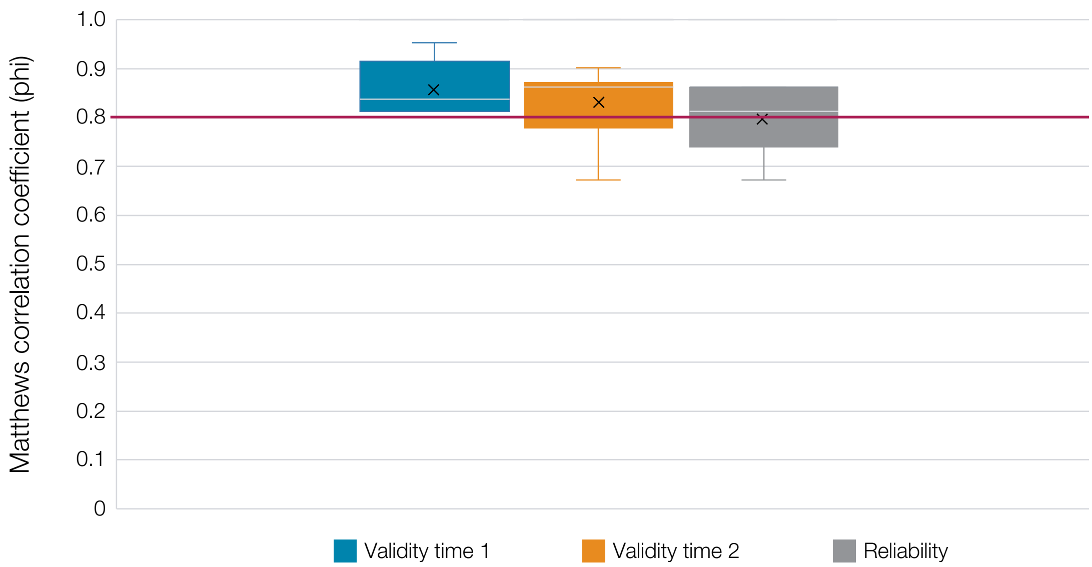
Figure 2.1: Reliability and validity of the RCIP analysts' Actor Maps



Source: Author's own

For the AcciMap, both validity and reliability were at an acceptable level, as shown in Figure 2.2, where the median line in the box-and-whisker plots is above 0.8.

Figure 2.2: Reliability and validity of the RCIP analysts' AcciMaps



Source: Author's own

2.4 Selection of collisions for analysis

Cases were selected by each of the RCIP analysts from their own area (Dorset, Devon and Cornwall; Humberside; and West Midlands). The process involved working backwards through the most recently closed case files and then conducting the investigations on those that had the most data associated with them (which therefore tended to be fatal or very serious in nature). The 37 collisions occurred between 2017 and 2019 (2017: n = 18; 2018: n = 10; 2019: n = 9). A summary of the collision types is shown in Table 2.1.

Table 2.1: Collision types investigated

Collision type	Report numbers
Car vs pedestrian(s)	12, 21, 22, 25, 26, 28, 29, 30, 33
Car vs stationary object (tree, wall, lamppost)	11, 16, 19, 34, 36
Motorcycle vs stationary object (tree, ditch, wooden fence, telegraph pole)	3, 13, 15, 31, 35
Car vs car	1, 23, 24, 32
Car vs motorcycle	5, 9, 18, 20
Van vs van	2
Coach vs car	4
Motorcycle vs motorcycle	6
HGV (heavy goods vehicle) vs bicycle	7
HGV vs vehicle recovery truck	8
Car vs bicycle	10
Car vs stationary vehicle transporter	14
Van vs bridge column	17
Tractor vs motorcycle	27
Van vs bicycle	37

Source: Author's own

As shown in Table 2.1, 'car vs pedestrian(s)' was the most frequent collision type, being investigated in nine reports. This was followed by 'car vs stationary object' and 'motorcycle vs stationary object', both with five reports each. 'Car vs car' and 'car vs motorcycle' both had four reports. The remainder of collision types had just one report apiece.

3. Method Part 2: Development of Taxonomy and Meta-Analysis

The second method section explains the approach taken to develop the Actor Map and AcciMap taxonomies as well as the meta-analyses undertaken on the 37 collision investigations.

3.1 Human factors analysts

The human factors analysts involved in the development of the classification schemes and meta-analyses both held doctorate degrees and each had over 30 years' experience in human factors research and practice. The research was approved by the University of Southampton Ethics Research and Governance Online (ERGO No. 49186.A1).

3.2 Coding of contributory actors and factors

The Actor Map taxonomy (which included people, groups, bodies, organisations, associations and non-human artefacts) was developed and extended from the UK road collision Actor Map developed in the STARS

(Sociotechnical Approach to Road Safety) global road safety project (McIlroy et al., 2019). The development of the AcciMap taxonomy was based initially upon two previous classification schemes, one generic (Salmon et al., 2020) and one derived from road freight transport (Newnam & Goode, 2015). Each of the 37 reports was analysed in turn to iteratively develop the taxonomy of actors (Actor Map) and factors (AcciMap), initially based on those already in existence and developing new categories as appropriate. One unique aspect of the current project was the distinction between the contributory and protective factors in the AcciMap.

Actor categories were identified at all eight systemic levels, 256 in total: *international influences* (35), *national influences* (7), *central government* (16), *regulatory bodies and associations* (42), *company management and local area government* (33), *technical and operational management* (20), *driving processes* (17), *equipment and environment* (86). The most frequently occurring actors from the 37 case studies are indicated in Table 3.1. The full list of actors, which are taken from collision investigation reports, is in Appendix A.

Table 3.1: Highest frequency actors identified across the eight systemic levels

System level	Actors with frequency 10 or greater
International influences	Vehicle manufacturers, European New Car Assessment Programme (Euro NCAP), European Union legislation, international researchers, European Transport Safety Council (ETSC), European Commission (e.g. Mobility and Transport)
National influences	Parliamentary Advisory Council for Transport Safety (PACTS), Transport Research Laboratory (TRL), British Standards Institution (BSI)
Central government	UK legislation (e.g. Road Traffic Act 1998, The Working Time Regulations 1998, Highway Code, etc.), Department for Transport (DfT), DfT THINK! road safety campaign, Home Office
Regulatory bodies and associations	UK road traffic police, Driver and Vehicle Licensing Agency (DVLA), Driver and Vehicle Standards Agency (DVSA), Royal Society for the Prevention of Accidents (RoSPA)
Company management and local area government	Local police force, local council (including local authority highways), insurance companies
Technical and operational management	Vehicle design engineers, local road planners and engineers, police officers
Driving processes	Drivers (car, van, lorry, coach, etc.), excessive speed, rider (motorcycle), passenger in vehicle, pedestrian
Equipment and environment	Vehicle (car), substance abuse (drugs and/or alcohol), single carriageway, no insurance, driving licence (points, convictions, suspended), vehicle (motorcycle), obscured view (hedge, tree, foliage)

Source: Author's own

As previously stated, the factors identified in the AcciMap were initially derived from previous studies (Newnam & Goode, 2015; Salmon et al., 2020). The taxonomy developed from the 37 RCIP reports distinguished between contributory factors (i.e. factors that were linked to the collision, whether directly (active factors) or indirectly (latent factors that created the necessary preconditions)) and protective factors (both active and latent) that could have reduced the likelihood of the collision or mitigated some of the negative consequences. Table 3.2 details the taxonomy, providing also a definition of each factor and an example of a contributory and a protective factor (events, decisions and actors, or the lack thereof) identified in the study. The full list of factors, which are taken from collision investigation reports, is in Appendix B.

