Murray Mackay Appreciation

The Need for Accident Investigation: Murray Mackay's work presented at Conferences of the International Research Council on Biomechanics of Injury from 1973 to 2013

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I. INTRODUCTION

As the current President of the International Research Council on Biomechanics of Injury (IRCOBI), I look upon the retirement in 2016 and 2017 of ten of our Council members with a mixture of personal sadness and concern at the loss of corporate memory. However, one retiree is particularly special to the crash safety community: Murray Mackay.

Murray was a founding member of IRCOBI and has been intimately involved with IRCOBI since its inception in 1971. For almost four decades, Murray served in a leadership role within the organisation, being Vice-President for almost 20 years (1971-1990), then President for 20 years (1990-2010), and he has continued as adviser until the present day. The goal of this review is not to address his leadership role within the organisation, but rather to reflect on his technical work on traffic safety published at IRCOBI conferences over that extended period of time. Although he excelled as a leader, it was his technical work that gave him the authority to do so.

Like any review, this one is written from a particular perspective. Mine is that I was introduced to Murray in 1995 when I attended my first IRCOBI Conference in Brunnen in Switzerland. As a graduate of mechanical engineering, but with a project on whiplash injuries under my belt, I was a mixture of diffidence, enthusiasm and cluelessness. In my memory, the introduction from him was something like "the name's Mackay, Murray Mackay", and I was instantly hooked. I cheekily sat at his table at the conference gala dinner. Over ten years later, Murray was generous in providing constructive criticism as well as a foreword to my book on pedestrian and cyclist impact mechanics, co-written with Denis Wood. Murray's demanding comments led to major changes to the main chapters on vehicle design and future perspectives, encouraging me to look to the future as well as reviewing advances from the past. Around that time I received an invitation from Murray to join the IRCOBI Council, which I was honoured to do.

Murray's written contributions to crash safety started significantly before the founding of IRCOBI, and were surely instrumental in his becoming a founding member of the organisation. However, in the context of his retirement from the IRCOBI Council this year, this review of his work is focused purely on his IRCOBI contributions. All of those papers are freely available to download from the IRCOBI website (except for the 1983 conference as noted below). Murray authored or co-authored 31 papers delivered at IRCOBI conferences, with the 1970s and 1990s being the most prolific decades. During that time, he was affiliated with the University of Birmingham, where he was Professor of Transport Safety and founder and director of the Birmingham Accident Research Centre for many years. Not all papers are directly referred to here, but they are all included in the reference list at the end.

II. ACCIDENT INVESTIGATION

Murray's IRCOBI papers overwhelmingly address accident investigation, and his main technical contributions to this field have been thoughtful field studies assessing evidence in the aftermath of real-world traffic collisions, alongside his authoritative but not authoritarian personality that helped to ensure people returned over many years to the annual IRCOBI conferences. A summary of the topics of his 1970s papers is given in Table I. It is perhaps fitting that the title of his first IRCOBI paper [1] (in 1973, the year I was born) was "The Epidemiology of Injury - a Review". It sets the context that road accidents were the single largest contributor to trauma by impact (between a third and a half of the total). At the time, fatality rates in most Western European

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countries were around double what they are today, and public policy on this topic was underdeveloped. Murray reviewed the implications of referring to road collisions as "accidents", and the consequent risk that the establishment of causal relationships and probabilities of involvement may not receive the required attention needed to reduce the incidence and consequences of road collisions. This was a theme which his predecessor Hugh De Haven had also grappled with in the United States.

The same paper also addresses the definition of injury severities and the importance of pedestrian collisions. In 1970s Britain, pedestrians represented nearly 40% of road collision fatalities and a third of these were children under ten years old. Murray was also aware of the value of translational research, comparing tolerance levels from free falls, military cases and sporting injuries. Given the rise in interest in sports injury biomechanics, now a dedicated IRCOBI theme and the topic of a keynote talk by Tron Krosshaug in 2013, the foresight of this first paper is striking. Finally, he was prescient in observing that the fatality rates were set to grow worldwide as the population of vehicles increased in countries which historically did not have high values of vehicle ownership. Today, India and China account for a very significant proportion of the road traffic fatality burden.

