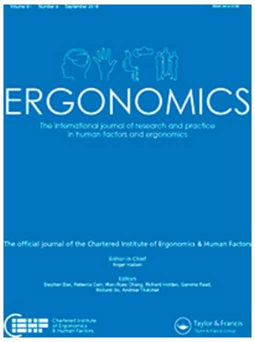
Interaction-centred design



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Interaction-centred design: an end user evaluation of road intersection concepts developed using the Cognitive Work Analysis Design Toolkit (CWA-DT)

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Abstract

Crashes at intersections represent an important road safety problem. Interactions between different road user types, such as between vehicles and vulnerable road users, are a particular concern. It has been suggested driver-centric road design plays a role in crashes. A multi-road user evaluation of three novel intersection designs is described. The designs were generated using the Cognitive Work Analysis Design Toolkit, underpinned by sociotechnical systems theory. The desktop evaluation involved drivers, motorcyclists, cyclists and pedestrians rating the design concepts against alignment with design goals, sociotechnical systems theory and usability, and providing feedback on the positive and negative aspects. Two concepts received more positive ratings and feedback in comparison to a concept that provided more user autonomy. The evaluation results also highlight clear differences in needs across road user groups. The design and evaluation process demonstrates how sociotechnical systems values and principles can be applied in the design of public spaces.

Keywords: *Sociotechnical Systems Theory, Design, Road Safety, Intersections, End user evaluation*

Practitioner statement: This study involved a participatory evaluation of novel road intersection designs, based on sociotechnical systems theory. The results identified important differences in needs and preferences across road user groups and demonstrate the value of sociotechnical systems theory and user participation in road transport design and evaluation processes.

Introduction

Collisions at intersections represent a significant road safety issue. Inherent in their design is the need to manage the requirements of different road users, travelling in conflicting directions, potentially at high speeds, with some more vulnerable in the event of a crash than others. Safety at intersections, or road junctions, is a concern for governments worldwide. Across the European Union in 2015, over 5,000 fatalities occurred at intersections (European Commission, 2017). In the United States, in 2011, approximately 40% of road crashes occurred at intersections (Dong, Clarke, Richards & Huang, 2014). Similarly, in Australia, most urban crashes and a substantial proportion of rural crashes occur at intersections (McLean et al. 2010). A considerable proportion of injuries to vulnerable road users such as pedestrians, cyclists and motorcyclists arise from crashes at intersections (e.g. Chong, Chiang, Allen, Fleegler & Lee, 2018; Clarke, Ward, Bartle & Truman, 2007; European Commission, 2017).

The prevalent approach to understanding and preventing collisions at intersections has tended to be component driven, focussing on physical features (e.g. geometry and signals; Highways Agency 2012), particular road user types (e.g., driver error; Gstalter and Fastenmeier 2010, Sandin 2009) and/or fixing a specific component of the problem (e.g., increasing the conspicuity of motorcycles; Gershon and Shinar 2013). However, an emerging set of literature (e.g. Cornelissen et al., 2013; Salmon et al., 2014a; 2014b) has highlighted the problems of driver-centric intersection designs and the need for design processes to be driven by consideration of all road user needs and behaviours, including the interactions between them. This represents a shift from a component view of the problem to a systems view.

This, in turn, requires an ergonomics design philosophy capable of supporting ‘interactions’ between different forms of road user, rather than focussing on the behaviour of individual road users in isolation. Sociotechnical systems theory; a values-based approach to system design with a strong focus on participatory design and understanding diverse end user needs (Walker et al., 2008), was adopted. This follows previous calls to apply sociotechnical systems thinking beyond traditional applications to explore its utility in new domains (Davis, Challenger, Jayewardene & Clegg, 2014).

A process for generating designs based on the sociotechnical approach, the Cognitive Work Analysis Design Toolkit (CWA-DT; Read, Salmon, Goode & Lenné, 2018; Read, Salmon & Lenné, 2016), was initially used by an expert group to develop three intersection designs to support safer road user interactions. The aim of this paper is to describe an end user evaluation of these designs.