Table 3.2: Taxonomy of AcciMap factors with definition and examples

Factor	Definition with contributory and protective examples
1. Standards (Salmon et al., 2020)	*Formally recognised standards for transport safety* Contributory: No Euro NCAP equivalent for motorcycles Protective: five-star Euro NCAP rating only for cars with autonomous emergency braking since 2019
2. Legislation and regulation (Newnam & Goode, 2015; Salmon et al., 2020)	*Laws and regulations that are mandatory* Contributory: tyre tread wear indicators are not mandatory Protective: seatbelts must be worn if fitted (fine of up to £500)
3. Evidence, data and statistics	*Reports containing evidence, data and statistics* Contributory: A&E driving cases involving alcohol have risen by 13% Protective: 97% of children in rear of vehicle wear seat belts
4. Campaigns, communication and co-ordination (Salmon et al., 2020)	*Focused campaigns related to road safety* Contributory: THINK! campaign on fatigue has been withdrawn Protective: THINK! campaigns on drink driving have been running for 50 years
5. Information for the public, industry and government	*Information that is made widely available to improve safety* Contributory: TyreSafe survey shows higher proportion of illegal tyres at the point of change Protective: Driving for Better Business has free resources and tools for companies to manage road risk
6. Budget and finance (Salmon et al., 2020)	*Effects of budgets and finances on road safety* Contributory: reduction in police testing for drug and drink driving due to budget cuts (reduction in officers and resources) Protective: government vehicle scrappage scheme leads to newer and safer cars on roads
7. Vehicle design	*Vehicle features that can have an impact on road safety* Contributory: safety features can be expensive optional extras Protective: visual seat belt warning in most vehicles
8. Training (Newnam & Goode, 2015; Salmon et al., 2020)	*Driver and rider training in vehicle control and safety* Contributory: no requirement for post-driving/riding test refresher or checks up to the age of 70 years old Protective: advanced courses available for riding for motorcyclists
9. Road design, signage and monitoring (Newnam & Goode, 2015)	*Aspects of road environment design that affect safety* Contributory: no centre lane rumble strips to alert driver to moving across the central point Protective: dual carriageway with central reservation

Factor	Definition with contributory and protective examples
10. Culture (Salmon et al., 2020)	*The values and beliefs that direct behaviour* Contributory: company allows driver to work all night and then commence 3-hour drive without a rest Protective: employer culture encouraged illness disclosure
11. Policy (Newnam & Goode, 2015; Salmon et al., 2020)	*Formal polices (or lack thereof) that affect road safety* Contributory: company policy did not prioritise purchase of vehicles with safety systems Protective: traffic officers prioritise collision hotspot zones
12. Personal protective equipment	*The provision, effectiveness and use of personal protective equipment* Contributory: vehicle passengers not wearing seatbelts Protective: SHARP (Safety Helmet Assessment and Rating Programme) provides information on motorcycle helmet degree of protection
13. Vehicle maintenance and condition (Newnam & Goode, 2015)	*State of vehicle, maintenance and MOT defects/advisories* Contributory: rear tyre of motorcycle was underinflated Protective: fuel stations have tyre pressure testing machines
14. Substances (drugs and alcohol) (Newnam & Goode, 2015)	*The effects of drugs and alcohol on road safety* Contributory: driving/riding under the influence of substances Protective: government review of funding allocation for alcohol abuse services in local councils nationally and assessment of the potential benefits for reducing drink-driving on roads
15. Vehicle control (Newnam & Goode, 2015)	*Aspects of vehicle control that could have contributed to the collision* Contributory: approaching bend at inappropriate speed Protective: driver attempts to correct the path of his vehicle into the correct lane
16. Medical conditions and medication (Newnam & Goode, 2015)	*Any relevant medication or conditions of those involved* Contributory: driver on strong medication for pain which has side effects, including drowsiness Protective: DVLA has online reporting system for medical conditions that has sped up processing times
17. Work pattern (Newnam & Goode, 2015)	*The influence of working patterns on the collision* Contributory: working 11 shifts with no day off and finishes 11-hour night shift at 06.00 Protective: mandatory rest breaks after night shift
18. Convictions	*Any prior or current convictions held by those involved* Contributory: history of traffic convictions Protective: retraining after driving ban
19. Road conditions (Newnam & Goode, 2015)	*The local effects of road condition on the collision* Contributory: wet road surface Protective: street lighting illuminated road well

Source: Author's own

3.3 Inter-rater reliability

An inter-rater reliability analysis (i.e. the degree of agreement between two different analysts) was conducted on the AcciMap classification scheme for five of the studies which involved a second analyst (Salmon et al., 2010; Vicente & Christoffersen, 2006; Nayak & Waterson, 2016). The full classification scheme was used, i.e. the categories together with the definitions and examples. Both percentage agreement and Cohen's kappa statistic were computed. Across the five studies a high level of agreement was found between the analysts (90.6% agreement with kappa = 0.64, which means substantial agreement).

3.4 Network analysis

The links between factors in the AcciMap network were analysed using the SocNetV (version 3.0.4) software program (a tool for analysing and visualising social networks). All the links were coded into a matrix using an Excel spreadsheet that put the 19 factors into a directed network. This network was imported into SocNetV and analysed using three metrics (in-degree, out-degree and power centrality) as described below.

In-degree centrality is used to quantify the incoming ties that a node receives in the network. For the purposes of the meta-analysis undertaken in this report, this means that a node (factor) having high in-degree centrality indicates that it was influenced by many other nodes (factors) in the AcciMap.

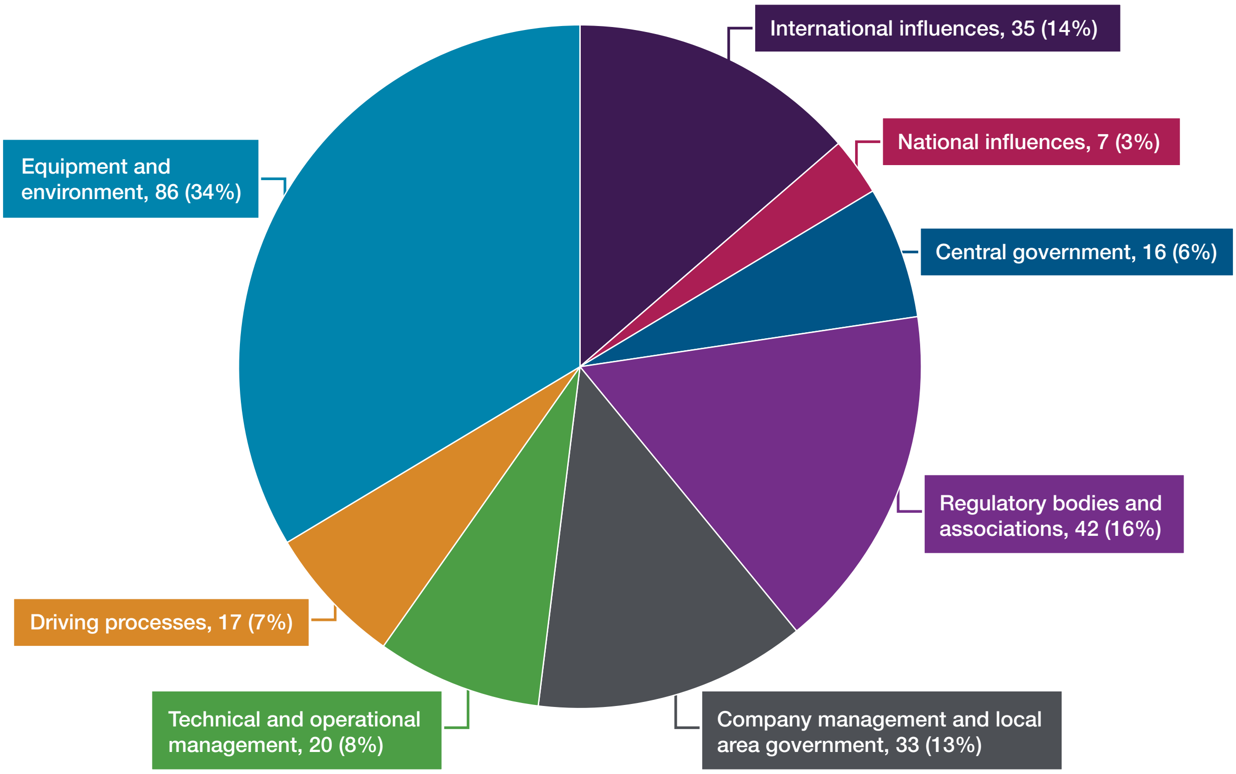
Out-degree centrality is used to quantify the outgoing ties that a node emits in the network. For the purposes of the meta-analysis undertaken in this report, this means that a node (factor) having high out-degree centrality indicates that it had influence over many other nodes (factors) in the AcciMap.

Power centrality is a combination of in-degree and out-degree centrality, to represent the degree of power dominance that each node (factor) has over other nodes (factors) in the network. More dominant nodes (factors) have greater influence over other nodes (factors), so the analysis shows which of the 19 factors in the AcciMap taxonomy is likely to have the largest overall influence on road safety (based on the 37 reports examined).

4. Actor Maps

A total of 256 actor categories were identified across the eight levels of the Actor Maps, comprising 1,195 actors in total. Figure 4.1 shows a summary of the frequencies of the actors at each of the levels, and the percentage of the total, with the largest group being at the bottom level (86 actor categories at the *equipment and environment* level, representing 33% of the total). *Regulatory bodies and associations* (16%), *international influences* (14%) and *company management and local area government* (13%) represent the next largest groupings. The smallest groupings are *technical and operational management* (8%), *driving processes* (7%), *central government* (6%) and *national influences* (3%).