A major contributor to the improvement in crashworthiness of vehicles over the last 40 years has been the mandatory crash testing of production vehicles. However, given the wide variety of real-world collision configurations, designing crash tests appropriate for homologation purposes is challenging. Murray's second IRCOBI paper [2] was titled "Field accident damage as a basis for crash tests", and it went directly to the heart of his contribution to traffic safety. This paper set out to use a representative "at-the-scene" collision sample combined with a retrospective study of serious collisions to establish the pattern of vehicle damage configurations in injury-producing accidents. This evidence was then used to propose an improved frontal impact test, specifically a quarter-overlap barrier test. The paper addresses bias in accident samples, but judged that "the sample correctly represents the damage distribution in serious injury frontal impacts in the UK". Although this statement might attract more attention from a reviewer today than then, it is one of Murray's standout characteristics that his engineering judgement was rarely in error. The papers are tersely written, but include statements in which his clear understanding of fundamental mechanics is implicit; for example, his assessment of steering column collapse in a frontal impact: "A large load is developed between the steering wheel and the driver's chest which gives rise to a considerable bending moment on the column which, in turn, causes further bending and locking". Murray's engineering judgement was almost certainly honed during painstaking examination of many crashed vehicles. In one paper alone, 184 cases were individually examined to classify the resulting damage distribution. The paper also recognises that crash performance optimisation ultimately involves a compromise in occupant protection for different crash directions, but he wryly noted that "field experience indicates that many present designs could be improved considerably before the inherent design conflicts became apparent". The paper concludes by questioning the utility of the then US Federal Motor Vehicle Safety Standard.

TABLE I
TOPICS ADDRESSED IN MURRAY'S 1970S IRCOBI PAPERS

Barrier Tests	Steering Columns	Eyes
Children	Seatbelts	Compatibility
Anthropometric diversity	Side impact	Computational modelling
Crash test dummies	Motorcycles	

Another paper [7] used field data to emphasize the risk of intrusion and belt misuse and particular focus is laid on the comparison of inertia reel versus static seatbelts, with the observation that the inertia reel belts at the time facilitated excessive forward displacement of the occupant. The data presented also starkly underline the low seatbelt usage rates in Britain in the early 1970s; less than 25% in city centre locations. The paper carries the sobering conclusion that "the collision performance of present-day inertia reels appears to be unsatisfactory".

A paper in 1978 [8] focussed on the risks of crash test standards with a single dummy and a single injury threshold to which manufacturers would then optimise their designs, not taking into account the distribution of collision severities and occupant diversity. The paper argues that a crash test must represent a large proportion of real-world crash configurations and should be primarily aimed at preventing fatal and serious injuries. It recognised that this may come at the cost of increasing injuries in less severe impacts, even though the latter are much more frequent events. This concept is illustrated by the argument that an impact load to the chest of a 25-year-old male which produces an undisplaced rib fracture may generate multiple life-threatening rib fractures and damage to the thoracic organs in a 65-year-old person. These age-dependent differences in injury risk remain highly relevant in accident data today. On the other hand, the paper concludes by reflecting that while spectacular accidents such as a bus collision with multiple fatalities can attract political engagement, it is not effective to overemphasize very severe impacts where fatalities may be difficult to prevent at the expense of the much more frequent though less severe collisions where interventions are likely to be more beneficial. The data again highlight socio-economic differences compared to today, with male drivers outnumbering female drivers by a ratio of 4:1, while females outnumbered males as front seat passengers by a ratio of 2:1.

Another 1978 paper [9] addressed the reconstruction of a collision involving a Leyland Mini struck from the side by a Vauxhall. The injuries are mapped to contacts with the side window, B pillar and intruding door. This is the first of Murray's IRCOBI papers to report on full-scale staged crash tests and the first to explicitly consider computer modelling, using the program CRASH to estimate the collision speeds. The paper notes the marked difference in model-predicted impact speed compared to the staged tests and urges caution relating to both the uncertainty in the input data required to run the computer simulation as well as the need to be sure that the case being reconstructed meets the assumptions of the underlying mathematical model. These words of caution are equally applicable today. Murray noted in these years that the field performance of safety equipment remains poorly understood. Although this has been partially addressed through legislation as well as consumer tests such as EuroNCAP, there remains a substantial time lag between the introduction of novel safety countermeasures and field accident data to assess their effectiveness.