The following section introduces the sociotechnical systems approach and describes how sociotechnical design values and principles apply to the design of intersections.

A sociotechnical systems approach to intersection design

Sociotechnical systems theory is an approach to work design that emerged from research undertaken at the Tavistock Institute in the 1950s. The approach, aligned with systems theory and based in philosophies of industrial democracy and participatory design, has been applied to organisational design for many decades (Mumford, 2006; Cherns, 1976; Clegg, 2000; Davis, 1982; Walker, Stanton, Salmon, & Jenkins, 2009). The core principle is joint optimisation of social and technical elements of a system. Through joint optimisation, a system has the capacity to adapt to changes in its environment and thus maintain successful performance over time (Walker et al., 2008).

Sociotechnical values

The values of sociotechnical systems theory are intended to underpin both the design process and the operation of the organisation or system being designed. Five values have been identified from the literature (Read, Salmon, Lenné & Stanton, 2015): humans as assets; technology as a tool to assist humans; promote quality of life; respect for individual differences and responsibility to all stakeholders. While these values have arisen from research into work design, they have a strong alignment with values applied in urban design to achieve equitable, ecological and economically viable built environments (Stevens, 2016) and have previously been used in transport design processes (e.g. Read, Salmon & Lenné, 2016).

The *humans as assets* value asserts that humans should be viewed as positive resources rather than as unpredictable, error-prone components that cause problems in otherwise well-designed technological systems. The sociotechnical approach acknowledges that no technical system is perfectly designed and humans play an important role of problem solving (Norros, 2014; Clegg, 2000). In relation to intersection design, this value suggests that the environment should support road users to make good decisions, through providing information and guidance; rather than constrain behaviour through physical barriers or enforcement mechanisms (e.g. traffic cameras).

The *technology as a tool to assist humans* value advocates that technology should not be viewed as being an end in its own right (Norros, 2014; Clegg, 2000). Clegg (2000) emphasises the frequency with which technology is proposed as a default solution, often as a replacement for humans, with little or no consideration of the goals of people's work or the social system required to make the technology work. The current trend in the promotion of more highly automated vehicles is an example of where these first two values appear to a large extent to be under threat. The increasing automation of road vehicles is heavily technology and engineering focused and safety 'blind spots' have been identified regarding the role of humans and integration of automated technologies into the wider road system (e.g. Noy, Shinar & Horrey, 2018).

The *promote quality of life* value is focussed on counteracting the assumption that humans are comparable to machines, and can be expected to behave in a similar manner (Robinson, 1982). Application of the machine metaphor in work design leads to issues such as strict requirements (e.g.

lack of flexibility around working hours and breaks), poor job design (e.g. repetitive tasks and lack of task rotation), and unachievable productivity targets. This value argues that instead, people should be provided with quality work, defined as that which is challenging, incorporates variety, includes scope for decision-making and choice, facilitates ongoing learning, incorporates social support and recognition, has social relevance to life outside work and leads to a desirable future (Cherns, 1976; 1987). Translated to road users at intersections, these ideas would suggest that users should be engaged with the task of traversing an intersection. Intersections that require road users to make decisions, rather than operate on 'auto pilot' can engender a sense of responsibility, particularly where intersections are also designed in a way that provokes a sense of risk in the user. This value also relates to notions of usability (e.g. intuitive design) and user experience (e.g. avoidance of frustrating user interactions).

The *respect for individual differences* value highlights the importance of taking into account the different needs and preferences of individual users in design processes. For example, some end users may prefer more autonomy and control than others. According to the sociotechnical systems approach, design processes should recognise and respect differences and work towards achieving a flexible design that incorporates different preferences, acknowledging that meeting all needs may not always be possible (Cherns, 1976; 1987). In relation to intersections, previous research has demonstrated that different road user groups have different ways of negotiating intersections and thus have different needs relating to information and infrastructure (Cornelissen et al. 2013; Salmon et al., 2014a; 2014b). It has been argued that the current road system has not balanced the needs of different groups well; instead being heavily driver-centric (e.g. Salmon et al., 2014a, b; Walker et al, 2011).