Figure 4.1: Pie chart of the total number and proportion of actor categories at each of the system levels



Source: Author's own

Note: Percentages may not appear to sum to 100% owing to rounding.

The number of categories differs substantially from those previously identified for UK road safety (167 vs 256), as shown in Table 4.1. The differences are particularly marked for *international influences* (10 vs 35), *regulatory bodies and associations* (26 vs 42), *technical and operational management* (31 vs 20) and *equipment and environment* (30 vs 86). Possible reasons for these differences will be discussed later.

Table 4.1: Comparison of number of Actor Map categories with previous study (McIlroy et al., 2019)

System levels	Number of Actor Map categories	
	Previous	Current
International influences	10	35
National influences	12	7
Central government	15	16
Regulatory bodies and associations	26	42
Company management and local area government	29	33
Technical and operational management	31	20
Driving processes	14	17
Equipment and environment	30	86
Total	**167**	**256**

Source: Author's own

Table 4.2 shows the most frequently identified actors (i.e. greater than f = 9) for each of the systemic levels in the AcciMap; these higher-frequency actors are the ones likely to have a greater role to play in contributing to road safety in the UK. The cut-off point of 9 is somewhat arbitrary, but it does serve to highlight actors that occur more frequently in the Actor Maps (whist keeping the actors at a manageable number in Table 4.2 – the full analysis is in Appendix A). The top actor for each of the levels identifies the following: Vehicle manufacturers, PACTS, UK legislation, Road traffic police, Local police force, Vehicle design engineers, Drivers, and Vehicle (car). The full analysis of all of the actors and the frequencies that they appeared in the 37 Actor Maps is presented in Appendix A.

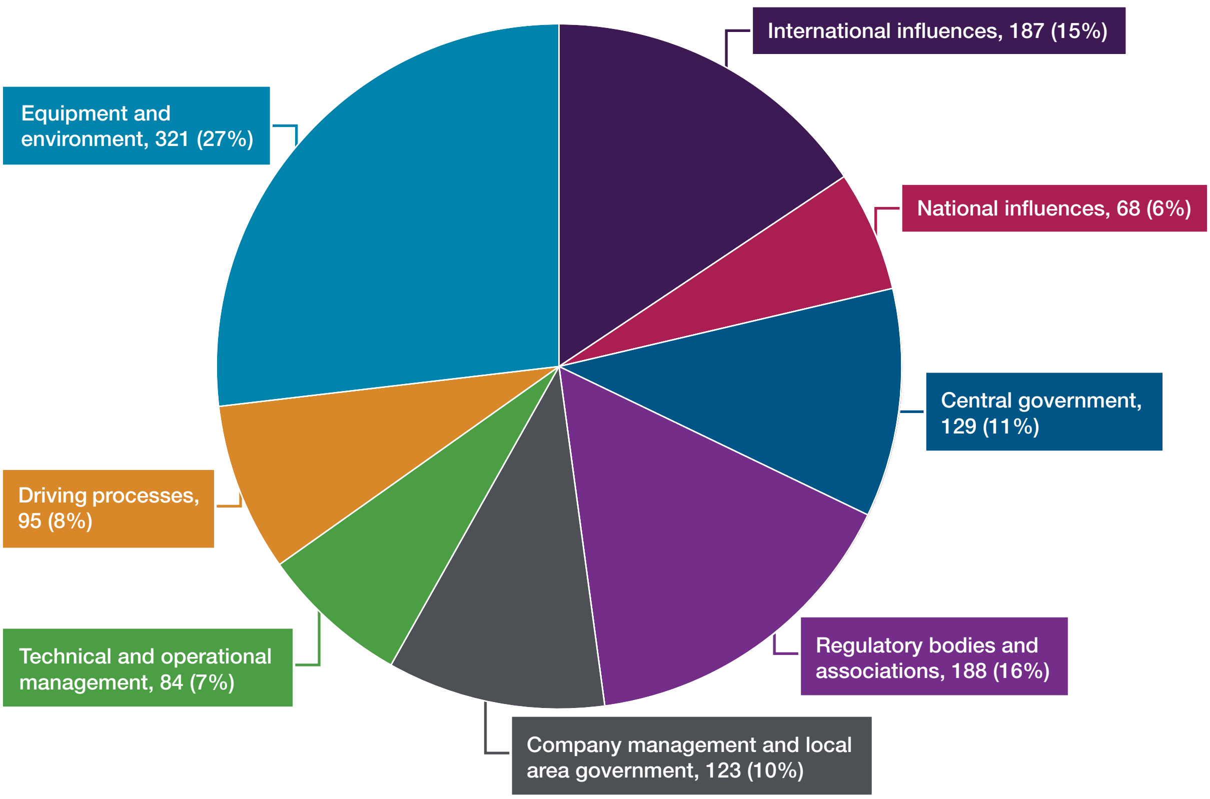
Table 4.2: Most frequent actors identified in Actor Maps by AcciMap levels

System levels	Actor with frequency 10 or greater	Frequency
International influences	Vehicle manufacturers	28
	European New Car Assessment Programme (Euro NCAP)	24
	European Union legislation	17
	International researchers	16
	European Transport Safety Council (ETSC)	12
	European Commission (e.g. Mobility and Transport)	11
National influences	Parliamentary Advisory Council for Transport Safety (PACTS)	23
	Transport Research Laboratory (TRL)	12
	British Standards Institution (BSI)	10
Central government	UK legislation (e.g. Road Traffic Act 1998, The Working Time Regulations 1998, Highway Code, smart motorways etc.)	27
	Department for Transport (DfT)	27
	DfT THINK! road safety campaign	26
	Home Office	10
Regulatory bodies and associations	UK road traffic police	21
	Driver and Vehicle Licensing Agency (DVLA)	19
	Driver and Vehicle Standards Agency (DVSA)	13
	Royal Society for the Prevention of Accidents (RoSPA)	12
Company management and local area government	Local police force	28
	Local council (including local authority highways)	25
	Insurance companies	15
Technical and operational management	Vehicle design engineers	16
	Local road planners and engineers	14
	Police officers	13
Driving processes	Drivers (car, van, lorry, coach, etc.)	30
	Excessive speed	13
	Rider (motorcycle)	11
	Passenger in vehicle	11
	Pedestrian	10
Equipment and environment	Vehicle (car)	25
	Substance abuse (drugs and/or alcohol)	21
	Single carriageway	18
	No insurance	13
	Driving licence points/convictions/suspended	11
	Vehicle (motorcycle)	11
	Obscured view (hedge, tree, foliage)	10

Source: Author's own

A total of 1,195 actors were identified in the analysis of the 37 Actor Maps. The frequencies of the actors that were identified at each of the system levels, and the percentage of the total, are presented in Figure 4.2. As with Figure 4.1, the largest proportion of actors are at the *equipment and environment* level (27%). The next largest proportion is at the *regulatory bodies and associations* (16%) and *international influences* (15%) levels. This is followed by the *central government* (11%) and *company management and local area government* (10%) levels. Finally, the lowest proportions are at the *driving processes* (8%), *technical and operational management* (7%) and *national influences* (6%) levels. The rank ordering of the levels is similar to Figure 4.1 (which shows proportion of actor groups rather than total number of actors) with the notable exception of *central government*, which has a larger proportion of actors in the Actor Maps.

Figure 4.2: Pie chart of the total number and proportion of actors at each of the system levels



Source: Author's own

5. AcciMaps

As shown in Table 5.1, a total of 1,656 individual factors were extracted from 37 AcciMaps, of which 1,063 were classified as contributory (i.e. factors that were linked to the collision) and 593 as protective (i.e. factors that could have reduced the likelihood of the collision, or mitigated some of the negative consequences). This means that there were almost twice as many contributory factors as protective factors.