TABLE II
TOPICS ADDRESSED IN MURRAY'S 1980S IRCOBI PAPERS

Child occupants	Two wheeled vehicles	windscreens
Seatbelt usage	Skin properties	

The range of topics on which Murray published in IRCOBI in the 1980s is shown in Table II. The first paper in the 1980s [11] deals with injuries to children in frontal impacts and the concept of a safe rear seat ride down envelope for children was introduced, see Figure 1. It also refers to Murray's concept of the Equivalent Test Speed to classify the severity of a collision, which he had introduced some years earlier. The paper uses a combination of analysis of accident data samples and surveying of restraint system usage. Unsurprisingly, the most severe injuries to children were to the head, and ejection was common for unrestrained children. More surprisingly, neck injuries in restrained forward-facing children due to inertial loading were not observed in the accident sample of severe crashes in the UK. This work also features the first explicitly reported use of statistical testing in a paper by Murray and is probably a reflection of the more large-scale and organised accident data collection in Britain in the 1980s than in the early 1970s.

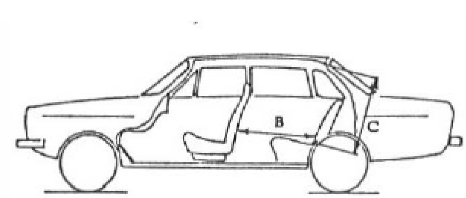

Fig. 1. Dimensions B and C to assess the safe ride down envelope for rear seated children [11].

The next paper [12] addressed injuries to motorcyclists and cyclists, noting the issue of underreporting of less severe cases for these collision types, which again remains an issue today. The underreporting then was dramatic: 88% of cyclist and 44% of motorcyclist injuries treated in hospital were not recorded in police files. For fatal motorcyclist injuries, the head was the most important body region, and the destructiveness of the injuries was noted: “frequently the whole cranium and its contents were destroyed”. For cyclists, upper limb injuries dominated, possibly due to voluntary action by the cyclist (raised arms etc), and this is still observed in recent work on cyclist injuries. The paper notes the difference in emphasis for motorcyclists compared to cyclists, for whom lower limb injuries are much more important.

Another 1981 paper [13] addressed the field assessment of injuries from contact with laminated glass, and presents a stylistic return to form with Murray as first author. The title accordingly starts with “Some observations on …”. This intriguing paper used national British data collected via several police forces to analyse soft tissue and brain injury differences from head impacts with conventional laminated windscreens compared to windscreens with thermally toughened glass. Problems with pre-fracture of the thermally toughened windscreen were observed, but the new design was associated with lower soft tissue injuries. No cases of severe brain injury from direct windscreen contact were recorded. The paper notes that the reported Head Injury Criterion (HIC) scores from experimental headform impacts on windscreens were quite high (200-800), and queried whether HIC is a suitable measure for head injury in windscreen contacts, with propensity to cause laceration being perhaps a more important assessment.

A 1982 paper [14] provides a fascinating view of contemporaneous thinking on risk compensation/risk homeostasis theories applied to road safety. The paper was written early in a process of continual decline in road fatalities in the Western world from the 1970s until today. It is remarkable then to read a contemporary proposal (not from Murray) that “protecting car occupants from the consequences of bad driving encourages bad driving”. The paper warns of the risks of drawing conclusions on the influence/consequences of human behaviour in traffic safety. An observational study draws comparisons of seatbelt usage before and after the introduction of mandatory seatbelt usage in Britain in 1982, and finds that seatbelt wearing did not affect driving speeds, thereby contradicting the risk homeostasis theory. On the other hand, new and larger cars did travel faster than older ones, and drivers of older cars had much lower belt usage rates.

Another 1982 paper [15] on cutting characteristics of skin and skin simulants is the first Murray paper at IRCOBI to directly address tissue mechanics (this is now a dedicated theme at the conference) and the paper gives an interesting insight into computer-based data acquisition, a relative novelty at the time. “The force pulse was … recorded in digital form on a paper tape which formed the input to a computer program allowing the peak force … to be accurately examined at leisure”. Some of the data presented is reproduced here in Figure 2. This method of data presentation is perhaps typical of the time, with individual data points not presented, but rather the general spread is shown in a semi-quantitative manner. Although in this approach the individual experimental results are lost to the reader, it also guides the mind towards interpreting general trends rather than deterministic values which have inevitable uncertainty. The paper addresses the energy absorption capabilities of subcutaneous fat and force generation capabilities of skin, and contains a detailed materials science description of the mechanics of cutting under different load circumstances. The paper also includes a valiant attempt to relate the laboratory findings back to previous observations of laceration injuries from windscreen impacts.