The final value, r*esponsibility to all stakeholders,* calls on designers to consider the impacts of their choices on all stakeholders, including end users, manufacturers, unions, industry bodies, government, and the wider community. Potential negative effects of design decisions could include physical damage or injury (e.g. collisions), economic loss, social harms and environmental harms (Cherns, 1987). Potential consequences should be considered throughout all stages of the system lifecycle from initial design decisions through to construction, use, maintenance and disposal. For example, intersection designers consider how the road will operate and what harms may come to end users because of a design decision (e.g. a decision not to install traffic lights at a complex intersection due to cost considerations). However, other design decisions (i.e. those that trade off efficiency for safety reasons) could cause economic harm to local businesses and communities, thus both direct and indirect harms and costs need to be considered.

Sociotechnical principles

In addition to the values, the sociotechnical approach encompasses a set of ‘process’ and ‘content’ principles (Cherns, 1976, 1987; Clegg, 2000; Davis, 1982). The former define how a sociotechnical systems design process should progress. The latter describe the key attributes that should be present in the designed system for it to be successful in supporting adaptive capacity. These principles have been adapted from the work of Cherns (1976, 1987), Clegg (2000) and Davis (1982).

The process principles include, amongst others: the adoption of agreed values and purposes to underpin the design process; user participation in design; joint design of social and technical elements (so that neither is optimised at the expense of the other); and multidisciplinary participation and learning throughout the design process.

The content principles include that:

- Tasks are allocated appropriately between and amongst humans and technology.
- Useful, meaningful and whole tasks are designed.
- Boundary locations are appropriate.

- Boundaries are managed.
- Problems are controlled at their source.
- Design incorporates the needs of the business, users and managers.
- Intimate units and environments are designed.
- Design is appropriate for the context (as opposed to an off-the-shelf solution).
- Adaptability is achieved through multifunctionalism (i.e. that system elements, people in particular, have the capability to perform multiple functions and to assist in tasks outside of their usual responsibilities where unpredictable events arise).
- System elements are congruent.
- Means for undertaking tasks are flexibly specified (i.e. that tasks should not be over-specified, enabling end user autonomy, as well as flexibility and adaptation).
- Authority and responsibility are allocated appropriately.
- Adaptability is achieved through flexible structures and mechanisms.
- Information is provided where action is needed (i.e. that information and feedback is provided directly to the user rather than those controlling or monitoring the system, in a manner that enables timely action).

Objectives and aims

The aim of this paper is to describe the evaluation of three intersection design concepts developed using the CWA-DT. The desktop evaluation elicited the views of end users (e.g. members of the public who represented drivers, cyclists, motorcyclists and pedestrians) on: 1) the extent to which the design concepts would minimise collisions and road trauma, maximise compliance with the road rules, maximise efficiency and appropriately optimise road user flexibility; 2) the extent to which they aligned with the sociotechnical systems values; and 3) the extent to which the intersections were usable (including a measure of preference, and perceptions regarding the positive and negative aspects of the designs).

Method

Design

A desktop evaluation approach was employed whereby end users attended a workshop involving a guided desktop review of the intersection concepts, with feedback collected through group discussions and questionnaires. The study was approved by the University of the Sunshine Coast Human Research Ethics Committee (A/14/585).

Participants

Participants were recruited via posters, social media and through an advertisement in a local newspaper. Recruitment materials invited members of the public, aged between 21 and 65 years who identified as an experienced driver, cyclist, motorcyclist or pedestrian to participate.