Table 5.1: Frequencies of contributory and protective factors identified in the AcciMaps

Factors	System levels																Totals	
	II		NI		CG		RB&A		CM&LAG		TOM		DP		E&E			
Contributory (–) / protective (+)	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+
1. Standards	13	19	2	6	7	8	4	6	1	1	0	0	0	0	0	0	**27**	**40**
2. Legislation and regulation	23	51	2	4	52	62	15	27	10	3	9	6	17	3	34	0	**162**	**156**
3. Evidence, data and statistics	25	21	26	14	22	4	28	6	10	6	7	0	0	0	0	0	**118**	**51**
4. Campaigns, communication and co-ordination	1	3	2	14	18	18	0	9	2	5	1	0	0	2	0	0	**24**	**51**
5. Information for the public, industry and government	9	9	7	15	2	18	5	27	4	16	2	4	0	0	0	0	**29**	**89**
6. Budget and finance	0	0	5	0	22	3	19	3	28	2	10	1	0	0	0	0	**84**	**9**
7. Vehicle design	5	4	0	1	0	0	0	1	10	1	10	4	1	0	26	4	**52**	**15**
8. Training	0	0	0	1	0	1	2	6	0	6	2	0	2	2	3	0	**9**	**15**
9. Road design, signage and monitoring	0	2	0	1	2	5	1	3	36	1	29	9	15	1	85	55	**168**	**77**
10. Culture	0	0	0	0	0	0	0	0	2	1	0	1	0	0	4	1	**6**	**3**
11. Policy	0	0	0	0	0	1	0	1	6	1	3	1	0	0	0	0	**9**	**4**
12. Personal protective equipment	0	0	0	0	1	1	0	0	6	4	1	1	19	1	51	7	**78**	**14**
13. Vehicle maintenance and condition	0	0	0	0	0	0	0	0	1	1	3	4	3	0	32	2	**39**	**7**
14. Substances (drugs, alcohol)	0	0	0	0	0	0	0	0	1	0	3	0	26	5	22	0	**52**	**5**
15. Vehicle control	0	0	0	0	0	0	0	0	0	0	0	0	119	6	20	0	**139**	**6**
16. Medical conditions and medication	0	0	1	2	0	1	0	4	0	0	2	0	9	0	8	0	**20**	**7**
17. Work pattern	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	**3**	**0**
18. Convictions	0	0	0	0	0	0	0	0	0	0	0	0	8	0	12	0	**20**	**0**
19. Road conditions	0	0	0	0	0	0	0	0	0	0	0	1	6	0	18	43	**24**	**44**
Totals	**76**	**109**	**45**	**57**	**126**	**122**	**74**	**93**	**117**	**48**	**82**	**32**	**227**	**20**	**316**	**112**	**1063**	**593**
Grand total																	**1,656**	

Source: Author's own

All of the factors were coded into one of the 19 thematic codes, as shown in Table 5.1. *Equipment and environment* (E&E: 25.8%) accounts for over 25% of the factors and together with *driving processes* (DP: 14.9%) makes just over 40% of the contributory and protective factors. The remaining contributory and protective factors (almost 60%) reside at the deeper system levels (i.e. from *international influences* (II) to *technical and operational management* (TOM) in Table 5.1). As shown in Table 5.1, the remaining factors are: *central government* (CG: 15.0%), *international influences* (II: 11.2%), *regulatory bodies and associations* (RB&A: 10.1%), *company management and local area government* (CM&LAG: 10.0%), *technical and operational management* (TOM: 6.9%) and *national influences* (NI: 6.2%).

Those factors with combined contributory and protective frequencies greater than 16 are represented in Figure 5.1 to show that relatively few are implicated in the majority of cases. As before, the cut-off point of 16 is somewhat arbitrary, but it does serve to highlight factors that occur more frequently in the AcciMaps (whist keeping the factors at a manageable level in Figure 5.1 – all of the factors are presented in Table 5.1 and the full analysis is provided in Appendix B). Legislation and regulation (5) together with evidence, data and statistics (5) appear most frequently, followed by information for the public, industry and government (5) together with road design, signage and monitoring (4). Next is budget and finance (3), followed by: campaigns, communication and co-ordination (2); personal protective equipment (PPE) (2); substances (drugs and alcohol) (2); and vehicle control (2). Finally, there is standards (1); vehicle design (1), vehicle maintenance and condition (1); and road conditions (1).

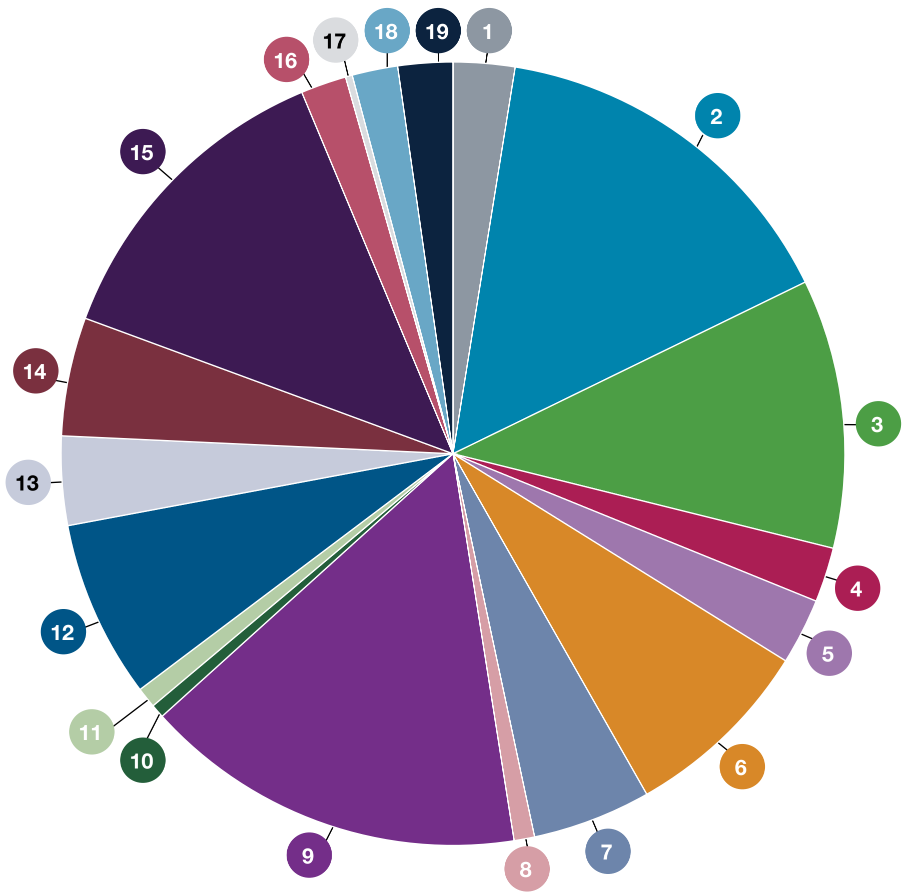
Figure 5.1: High-frequency factors from meta-analysis of AcciMap (n>16)

II	Standards	Legislation and regulation	Evidence, data and statistics	Information for the public...				
NI	Evidence, data and statistics	Campaigns, comms and co-ordination	Information for the public...					
CG	Legislation and regulation	Evidence, data and statistics	Campaigns, comms and co-ordination	Information for the public...	Budget and finance			
RB&A	Legislation and regulation	Evidence, data and statistics	Information for the public...	Budget and finance				
CM&LAG	Evidence, data and statistics	Information for the public...	Budget and finance	Road design, signage and monitoring				
TOM	Road design, signage and monitoring							
DP	Legislation and regulation	Road design, signage and monitoring	Personal protective equipment	Substances (drugs and alcohol)	Vehicle control			
E&E	Legislation and regulation	Vehicle design	Road design, signage and monitoring	Personal protective equipment	Vehicle maintenance & condition	Substances (drugs and alcohol)	Vehicle control	Road conditions

Source: Author's own

The relative proportions and frequencies of the contributory factors are shown in Figure 5.2, and those of the protective factors in Figure 5.3. The major factors that are contributing towards collisions are: road design, signage and monitoring (16%), legislation and regulation (15%), vehicle control (13%) and evidence, data and statistics (11%). These four factors account for 55% of contributory factors associated with the 37 collisions analysed. Other significant factors in terms of frequency include: budget and finance (8%), PPE (7%), vehicle design (5%) and substances (i.e. drugs and alcohol) (5%).