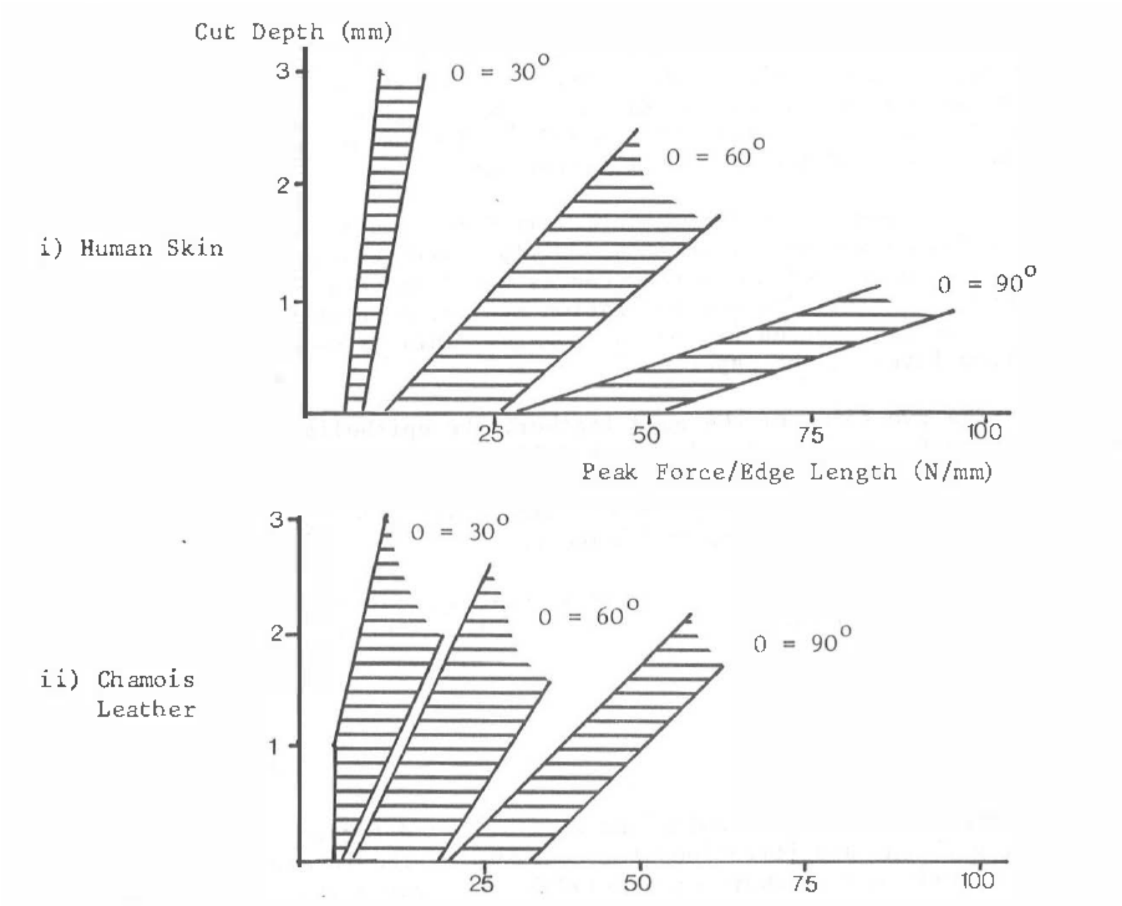

Fig. 2 Experimental cutting characteristics of skin and skin simulants [15].

In 1983, IRCOBI held a joint conference with the SAE in the US. For copyright reasons, these papers are not freely available on the IRCOBI website, but one of the papers was by Ashton and Mackay on “Benefits from changes in vehicle exterior design - field accident and experimental work in Europe”, and it addresses the area of pedestrian safety, to which Murray has made a very significant contribution. The paper (SAE 830626) addresses the influence of bumper height, bonnet height, bonnet leading edge height and stiffness on pelvic and leg injuries, and these issues are now formally assessed by subsystem impactor tests in many jurisdictions, as well as through new car assessment programs such as EuroNCAP.