Twenty-one participants attended the workshop. Overall, participants had a mean age of 42.43 years (*SD* = 12.97) and the majority were male (n = 13, 61.9%). Table 1 shows participant demographics by group. Participants self-rated their level of experience in the transport mode they were representing in the workshop on a scale of 1 (no experience) to 5 (extensive experience).

Table 1. Participant demographics

		Gender		**Age (years)**		**Years' experience (years)**		**Self-reported experience level**	
Road user group	*N*	M	F	*M*	*SD*	*M*	*SD*	*M*	*SD*
Drivers	5	60%	40%	46.4	10.57	29	11.34	4.74	0.58
Motorcyclists	5	100%	-	45.4	14.61	26.4	14.15	4.6	0.55
Cyclists	6	67%	33%	48.67	10.91	15	9.36	4.67	0.52
Pedestrians	5	20%	80%	28	4.18	-	-	4.4	0.89

Note, pedestrians were not asked to provide years' experience as it is assumed that they had used the road transport system as a pedestrian from a young age.

Many participants, regardless of allocation in the workshop, had experience across multiple transport modes. Most notably, all but one participant held a drivers' licence and had current driving experience.

Materials

The design concepts

The CWA-DT was used to generate the novel intersection designs. The full design process is described in a previous publication (Read, Salmon & Lenné, 2015a); a summary is given here. The goal was to improve road user interactions and prevent collisions. Eleven experts (comprising researchers and road transport experts) engaged in a design workshop held over two days.
The process was driven by a design brief which was developed around analysis findings and insights from studies of road user interactions at intersections (Salmon et al., 2014a; 2014b) and a Work Domain Analysis (WDA) of road intersections (Salmon, Read, Walker, Lenné & Stanton, 2018).

The design process aimed to meet a set of design goals, based on the WDA. The goals were to generate designs that would: minimise collisions and road trauma; maximise compliance with the road rules; maximise efficiency; and appropriately optimise flexibility (i.e. give road users the option to select their own path). Further, the design process aimed to create designs that aligned with the five sociotechnical values.

Experts were asked to develop the new designs within an existing intersection 'footprint' which comprised an intersection between two major arterial roads in the South-Eastern suburbs of Melbourne, Victoria (Figure 1). The existing intersection was fully signalised with traffic lights and turning arrows, an approach speed limit of 80km/h, three lanes on each approach and signalised pedestrian crossings across all roads within the intersection.

Figure 1. Aerial image of the existing intersection, used as a footprint for new design concepts.

The experts were provided an overview of the previous research findings, and the design brief, then engaged in a range of CWA-DT activities to create new designs. A number of activities are adapted from design thinking processes and guidance for improving creativity and innovation (e.g. Imber, 2009). The activities are summarised in Table 2.

Table 2. Design activities undertaken in the expert workshop.

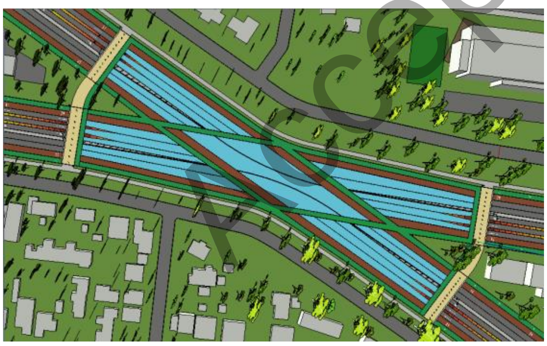
Design process element	Description
Lateral thinking exercises	Short exercises, such as the 'Impossible Challenge' were used at the beginning of each day to encourage lateral thinking, rather than common rational, analytical thinking.
Assumption crushing exercise	An exercise to identify and challenge unconscious assumptions underlying the current design. Assumptions can limit the breadth of the design space being explored. The assumption crushing exercise takes assumptions identified during the analysis and 'crushes' them to enable novel idea generation. An example assumption uncovered by the analysis was that *Roads should be built for cars, as they are the most common mode of transport.* The experts generated alternative assumptions including that roads should be designed for