Figure 5.2: Pie chart of the proportions of contributory factors

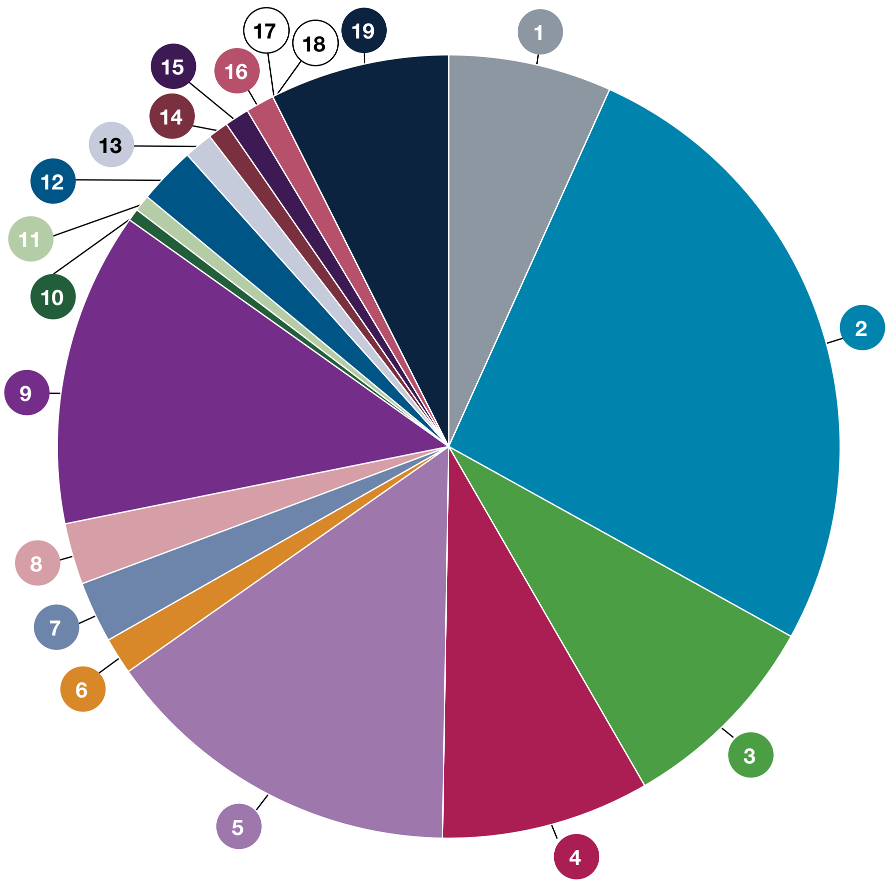


1 Standards, 27 (3%)
2 Legislation and regulation, 162 (15%)
3 Evidence, data and statistics, 118 (11%)
4 Campaigns, communication and co-ordination, 24 (2%)
5 Information for the public, industry and government, 29 (3%)
6 Budget and finance, 84 (8%)
7 Vehicle design, 52 (2%)
8 Training 9, (1%)
9 Road design, signage and monitoring, 168 (16%)
10 Culture, 6 (1%)
11 Policy, 9 (1%)
12 PPE, 78 (7%)
13 Vehicle maintenance and condition, 39 (4%)
14 Substances (drugs, alcohol), 52 (5%)
15 Vehicle control, 139 (13%)
16 Medical conditions and medication, 20 (2%)
17 Work pattern, 3 (0%)
18 Convictions, 20 (2%)
19 Road conditions, 24 (2%)

Source: Author's own

The major factors that are protecting against collisions shown in Figure 5.3 are revealed to be: legislation and regulation (26%); information for the public, industry and government (15%); and road design, signage and monitoring (13%). These three factors account for 54% of protective factors associated with the 37 collisions analysed. Other significant factors in terms of frequency include: evidence, data and statistics (9%); campaigns, communication and co-ordination (9%); road conditions (7%); and standards (7%).

Figure 5.3: Pie chart of the proportions of protective factors



1 Standards, 40 (7%)

2 Legislation and regulation, 156 (26%)

3 Evidence, data and statistics, 51 (9%)

4 Campaigns, communication and co-ordination, 51 (9%)

5 Information for the public, industry and government, 89 (15%)

6 Budget and finance, 9 (2%)

7 Vehicle design, 15 (3%)

8 Training 15, (3%)

9 Road design, signage and monitoring, 77 (13%)

10 Culture, 3 (1%)

11 Policy, 4 (1%)

12 PPE,14 (2%)

13 Vehicle maintenance and condition, 7 (1%)

14 Substances (drugs, alcohol), 5 (1%)

15 Vehicle control, 6 (1%)

16 Medical conditions and medication, 7 (1%)

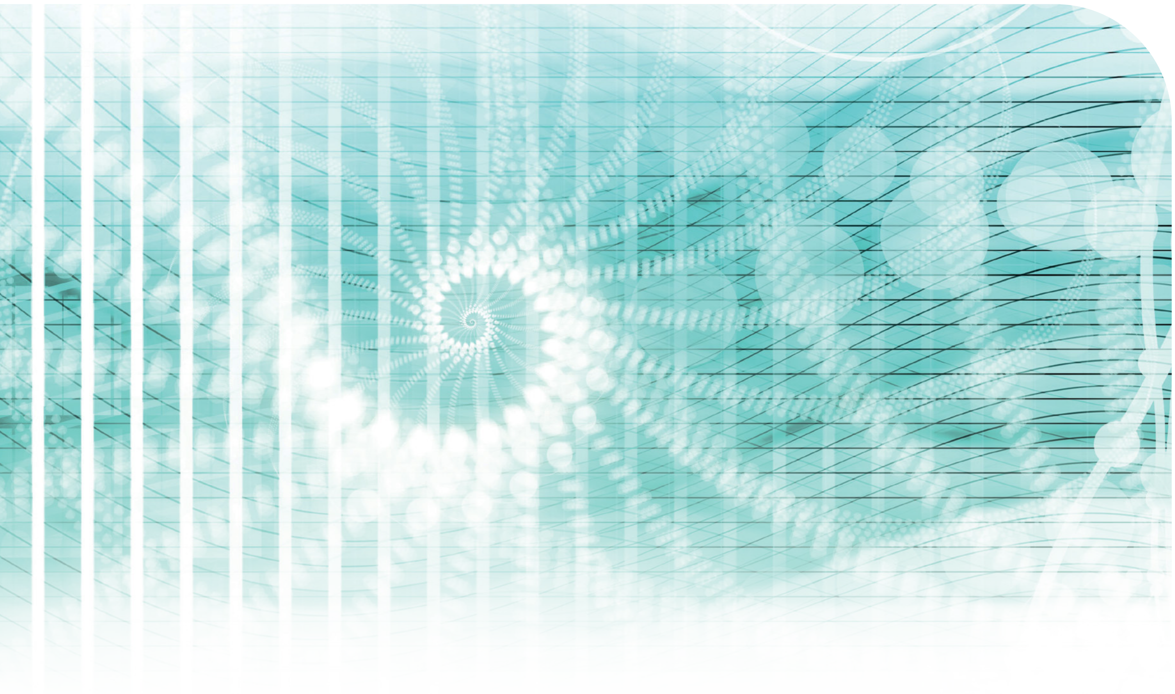
17 Work pattern, 0 (0%)

18 Convictions, 0 (0%)

19 Road conditions, 44 (7%)

Source: Author's own

6. Network Analysis



The in-degree centrality and out-degree centrality metrics were computed for each of the factors as nodes in a network, on the basis of the connections summarised from all of the 37 AcciMap road collision investigations. The rank ordering for each of the 19 factors listed earlier in Table 3.2 is presented in Table 6.1. In-degree centrality metrics are higher for those factors that were most likely to have been influenced by many other factors in the network (see subsection 3.4). As Table 6.1 shows, vehicle control has the highest rank in the network. This suggests that vehicle control is influenced by many other factors, for example: legislation and regulation; vehicle design; road design, signage and monitoring; PPE; substances (drugs and alcohol); and road conditions. Out-degree centrality metrics are higher for those factors that are most likely to influence many other factors in the network, in this case first and foremost legislation and regulation (which is also the second highest ranked on the in-degree centrality metric). This suggests that legislation and regulation influences many other factors, for example: evidence, data and statistics; information for the public, industry and government; vehicle design; road design, signage and monitoring; PPE; and vehicle control. These metrics, particularly out-degree centrality, can indicate where most effort might be focused to improve road safety. In this case, that would include: legislation and regulation; evidence, data and statistics; road design, signage and monitoring; information for the public, industry and government; standards; campaigns, communication and co-ordination; and budget and finance (which are the top seven factors in the rankings).

