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Sand, surf and sideways: A systems analysis of beaches as complex roadway environments ☆

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ABSTRACT

Between 2002 and 2014 there have been over 150 reported incidents, including 4 fatalities, involving motor vehicles on the world heritage listed sand island Fraser Island (K'gari), off the southern Queensland coast, Australia. While regulation has been established, the beach as a roadway environment is complex and is a unique challenge for drivers. This paper describes the results of applying two systems analysis approaches, Accimap and Cognitive Work Analysis (CWA), to explore beach driving. Accimap is used to describe the actors within the system and the contributory factors involved in two recent fatal incidents. CWA is then used to describe the beach driving system within which these accidents are occurring, including the range of constraints impacting behaviour. The findings show that beaches present as complex multifaceted driving environments with a variety of competing and conflicting priorities. Further, the systems lens adopted enabled exploration of a range of contributory factors and revealed alternate likely pathways of accident causation and dependence within the management and regulation of beaches as roads. In closing we articulate a research agenda designed to enhance our understanding of the cultural, economic, and social implications of beach and off-road driving to improve safety and stakeholder coordination.

1. Introduction

There is now a groundswell of researchers and practitioners applying systems thinking approaches to road safety (Salmon and Lenne, 2015). This involves applying models, (e.g. Rasmussen, 1997) systems analysis and design methods (e.g. Regan et al., 2015), and design principles from systems thinking to tackle long standing road safety issues such as intersections (Cornelissen et al., 2015), rail level crossings (Salmon et al., 2016), distraction (Young and Salmon, 2015) and young drivers (Scott-Parker et al., 2015). The key philosophy underpinning the approach is that it is the overall system that should be focussed on during road safety efforts, as opposed to individual road users. Accordingly, the emphasis is on identifying the network of interacting factors that influence behaviour, rather than behaviours typically implicated in road crash analysis (e.g. driver errors, vehicle factors, road design flaws).

Whilst road traffic crashes are now generally well understood, a less well known 'road safety' issue is that of crashes that occur on beaches during off road driving. The outcomes, however, can be no less traumatic than road collisions. Since 2002, for example, there have been four fatalities from single vehicle rollovers on Fraser Island (K'gari) in Queensland, Australia. The most recent tragedy occurred in November 2014 and involved the death of a 23 year old English backpacker when the 4WD vehicle in which she was a passenger rolled on an unsealed sand road. Beach users are also at risk. In December 2013, for example, two tourists lying on the beach were run over and seriously injured by a vehicle operated by Queensland Surf Life Saving Association on the Gold Coast, Queensland. Internationally there are similar issues. In the US, for example, between 2005 and 2010 on a single beach in Florida, more than 40 people were struck or run over by vehicles, with 2 children under 5 killed in 2010 alone (Cave, 2010).

While the challenges of beach and off-road driving safety are recognised (Stevens and Salmon, 2015), there is limited empirical research exploring these driving environments and the causes of trauma within them. Similar to conventional road safety research, current national and international literature has a tendency to focus on the parts of the system, for example the safety of the

☆ *Statement of relevance:* Beaches are complex roadway environments and have experienced numerous crashes and fatalities worldwide. The analysis presented is relevant as it shows the unique set of contributory factors involved and provides an analysis of the system around beach driving. Both outcomes support practitioners in developing countermeasures.

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vehicles involved (Rakotonirainy et al., 2006; Huff et al., 2012) or accident types, such as single vehicle rollovers (Fréchède et al., 2011). Additionally there is a body of work which considers injury prevention in the context of quad style vehicles or All-Terrain Vehicles (ATVs) which identifies and determines epidemiology and some of the risk factors, including alcohol, speed, downhill driving, unsealed roads, driving backwards, driving downhill and sideways rollovers (O'Connor et al., 2009; Lord et al., 2010; Shulruf and Balemi, 2010; Winfield et al., 2010; Denning et al., 2013; Rechnitzer et al., 2013). Alternately there is work which recognises impacts and opportunities of motorised recreation and tourism (Albritton and Stein, 2011) and conversely the environmental harm caused by four wheel driving (Weston et al., 2014).

It is clear then that knowledge gaps exist surrounding the causes of beach driving crashes, the nature of beach driving systems and subsequently whether a conventional road safety approach is applicable. The significance of these gaps is heightened by the fact that more than 50% of global roadways are unsealed (CIA, 2014) and likely increases in traffic numbers may exacerbate the issue of crashes in these road environments. This paper is a direct response to these knowledge gaps, presenting systems analyses of the K'gari beaching driving system and of recent crashes that have occurred within it. Specifically, we present Accimap analyses (Svedung and Rasmussen, 2002) of two recent K'gari fatal beaching driving incidents. Following this a Work Domain Analysis (Naikar, 2013) of beach driving on K'gari, the largest sand island in the world is presented. The aim is first to identify some of the unique contributory factors involved in beach driving crashes, and second to identify what beach driving systems comprise, and thus how they differ from standard road environments. The intention is not only to highlight the importance and complexity of beaching driving crashes, but also to propose suitable frameworks for practitioners wishing to examine the issue and to lay a research agenda designed to work towards improving beach driving safety.