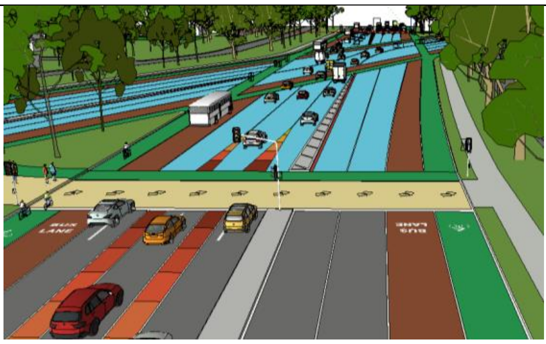
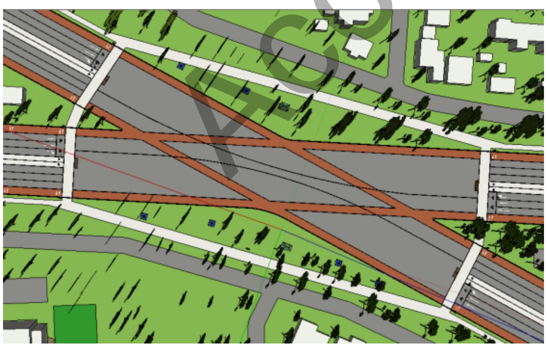
	demand, that they should be designed to discourage car use, or that they should be designed for the most vulnerable user group, then brainstormed ideas aligned with these new assumptions.
Metaphor exercise	An exercise to identify and use metaphorical thinking in design. Metaphors can assist designers to take inspiration from elsewhere. The metaphor of 'team' was identified in the insight generation process. That is, like road users, teams (e.g. sports teams, research teams) must maintain awareness of other team members to ensure they achieve common goals. The experts brainstormed ways that teams maintain awareness and how this could be applied at intersections.
Design with intent cards	In this exercise, participants were asked to consider desirable end user behaviour and to use a set of 'Design with Intent' cards (Lockton, Harrison & Stanton, 2010) to determine how these behaviours could be encouraged through design.
Constraint crushing exercise	An exercise which used the WDA to identify the constraints on behaviour in the current system. The experts were introduced to the WDA and asked to identify the key constraints for each user group (e.g. drivers, cyclists and motorcyclists, and pedestrians). For example, a key constraint identified for drivers was the road markings. Each constraint was then either: 'crushed' to expand design thinking beyond the existing system constraints; strengthened where required; or made more visible where there was a benefit to enhancing end user awareness of constraints.
Design concept definition	Following the design activities, the experts generated one or two distinct design concepts based on the ideas they had discussed. These were documented on design concept templates.
Design concept evaluation & refinement	Towards the end of each day, the experts considered all the design concepts they had generated and use an evaluation sheet to consider how the different designs compared against the sociotechnical systems theory content principles. They then selected and refined the most promising concept and presented it to the larger group.
Design concept shortlisting	Group discussion was held to determine a short list of design concepts, from those generated over both days.

The design workshop resulted in three novel design concepts: the Self-regulating Intersection, the Turning Teams concept and the Circular Concept. From the notes and sketches produced in the workshops, detailed designs were produced as 3D drawings using SketchUp software. Table 3 provides an overview of the key features and how they align with the sociotechnical systems theory values and content principles.

Table 3. Key design elements and their relationship to the sociotechnical systems theory values and principles