Table 6.1: Rank order of factors by in-degree and out-degree centrality analysis

Rank	In-degree centrality	Out-degree centrality
1	15. Vehicle control	2. Legislation and regulation
2	2. Legislation and regulation	3. Evidence, data and statistics
3	3. Evidence, data and statistics	9. Road design, signage and monitoring
4	9. Road design, signage and monitoring	5. Information for the public, industry and government
5	5. Information for the public, industry and government	1. Standards
6	7. Vehicle design	4. Campaigns, communication and co-ordination
7	12. Personal protective equipment	6. Budget and finance
8	4. Campaigns, communication and co-ordination	14. Substances (drugs and alcohol)
9	14. Substances (drugs and alcohol)	7. Vehicle design
10	6. Budget and finance	12. Personal protective equipment
11	1. Standards	19. Road conditions
12	19. Road conditions	13. Vehicle maintenance and condition
13	8. Training	15. Vehicle control
14	11. Policy	8. Training
15	13. Vehicle maintenance and condition	16. Medical conditions and medication
16	16. Medical conditions and medication	10. Culture
17	17. Work pattern	11. Policy
18	10. Culture	17. Work pattern
19	18. Convictions	18. Convictions

Source: Author's own

In Social Network Analysis terms, the network can be described as an asymmetric directed network, comprising 19 nodes (factors), with 125 arcs (nodal in–out connections), a density of 0.37 (low-to-medium) and a diameter of 2 (short edge-to-edge hops). Further network analysis is presented in Figure 6.1, showing the centrality power analysis of the 19 contributory/protective factors. Those factors toward the centre of the figure have greater influence over the network than those toward the outside. From this analysis, legislation and regulation is at the centre of the network and is the factor that has the most power over the rest of the factors. The factors have been put into ten tiers of influence in Table 6.2, which ranks them from the most powerful (tier 1) to the least powerful (tier 10) on the basis of the 37 AcciMaps analysed. This analysis suggests that the blunt-end factors have far more power to influence road safety than the sharp-end factors, which supports the premise of the sociotechnical approach in general and the Actor Map and AcciMap frameworks in particular.

Figure 6.1: Centrality power analysis of the contributory/protective factors

- 1 Standards
- 2 Legislation and regulation
- 3 Evidence, data and statistics
- 4 Campaigns, communication and co-ordination
- 5 Information for the public, industry and government
- 6 Budget and finance
- 7 Vehicle design
- 8 Training
- 9 Road design, signage and monitoring
- 10 Culture
- 11 Policy
- 12 Personal protective equipment
- 13 Vehicle maintenance and condition
- 14 Substances (drugs, alcohol)
- 15 Vehicle control
- 16 Medical conditions and medication
- 17 Work patterns
- 18 Convictions
- 19 Road conditions

Source: Author's own

Table 6.2: Tiers of influence based on centrality power analysis

Tier	Factor(s)
1	2. Legislation and regulation
2	3. Evidence, data and statistics
3	1. Standards
4	5. Information for the public, industry and government
5	6. Budget and finance; 9. Road design, signage and monitoring
6	4. Campaigns, communication and co-ordination
7	12. Personal protective equipment
8	14. Substances (drugs and alcohol); 19. Road conditions
9	7. Vehicle design; 13. Vehicle maintenance and condition; 15. Vehicle control; 16. Medical conditions and medication
10	8. Training; 10. Culture; 11. Policy; 17. Work pattern; 18. Convictions

Source: Author's own

The analysis presented in Figures 4.1 to 6.1 and Tables 4.1 to 6.2 point to a common contributory network in most road collisions. An understanding of this network will assist in developing sociotechnical interventions at all of the system levels. An example of that approach in presented in the next section.

6.1 An example of systemic influences

By way of an example of the systemic approach to collision investigation and common causes, the case of many factors contributing across the system levels leading to motorcycle collisions may be examined. Of the 37 collisions investigated, 11 referred to involvement of motorcycles (2017: n = 7; 2018: n = 2; 2019: n = 2), and typically they are overrepresented in the collision statistics (McIlroy et al., 2021). At the level of *international influences*, there is no Euro NCAP equivalent for motorcycles and, as a consequence, very little attention given to designing these machines so as to protect the rider and pillion in the event of a collision. Indeed, PACTS has reported on the need to do more to reduce motorcycle collisions at the level of *national influences*. Whilst there are standards for motorcycle PPE (at both international and national levels), there is no legal requirement for it to be worn at the level of *central government* (apart from the mandatory crash helmet, which does have a minimum standard, but SHARP (Safety Helmet Assessment and Rating Programme) ratings are not printed on helmets, nor is every helmet tested). There is resistance to having mandatory requirements for riders to wear PPE and high-visibility clothing at both the *international influences* (FEMA, the Federation of European Motorcyclists' Associations) and *national influences* (MAG, the Motorcycle Action Group) levels (*regulatory bodies and associations*), although these organisations do recommend it. Motorcycle retailers often neglect to stress the importance of PPE (which can be quite expensive) and high-visibility clothing when selling motorcycles, and fail to point out the difference in the standards and levels of protection offered (at the *company management and local area government* level). At the level of *technical and operational management*, decisions about road design – such as the position and type of road furniture that can kill or seriously injure a rider on contact (e.g. posts, pillars, fences and crash barriers) – do not favour motorcyclists.

As described earlier, all of the deeper systemic features create the preconditions that are both necessary and sufficient for collisions to occur. It is essential that these preconditions are addressed to make substantial and sustainable improvements to road safety (Newnam & Goode, 2015; Newnam et al., 2017; Salmon et al., 2019; McIlroy et al., 2019; Parnell et al., 2017). Referring back to Figure 5.3 and Table 6.2, it seems that the top five factors could have a major impact on motorcycle safety: legislation and regulation (mandating rider PPE); evidence, data and statistics (providing KSI – killed or seriously injured – data to show the effectiveness of rider PPE); standards (providing clear minimum standards for PPE); information for the public, industry and government (providing information and guidance on the design, manufacture, retail, purchase and use of PPE); and budget and finance (making PPE more affordable, for example by zero-rating them for VAT). This is just one example, but the systems approach can be applied to all road users and all modes of transport (Das et al., 2021; Salmon et al., 2012; Blokland & Reniers, 2020), although there is a sharp contrast between the safety requirements for cars and motorcycles.

7. Discussion

This study has set out to extend previous research into road collision investigation (Svedung & Rasmussen, 2002; Gooding, 2017; Stanton, 2019; Stanton et al., 2019; Newnam & Goode, 2015; Newnam et al., 2017) in two main ways. First, by developing classification schemes for Actor Maps and AcciMaps that were designed to the UK road safety context. Second, by undertaking meta-analyses of 37 road collision investigations using the Actor Map and AcciMap taxonomies. The Actor Map taxonomy shared some similarities with the one reported previously (McIlroy et al., 2019), although it did extend it in some important ways, with almost 100 new categories. This was possibly due to the different ways in which the two Actor Maps were developed. The previous Actor Map was developed through workshops and interviews with subject matter experts, and thus relied largely upon the recall of those involved. By way of contrast, although the development of the current Actor Map taxonomy started with the previous one, it was based primarily on the content of the 37 Actor Maps that have been developed by the RCIP analysts. In this way, the categories were based on real data rather than recall of experts. It is possible that as more collisions are investigated, the categories will continue to expand. A total of 1,195 actors were identified across the eight levels of the 37 Actor Maps that were analysed in the current study, distributed across the levels thus: *international influences* (187), *national influences* (68), *central government* (129), *regulatory bodies and associations* (188), *company management and local area government* (123), *technical and operational management* (84), *driving processes* (95) and *equipment and environment* (321). This analysis confirms the premise that actors are distributed across the system (McIlroy et al., 2019) and that consideration of only those actors that are close to the road collision misses many of the other less immediately obvious contributing actors (McIlroy et al., 2021).

The AcciMap taxonomy comprised a total of 1,656 factors across the eight levels of the AcciMap, of which 1,063 were classified as contributory and 593 were classified as protective. The frequency of factors at each of the eight levels is as follows (contributory/protective): *international influences* (76/109), *national influences* (45/57), *central government* (126/122), *regulatory bodies and associations* (74/93), *company management and local area government* (117/48), *technical and operational management* (82/32), *driving processes* (227/20) and *equipment and environment* (316/112). The ratio of contributory to protective factors is relatively even in the top half of the AcciMap – from *international influences* (for which the ratio is actually in favour of protective) to *regulatory bodies and associations* – whereas the contributory factors clearly outweigh the protective factors in the bottom half of the AcciMap (i.e. from *company management and local area government* to *equipment and environment*). A previous study reported that over 50% of the contributory factors at the sharp end of operations related to human operators (Salmon et al., 2020), whereas *driving processes* accounted for only 15% of the factors in the current study. *Driving processes* together with *equipment and environment* accounted for just over 40% of all factors, which means that almost 60% are related to blunt-end system factors.

Currently, most road collision investigations focus on the lower-order (sharp-end) system factors (Salmon et al., 2020), which are much easier to identify as they are immediate to the collision event (McIlroy et al., 2021). This includes factors such as: road design, signage, and monitoring; vehicle maintenance and condition; substances (drugs and alcohol); vehicle control; medical conditions; work patterns; and convictions (which represent seven of the 19 categories in the AcciMap taxonomy). Using the Actor Map and AcciMap frameworks together with the taxonomies developed in this research (combined with appropriate training in the approach) will encourage analysts to consider the potential role of higher-order (blunt-end) system factors, which are most likely to have more far-reaching road safety interventions at a national level (a stated aim of the RCIP). Potentially, this could have a positive effect upon road safety, and address the stagnation in KSI statistics, which have plateaued over the past decade (DfT, 2020).