Another 1983 paper (SAE 831610) with Bertil Aldman and Hugo Mellander (also IRCOBI Council members; Aldman was the first IRCOBI President) addressed the “Structure of European research into the biomechanics of impact”, and this paper identifies the need to examine injury at a cellular level (rather than primarily through crash test dummies) as well as challenges for introducing legislative tests in Europe. Murray returned to this theme in his Bertil Aldman IRCOBI award lecture in 2013.

The 1990s were again a prolific period for IRCOBI papers by Murray, see Table III. The first one [16] reviewed 300 motorcycle accidents in rural and urban areas around Birmingham, and opened with the familiar theme of the need to have detailed accident investigation as a precursor to reducing collision-related injuries. The paper emphasises the importance of single-vehicle accidents for motorcycle fatalities and reports on the high incidence of severe internal chest and abdominal injuries without accompanying skeletal damage. A surprisingly high number of helmeted riders lost their helmet during the collision, for reasons varying from fracture of the helmet to incorrect fitment. The challenges with protecting motorcyclist heads were summarised by the recognition that “in many cases the loads applied to the helmets were greater than that which any structure of limited thickness could be expected to reduce to a tolerable level”. The paper finishes with a discussion of the limitations of police and hospital accident data collection methods, and the need for their compatibility for combining into national statistics. There is also recognition that some accident investigation approaches generate superfluous data and proposes that accident data collection is most efficient when aimed at a specific target, for example before and after the introduction of a specific intervention.

TABLE III
TOPICS ADDRESSED IN MURRAY'S 1990S IRCOBI PAPERS

Motorcyclists	Seatbelts	Steering wheels
Intelligent restraints	Side impact airbags	Car to truck impacts

In a 1992 paper [17], a review of occupant injuries found that injuries to the head, face and thorax predominated, with the contact source being the steering wheel and seatbelt in almost 75% of cases. Brain injury was more common than skull fracture, though in fatal cases skull fracture and brain injury were frequently combined. Internal thoracic injuries were common in fatal cases. Older females were at much higher risk of serious chest injury. However, this trend was more evident in less severe cases and this is a common feature of risk differences in automotive collisions, where at sufficiently high speeds the outcome is ultimately always fatal, such that gender, age and other differences become unimportant. Surprisingly, the study found that poor seatbelt geometry and restraint misuse were not common in the accident sample, and submarining (movement of the occupants such that the belt loading passes through the soft abdomen instead of the bony pelvis) was only found in isolated cases. The sample size was small for assessing the effects of anthropometric differences on abdominal injuries, but evidence was presented for increased risk for overweight occupants. This is a focus of considerable research today, especially in the United States.

Another 1990s paper [18] focused on driver injuries from contacting the steering wheel in frontal impacts. It reports 50% of restrained drivers suffered injuries from this contact, most frequently facial contusion and laceration. The main theme is again assessment of the suitability of existing crash tests in the context of field evidence of injuries and vehicle damage. The paper's contribution relies on the investigators' ability to apportion injuries recorded in hospital files to specific vehicle components, and to use the damage profile to estimate an equivalent test speed. The paper grapples with separating the influence on injury outcome of increased energy and increased steering wheel intrusion at higher speeds, and concludes that minimising steering wheel intrusion at speeds below 50 km/hour would bring substantial reductions in occupant injuries.

Paper [19] tackles the need for restraint systems to be "intelligent" enough to recognise the variability of anthropometric dimensions and biomechanical tolerances of the population of vehicle occupants, and is another strong example of Murray's ability to see the bigger picture and to project forward to future areas of focus. The paper starts with a succinct summary of limitations with existing seatbelt performance, listing driver head impacts with the steering wheel, intrusion of forward structures into the seatbelt ride-down zone, impact with unrestrained occupants/objects striking front seat occupants from the rear, misuse of the seatbelt (especially incorrect lap belt placement leading to severe abdominal loading) and injuries from the seatbelt either at higher impact severities or for people with reduced tolerances. The risks associated with anthropometric variations are neatly illustrated by the comment that the 5th percentile female is 38 cm closer to the steering wheel hub than the 50th percentile male, and is thus far more exposed to direct head impacts on the steering wheel and to a potentially unfavourable interaction with an airbag mounted on the steering wheel. The paper then sets out the requirements of an idealised restraint system, which would apply variable restraint accounting for the occupant's weight, seating position and biomechanical tolerances, as well as the severity of the crash, the occupant compartment geometry and stiffness, and the risk of intrusion. Now over 20 years later, the majority of seat belts and production vehicles worldwide are still not designed to take these diversity factors into account, though much of the required technology is available. A follow-up paper in 1996 [23] addressed the positioning of head restraints for occupant protection in rear impact. A survey of head restraint positions showed the great majority of head restraints were too low and too far behind the head to offer adequate protection. Since then, static geometry measurements of head restraint positions form a standardised part of vehicle assessment.