1.1. The beach driving context

The beaches of Queensland are both a necessary and recreational form of vehicular access to permanent and semi-permanent settlements along the coast. Until the 1980s the beach as a road was an environment that lacked jurisdictional regulation. As a response to the perceived challenges of enforcement, the Queensland state government established that all beaches, permitting vehicular access were to be re-classified as 'gazetted' roadways. This gazetting means that beaches now appear within the published network of government controlled roadways. As such all road rules and conventions that pertain to state and local government constructed and managed roadways also apply to the beaches. While this has allowed for greater levels of regulation, enforcement and prosecution, it is not without its difficulties and trade-offs. Principally, as a gazetted road any individual who currently possesses standard on-road or international licensing is allowed to drive on a beach at up to 80 km/h. As a corollary, tourists holding a full driving licence are free to drive on K'gari.

The reality is that the beach driving environment is a complex and dynamic one. It is a setting of rapid change with unstable sand surfaces, physical hazards, such as rocks, a roadway often crowded with people engaged in a wide range of activities (fishing, hiking, sunbathing, flying kites, playing sport, etc.), different kinds of vehicles (e.g. cars, tour buses, aeroplanes) and with limited signage or road infrastructure. It is a driving context of vast unfamiliarity for the majority of users further compounded by the necessity of the use of 4WD vehicles which have higher rollover risks for inexperienced drivers (Keall and Newstead, 2007).

1.2. Systems thinking and beach driving

The term 'systems thinking' in this case is used to describe a philosophy currently prevalent within the discipline of human factors that is applied to understand and improve performance and safety in complex sociotechnical systems (Salmon and Lenne, 2015). It has been prominent for the last two decades in the area of accident analysis (e.g. Leveson, 2004; Rasmussen, 1997) but has also enjoyed significant attention in the areas of systems analysis and design (Karsh et al., 2014; McIlroy and Stanton, 2011; Rechard et al., 2015; Salmon et al., 2014; Stanton and Bessell, 2014; Walker et al., 2014).

The prevailing philosophy is that safety, and indeed accidents, are emergent properties arising from non-linear interactions between multiple components across complex sociotechnical systems (e.g. Leveson, 2004). In short, accidents are underpinned by a network of interacting, contributory factors that reside across the overall system. Recently road safety applications have involved applying Rasmussen's (1997) risk management framework to road design (Cornelissen et al., 2015), crash analysis (Salmon et al., 2013; Newnam and Goode, 2015), pedestrian behaviours (Stefanova et al., 2015), and specific road safety issues, such as driver distraction (Young and Salmon, 2015). A key implication is that it is not possible to truly understand safety and performance through decomposing the system into component parts and examining these parts alone (e.g. drivers, vehicles); rather, it is the interactions between the components that are of interest.

In an editorial for a recent special issue of this journal on systems thinking in road safety, Salmon and Lenne (2015) called for further road safety applications involving Rasmussen's framework and presented a modified set of Rasmussen's tenets to drive future research. These assert that:

- Road safety and road crashes are emergent properties impacted by the decisions and actions of all actors, not just road users alone.
- Threats to road safety are caused by multiple contributing factors, not just a single poor decision or action.
- Threats to road safety can result from a lack of poor communication and feedback (or 'vertical integration') across levels of the system, not just from deficiencies at one level alone.
- Lack of vertical integration is caused, in part, by lack of feedback across levels of the road transport system.
- Road system behaviours are not static, they migrate over time and under the influence of various pressures such as financial and psychological pressures.
- Migration occurs at multiple levels of the road transport system.
- Migration of practices cause system defences to degrade and erode gradually over time, not all at once. Road crashes are caused by a combination of this migration and a triggering event(s).

In the present paper it is argued that two currently popular frameworks can be used to investigate these tenets in the beach driving context: Accimap (Svedung and Rasmussen, 2002) and the Work Domain Analysis phase of Cognitive Work Analysis (Vicente, 1999).

2. Methodology

2.1. Accimap analysis framework

Rasmussen proposes the Accimap analysis framework as an appropriate methodology for understanding accidents in line with his risk management framework. Accimap is used to graphically