The AcciMap taxonomy shared some similar categories with the two previous referent taxonomies that were developed for generic incidents (Salmon et al., 2020) and road freight transport (Newnam & Goode, 2015). Table 7.1 shows which categories were shared and which were unique to this study. The five unique categories were evidence, data and statistics; information for the public, industry and government; vehicle design; PPE; and convictions. All remaining 14 categories were either the same as or similar to categories in one or both of the previous studies. To some extent at least, the fact that common categories were found in one or more referent studies offers a parallel form of validation of the taxonomy used in the current study. Certainly, this present study has shown that it is possible to develop a taxonomy that is both relevant and appropriate for road safety and collision investigation in the UK. As with the Actor Map taxonomy, it is likely that with analysis of more cases that the AcciMap taxonomy will expand to include more categories.

Table 7.1: Comparison of factors with other AcciMap taxonomies

Factor	Referent study	
	Newnam & Goode (2015)	Salmon et al. (2020)
1. Standards		■
2. Legislation and regulation	■	■
3. Evidence, data and statistics		
4. Campaigns, communication and co-ordination		■
5. Information for the public, industry and government		
6. Budget and finance		■
7. Vehicle design		
8. Training	■	■
9. Road design, signage and monitoring	■	
10. Culture		■
11. Policy	■	■
12. Personal protective equipment		
13. Vehicle maintenance and condition	■	
14. Substances (drugs and alcohol)	■	
15. Vehicle control	■	
16. Medical conditions and medication	■	
17. Work pattern	■	
18. Convictions		
19. Road conditions	■	

Source: Author's own
Note: A shaded square means that the factor is the same as or similar to categories in the study at the head of that column. Thus the rows with no shading correspond to categories unique to this study.

It is worth noting that the two previous referent taxonomies had distinct and different categories for each layer of the AcciMap, whereas the taxonomy developed in the current project can be applied across all of the AcciMap levels. This has the advantage of being simpler to use, as well as offering the possibility of developing a generic road collision model that can be independent of the AcciMap framework (as shown in Figure 5.3).

The study also points toward the existence of a common contributory (and protective) network for road collisions (Salmon et al., 2020). Two examples of common frameworks are shown in Figure 5.1 and Figure 6.1, both of which indicate that there are indeed a common set of recurring factors that play a part in the majority of road collisions, regardless of the nature of the collision or what actors are involved at the sharp end (i.e. the lower system levels of *driving processes* and *equipment and environment*). In Figure 5.1, there are relatively few factors at each of the eight levels that were identified most frequently: *international influences* (4), *national influences* (3), *central government* (5), *regulatory bodies and associations* (4), *company management and local area government* (4), *technical and operational management* (1), *driving processes* (5) and *equipment and environment* (8). These comprise those that are typically thought of as blunt-end (i.e. legislation and regulation; information for the public, industry and government; budget and finance; standards; campaigns, communication and co-ordination) and sharp-end (road design, signage and monitoring; PPE; substances (drugs and alcohol); vehicle control; vehicle design; vehicle maintenance and condition; and road conditions) factors. To take into consideration both the sharp-end and blunt-end factors together is to take a truly sociotechnical systems approach (Salmon et al., 2020; Stanton et al., 2019; Salmon et al., 2019; McIlroy et al., 2021).

Similarly, as shown in Figure 6.1, the 19 contributory/protective factors were put into a network model in order to identify the power relationships, which showed that legislation and regulation was the most influential factor at the centre of the network. This network was a summation (meta-analysis) of the 37 road collision investigations, so reflected a common network of factors across all of the studies. The same network can be used to interpret other road collisions and to support interventions. It is proposed that interventions that will have most influence on the safety of the road transport system will be those at the centre of the network (in order of influence), i.e. legislation and regulation; evidence, data and statistics; standards; and information for the public, industry and government.

The classification schemes developed in this study will help with the reliability, validity and utility of the application of Actor Maps and AcciMaps in road collision investigation. Initial reports of reliability and validity in this study are encouraging, but further verification should be sought as more studies are conducted. The Actor Map taxonomy in Appendix A comprises the eight system levels in separate Excel tabs and can be used as a guide for future road collision investigations. More categories can be added if required. The AcciMap taxonomy in Appendix B comprises 19 categories over the eight systems levels, with examples that can be used to guide road collision analysts. Again, more categories can be added if required. Both of these taxonomies can help to guide analysts and reduce the subjectivity of the analysis if used properly. One of the benefits of using common taxonomies is that it enables comparison studies and meta-analyses (Newnam & Goode, 2015; Newnam et al., 2017; Salmon et al., 2020; Stanton et al., 2019), which is particularly useful for developing national interventions. A future aim of the research should be to implement this vision in a national Road Collision Investigation Branch similar to that found in air, maritime and rail.

8. Conclusions and Recommendations

In conclusion, the study reported in this document has developed an Actor Map taxonomy (comprising 256 categories from 1,195 actors) and an AcciMap taxonomy (comprising 19 categories from 1,656 factors). These taxonomies were used to undertake meta-analyses of 37 road collision investigations. The meta-analysis of the Actor Maps showed that relatively few categories of actors (35 out of 256) are associated with the majority of collisions. Similarly, the meta-analysis of the AcciMaps showed that all of the 1,656 factors could be placed into just 19 categories, and that across the eight AcciMap levels there were just 11 factors that appeared far more frequently than any others. Both of these taxonomies, together with the meta-analysis, enabled an overview and summary of the analysis as well as the derivation of recommendations for the most effective interventions at a national level. On the basis of the study reported here, it is recommended that future effort and resources should be focused on:

1. training road safety investigators in the sociotechnical systems approach using the Actor Map and AcciMap frameworks;
2. undertaking continuous adherence training to ensure that road safety analysts are using the methods appropriately;

3. undertaking a national roll-out of Actor Map and AcciMap frameworks, together with the taxonomies for road safety investigations;
4. prioritising road safety investigations so as to maximise the benefits from the available resources (for example by focusing on: major incidents, indicative incidents that occur frequently, incidents that involve vulnerable road users, incidents involving new technologies such as electric/automated vehicles, and so on);
5. developing a national sociotechnical road safety plan from meta-analysis of Actor Map and AcciMap road safety investigations that increase the protective factors and reduce the contributory factors;
6. continuing to develop and refine the Actor Map and AcciMap taxonomies; and
7. gathering evidence to support the effectiveness of the road safety interventions from the national sociotechnical road safety plan.

Appendix A: Actor Map Taxonomy with Frequencies

For details of the Actor Map taxonomy with frequencies, please see the supplementary data sheet **here** or go to https://tinyurl.com/yc8hvsny.

Appendix B: AcciMap Taxonomy with Frequencies

For details of the AcciMap taxonomy with frequencies, please see the supplementary data sheet **here** or go to https://tinyurl.com/mwah5xea.

References

Blokland, P. & Reniers, G. (2020). Safety science, a systems thinking perspective: From events to mental models and sustainable safety. *Sustainability*, 12(12): article 5164. Accessed 4 April 2022 from: www.mdpi.com/2071-1050/12/12/5164/pdf

Branford, K. (2011). Seeing the big picture of mishaps: Applying the AcciMap approach to analyze system accidents. *Aviation Psychology and Applied Human Factors*, 1: 31–37. Accessed 4 April 2022 from: www.researchgate.net/profile/Kate-Branford/publication/245025224_Seeing_the_Big_Picture_of_Mishaps_Applying_the_AcciMap_Approach_to_Analyze_System_Accidents/links/0c96051d5fc9899fe9000000/Seeing-the-Big-Picture-of-Mishaps-Applying-the-AcciMap-Approach-to-Analyze-System-Accidents.pdf

Das, R. C., Shafie, I. K., Hamim, O. F., Hoque, M. S., McIlroy, R. C., Plant, K. L. & Stanton, N. A. (2021). Why do road traffic collision types repeat themselves? Look back before moving forward. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 31(6): 652–663.