A pair of papers in 1994 and 1995 [20, 21] used field accident data from the Cooperative Crash Injury Study to propose a location for a crush-based side impact sensor, as well as a supplementary acceleration-based side impact sensor to address cases with low intrusion, but where AIS2 injuries were still occurring.

A 1995 comparison [22] of impacts between either heavy goods vehicles or light goods vehicles striking passenger cars found that the velocity change of the passenger cars was similar in both cases, but the passenger car crush at the head and chest level was significantly higher for heavy goods vehicles. The need for regulation to limit these types of collisions was stressed, and the challenges in the United States with these collision types was raised.

A 1997 paper [25] addressed the relationship between thoracic injury and collision severity in side impacts, again using accident data from the Cooperative Crash Injury Study. Chest injuries were a significant contributor to fatalities in side impacts and the estimation of equivalent test speed was used to produce a cumulative frequency of injuries as a function of equivalent speed of crash, showing that the proposed 25 km/h European side impact test was too low speed to address most of the real-world cases producing side impact injuries. This study also noted the growth of sport utility vehicles and light trucks in the European market, which at the time was a new trend.

TABLE IV
TOPICS ADDRESSED IN MURRAY'S IRCOBI PAPERS AFTER 2000

Laminated glazing	Restraint effectiveness	Vehicle size and mass	Whiplash

Murray started his 21st century IRCOBI activities by hosting the annual Conference in the Isle of Man. The topics he tackled in the first decade are summarised in Table IV. A 2001 paper [26] was a theoretical assessment of the potential benefits of laminated glass in reducing occupant ejection in side impacts. The paper combined accident data from Germany, France and the UK, noting challenges associated with inclusion criteria from these diverse sources. Accident investigators classified individual cases according to whether either partial or complete ejection had occurred, noting that ejection generally results in more severe injuries. The paper concludes that intrusion-resistant glazing fitted to the side and rear windows should have a positive effect on occupant risk due to its capacity to reduce occupant ejection.

Another 2001 paper [27] returned to the theme of restraint system effectiveness for diverse populations, and this paper is also notable for its first reference to a paper by Jeff Crandall, who was to succeed Murray in 2010 as the next President of IRCOBI. The paper assembled a large dataset of European steering wheel airbag deployment cases for belted drivers, and used basic assumptions to estimate the potential for injury reduction in the event of having optimised restraint systems for the specific occupant. Although apparently not validated, the predictive approach presented here is an important component in the life-cycle of road safety countermeasures, since some form of assessment of likely benefit is needed to encourage future developments. The paper concluded that very significant benefits should accrue from airbags in general, and that adaptive restraints could further reduce moderate injuries by around a third.

A 2003 paper [28] addressed challenges in mapping police assessments of collision severity against the Abbreviated Injury Score (AIS), which is a detailed injury coding scheme introduced to allow a consistent comparison of injuries. Despite the long presence of the AIS, these challenges remain unresolved today in many jurisdictions, largely due to resource constraints.

A 2004 paper [29] addressed the difference in vehicle fleets between the US and the UK, in the context of evaluating the relationship between vehicle size and mass and occupant injury risk. Due to the strong correlation between size and mass, decoupling the respective influences on occupant safety is not trivial, and this was a sizable research theme for over 10 years. The study used accident data from the UK and the US and found the variation in mass ratio in light truck-to-car impacts was higher for US cases than in the UK. The study clearly showed a much stronger effect of vehicle mass ratio than stiffness on occupant injury risk, but also found that struck driver age and belt usage are often even more important determinants, and as such need to be controlled for when assessing vehicle design effects.

A 2011 paper [30] addressed whiplash injury risk in an algorithmic form, harnessing information from damage severity estimation, seat performance characteristics and occupant specific modifiers. Despite their low injury severity, claims for whiplash type injuries are more costly than all other accident modes combined, largely due to the slow recovery rate and the consequent disabilities, but also the difficulty in proving the veracity of the claims. It was concluded that the fuzzy Logic system presented has the capacity to separate cases with a very low injury risk from those with a high risk.

III. Conclusion

The 2011 paper on whiplash injury risk [30] has been Murray's last technical contribution to date. However, he presented a review lecture on traffic safety in 2013 [31], when he was honoured as the Bertil Aldman speaker for his contribution to traffic safety over four decades. In it, he reflected that the 10 years from 1973 to 1982 were a golden age for crash investigation. In my view and that of many other colleagues, his own papers were clearly a significant contribution to this. Probably paraphrasing Churchill, Murray mused that "rarely was there so much that was so wrong that could be so easily fixed", and the sharp reductions in road fatalities that began in many countries around that time bear a sharp testament to this.

The written paper and the presentation he gave at the conference in 2013 [31] provided a unique and fascinating overview of the developments in crash safety over four decades from 1973 to 2013, and cannot be adequately summarised here. However, his view of the future addressed the manner in which the scope of IRCOBI has broadened so dramatically, with significant input now from researchers in military safety and sports injuries, as well as human-machine interface issues and active safety. He unsurprisingly returned to his main theme regarding the need for accident data collection. He commented that since the fundamental benefit to society of our research is to find out what happens to real people in real collisions as a precursor to reducing crash-related harm, there is not enough detailed accident investigation taking place. He cautions that while road fatalities have substantially decreased in Western countries, on a worldwide basis the World Health Organisation has predicted an increase of around 50% by the year 2030. This is due to the dominance of collisions predicted to occur in heavily populated and rapidly motorising regions such as India and China and Africa. Clearly, our work in traffic safety is not "done", despite consistent reductions in road traffic fatalities in some countries.

Many of the advances have arisen from collaborative interdisciplinary work and Murray certainly excelled at this. It would not be wise to classify which individuals made the most significant contributions to traffic safety which have occurred over the last four decades, but should one attempt to do so, Murray would surely feature at the top table. His dedication of his professional life, which has so far lasted over four decades, to the topic of traffic safety is a remarkable achievement, and the IRCOBI community owes him a collective debt of gratitude.

IV. Acknowledgement

Thank you to Elaine Mackay for helpful suggestions for improvements to this review.

V. References

Papers authored or co-authored by Murray Mackay and presented at annual IRCOBI conferences (full text of all papers available at www.ircobi.org):

[1] The epidemiology of injury – a review, Proceedings of the 1973 IRCOBI Conference.

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[4] Eye injuries in road traffic accidents, Proceedings of the 1973 IRCOBI Conference.

[5] Trauma to children as car occupants, Proceedings of the 1974 IRCOBI Conference.

[6] Child pedestrian injuries, Proceedings of the 1974 IRCOBI Conference.

[7] Serious trauma to car occupants wearing seat belts, Proceedings of the 1975 IRCOBI Conference.

[8] Some characteristics of collisions, the population of car occupant casualties and the relevance to performance testing, Proceedings of the 1978 IRCOBI Conference.

[9] Some observations on the reconstruction of a side impact accident, Proceedings of the 1978 IRCOBI Conference.

[10] A study of 93 fatal two wheeled accidents, Proceedings of the 1979 IRCOBI Conference.

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[12] A study of two-wheeled vehicle casualties treated at a city hospital, Proceedings of the 1981 IRCOBI Conference.

[13] Some observations on laminated glass windscreens and the injuries they cause in actual road accidents, Proceedings of the 1981 IRCOBI Conference.

[14] Seat belts under a voluntary regime - some aspects of use related to occupant and vehicle characteristics, and driving behaviour, Proceedings of the 1982 IRCOBI Conference.

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[17] Car occupant injury patterns with special reference to chest and abdominal injuries caused by seat belt loading, Proceedings of the 1992 IRCOBI Conference.

[18] An assessment of real-world steering wheel intrusion characteristics and their implications for head and face injuries to restrained drivers in frontal impacts, Proceedings of the 1992 IRCOBI Conference.

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[31]Bertil Aldman Award Lecture – IRCOBI past, present and future, Proceedings of the 2013 IRCOBI Conference.