DfT (Department for Transport) (2020). *Reported Road Casualties in Great Britain: 2019 annual report*. Accessed 2 April 2022 from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/922717/reported-road-casualties-annual-report-2019.pdf

DfT (2021). *Reported Road Casualties in Great Britain, Provisional Estimates: Year ending June 2021*. Accessed 4 April 2022 from: www.gov.uk/government/statistics/reported-road-casualties-in-great-britain-provisional-estimates-year-ending-june-2021/reported-road-casualties-in-great-britain-provisional-estimates-year-ending-june-2021

Gooding, S. (2017). *Towards an Accident Investigation Branch for Roads?* RAC Foundation. Accessed 2 April 2022 from www.racfoundation.org/wp-content/uploads/2017/12/Towards_an_Accident_Investigation_Branch_for_Roads_Steve_Gooding_December_2017.pdf

Grant, E., Salmon, P. M. & Stevens, N. J. (2019). The usual suspects? A novel extension to AcciMap using accident causation model tenets. *Theoretical Issues in Ergonomics Science*, 20(4): 397–418.

Grant, E., Salmon, P. M., Stevens, N. J., Goode, N. & Read, G. J. M. (2018). Back to the future: What do accident causation models tell us about accident prediction? *Safety Science*, 104: 99–109.

Hulme, A., Stanton, N. A., Walker, G. H., Waterson, P. & Salmon, P. M. (2019). What do applications of systems thinking accident analysis methods tell us about accident causation? A systematic review of applications between 1990 and 2018. *Safety Science*, 117: 164–183.

Jenkins, D. P., Salmon, P. M., Stanton, N. A. & Walker, G. H. (2010). A systemic approach to accident analysis: A case study of the Stockwell shooting. *Ergonomics*, 53(1): 1–17.

Matthews, B. W. (1975). Comparison of the predicted and observed secondary structure of T4 phage lysozyme. *Biochimica et Biophysica Acta (BBA) Protein Structure*, 405: 442–451.

McIlroy, R. C., Plant, K. L., Hoque, M. S., Wu, J., Kokwaro, G. O., Vũ, N. H. & Stanton, N. A. (2019). Who is responsible for global road safety? A cross-cultural comparison of Actor Maps. *Accident Analysis & Prevention*, 122: 8–18.

McIlroy, R. C., Plant, K. L. & Stanton, N. A. (2021). Intuition, the Accimap, and the question "why?" Identifying and classifying higher‐order factors contributing to road traffic collisions. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 31(5): 546–558. Accessed 4 April 2022 from: https://onlinelibrary.wiley.com/doi/epdf/10.1002/hfm.20902

Nayak, R. & Waterson, P. (2016). 'When food kills': A socio-technical systems analysis of the UK Pennington 1996 and 2005 E. coli O157 outbreak reports. *Safety Science*, 86: 36–47.

Newnam, S. & Goode, N. (2015). Do not blame the driver: A systems analysis of the causes of road freight crashes. *Accident Analysis & Prevention*, 76: 141–151.

Newnam, S., Goode, N., Salmon, P. M. & Stevenson, M. (2017). Reforming the road freight transportation system using systems thinking: An investigation of Coronial inquests in *Australia. Accident Analysis & Prevention*, 101: 28–36.

Parnell, K. J., Stanton, N. A. & Plant, K. L. (2017). What's the law got to do with it? Legislation regarding in-vehicle technology use and its impact on driver distraction. *Accident Analysis & Prevention*, 100: 1–14.

Read, G. J. M., Shorrock, S., Walker, G. H. & Salmon, P. M. (2021). State of science: Evolving perspectives on 'human error'. *Ergonomics*, 64(9): 1091–1114. Accessed 4 April 2022 from: www.tandfonline.com/doi/pdf/10.1080/00140139.2021.1953615

RoSPA (Royal Society for the Prevention of Accidents) (2017). *Designing Evidence Based Road Safety Interventions: A practitioner's guide.* Accessed 4 April 2022 from: https://www.rospa.com/rospaweb/docs/advice-services/road-safety/practitioners/evidence-based-intervention-guide.pdf

Salmon, P. M., Goode, N., Archer, F., Spencer, C., McArdle, D. & McClure, R. J. (2014a). A systems approach to examining disaster response: Using AcciMap to describe the factors influencing bushfire response. *Safety Science*, 70: 114–122.

Salmon, P. M., Goode, N., Lenné, M. G., Finch, C. F. & Cassell, E. (2014b). Injury causation in the great outdoors: A systems analysis of led outdoor activity injury incidents. *Accident Analysis & Prevention*, 63: 111–120.

Salmon, P. M., Hulme, A., Walker, G. H., Waterson, P., Berber, E. & Stanton, N. A. (2020). The big picture on accident causation: A review, synthesis and meta-analysis of AcciMap studies. *Safety Science*, 126: article 104650.

Salmon, P. M., McClure, R. & Stanton, N. A. (2012). Road transport in drift? Applying contemporary systems thinking to road safety. *Safety Science*, 50(9): 1829–1838.

Salmon, P. M., Read, G. J. M., Beanland, V., Thompson, J., Filtness, A. J., Hulme, A., McClure, R. & Johnston, I. (2019). Bad behaviour or societal failure? Perceptions of the factors contributing to drivers' engagement in the fatal five driving behaviours. *Applied Ergonomics*, 74: 162–171.

Salmon, P. M., Read, G. J. M., Stanton, N. A. & Lenné, M. G. (2013). The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non‐compliance at rail level crossings. *Accident Analysis & Prevention*, 50: 1278‐1288.

Salmon, P. M., Williamson, A., Lenné, M., Mitsopoulos-Rubens, E. & Rudin-Brown, C. M. (2010). Systems-based accident analysis in the led outdoor activity domain: Application and evaluation of a risk management framework. *Ergonomics*, 53(8): 927–939.

Stanton, N. A. & Young, M. S. (1999) What price ergonomics? *Nature*, 399: 197–198.

Stanton, N. A. & Young, M. S. (2003). Giving ergonomics away? The application of ergonomics methods by novices. *Applied Ergonomics*, 34(5): 479–490.

Stanton, N. A. (2016). On the reliability and validity of, and training in, ergonomics methods: A challenge revisited. *Theoretical Issues in Ergonomics Science*, 17(4): 345–353.

Stanton, N. A. (2019). *Models and Methods for Collision Analysis: A guide for policymakers and practitioners.* RAC Foundation. Accessed 2 April 2022 from www.racfoundation.org/wp-content/uploads/Models_and_methods_for_collision_analysis_Stanton_March_2019.pdf

Stanton, N. A., Brown, J. W., Revell, K. M. A., Kim, J., Richardson, J., Langdon, P., Bradley, M., Caber, N., Skrypchuk, L. & Thompson, S. (2021). OESDs in an on-road study of semi-automated vehicle to human driver handovers. (in press). *Cognition, Technology & Work.* Accessed 5 April 2022 from: https://link.springer.com/content/pdf/10.1007/s10111-021-00682-z.pdf

Stanton, N. A., Salmon, P. M., Walker, G. H & Stanton, M. (2019). Models and methods for collision analysis: A comparison study based on the Uber collision with a pedestrian. *Safety Science*, 120: 117–128. Accessed 4 April 2022 from: www.researchgate.net/profile/Neville-Stanton/publication/337659042_Models_and_methods_for_collision_analysis_A_comparison_study_based_on_the_Uber_collision_with_a_pedestrian/links/5de8b6df92851c836462a721/Models-and-methods-for-collision-analysis-A-comparison-study-based-on-the-Uber-collision-with-a-pedestrian.pdf

Svedung, I. & Rasmussen, J. (2002). Graphic representation of accident scenarios: Mapping system structure and the causation of accidents. *Safety Science*, 40: 397–417.

Vicente, K. J. & Christoffersen, K. (2006). The Walkerton *E. coli* outbreak: A test of Rasmussen's framework for risk management in a dynamic society. *Theoretical Issues in Ergonomics Science*, 7(2): 93–112.

Waterson, P. (2009). A systems ergonomics analysis of the Maidstone and Tunbridge Wells infection outbreaks. *Ergonomics*, 52(10): 1196–1205.

Waterson, P., Robertson, M. M., Cooke, N. J., Militello, L., Roth, E. & Stanton, N. A. (2015). Defining the methodological challenges and opportunities for an effective science of sociotechnical systems and safety. *Ergonomics*, 58(4): 565–599. Accessed 4 April 2022 from: www.tandfonline.com/doi/pdf/10.1080/00140139.2015.1015622

RAC Foundation

Mobility • Safety • Economy • Environment

The Royal Automobile Club Foundation for Motoring Ltd is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

Tel no: 020 7747 3445
www.racfoundation.org

Registered Charity No. 1002705
June 2022 © Copyright Royal Automobile Club Foundation for Motoring Ltd

Designed and printed by
The Javelin Partnership Ltd
Tel: 0118 907 3494

Produced on paper from a managed
sustainable source which is FSC certified
as containing 50% recycled waste.

Main proofreader:
Beneficial Proofreading Services
Tel: 07979 763116

ISBN: 978-1-9160527-2-7