Concept	Key elements of each design	Values and principles encompassed
Self-regulating Intersection This design is based on the notion of maintaining flow. A large oval shaped median strip in the centre of the intersection stops motorised traffic from performing a standard right-hand turn. Instead, when traffic from each intersecting road is given priority to enter the intersection, road users move around the median strip in the same direction, and exit where they wish. From a sociotechnical systems perspective, end user autonomy is prioritised within this concept. Fewer external constraints (i.e. traffic controls) are used to enable road users to self-organise and self-regulate functioning of the intersection. 	Filtering lights allow vehicles to enter the intersection in a steady flow, then users continue through the intersection in the same direction (similar to a roundabout), self-regulating their speed. Given high traffic flow, speeds are expected to be slow (i.e. 20km/h), yet flow is maintained.	• Humans as assets *(value)* • Promote quality of life *(value)* • Means for undertaking tasks are flexibly specified *(content principle)*
	Cyclists have options to either move with motorised traffic or 'cut through' the intersection via dedicated lanes available through the central median strip.	• Respect for individual differences *(value)* • Means for undertaking tasks are flexibly specified *(content principle)*
	Removal of lane markings in the intersection to promote connectedness between road users who must negotiate their path with other road users.	• Humans as assets *(value)* • Means for undertaking tasks are flexibly specified *(content principle)* • Adaptability is achieved through flexible structures and mechanisms *(content principle)*

		
Turning Teams The design aims to allow all those not in conflict to proceed simultaneously, based on traffic light phasing and clearly defined lanes. For example, in one traffic cycle, traffic in the right-hand turn lane would turn right, cyclists would go straight ahead and to the right, and the bus could proceed straight ahead. Next, once the cyclists will have cleared, motorised traffic can proceed straight ahead. Pedestrian phases are activated where there are no conflicts. From a sociotechnical systems perspective a core aspect of this design is the manipulation of how boundaries are managed in relation to traffic priority. Through this, the concept intends to create a more collaborative road system where road users work together to traverse the intersection, and create a social connection with other types of road users, as opposed to competing against them. 	Traffic lights are phased based on 'teams' which encompass both road user type and direction of travel.	• Promote quality of life *(value)* • Boundaries are managed *(content principle)* • Intimate units and environments are designed *(content principle)*
	Traffic lights are moved to ensure that pedestrian crossings match desire lines (i.e. paths already used by pedestrians representing the shortest distance to cross based on the location of buildings and adjoining pedestrian paths).	• Promote quality of life (*value*) • Design is appropriate to the particular context (*content principle*)
	Footpath is widened and cyclists not comfortable to traverse the intersection with the motorised traffic are given the official alternative of crossing with pedestrians.	• Respect for individual differences *(value)* • Means for undertaking tasks are flexibly specified *(content principle)*
	Lanes are colour-coded to assist users to determine the appropriate lane.	• Boundaries are managed *(content principle)* • Information is provided where action is needed *(content principle)* • System elements are congruent *(content principle)*
	Bicycle lane provided, as well as a	• Boundaries are managed

	cyclist priority light which is used to clear cyclists from the intersection prior to allowing motorised traffic to enter.	*(content principle)*
	Filtering lanes for motorcyclists are provided.	• Boundaries are managed *(content principle)* • Means for undertaking tasks are flexibly specified *(content principle)*
Circular Concept This concept focuses on clear separation between motorised and non-motorised traffic. A circular path surrounds the intersection and is shared by pedestrians and by cyclists who join the path from bicycle lanes down the centre of the intersecting roads. While pedestrians and cyclists must travel further distances to traverse the intersection, this is compensated by making their environment more pleasant. From a sociotechnical systems perspective this design had a focus on boundary management achieved through increased separation of motorised and vulnerable road users. It also intended to create an improved public space around the intersection to benefit end users through improving quality of life. This also aimed to meet responsibilities to wider community stakeholders through providing infrastructure to improve social interaction including cafes, gardens, BBQ areas and seating.	Cyclists share the circular path around the intersection with pedestrians.	• Boundaries are managed *(content principle)*
	Bicycle lanes are provided down the centre of the intersecting roads.	• Boundaries are managed *(content principle)*
	Areas adjacent to the walking / cycling path have cafes, gardens, BBQ areas, and seating provided.	• Promote quality of life *(value)* • Responsibility to all stakeholders *(value)* • Intimate units and environments are designed *(content principle)* • Design is appropriate to the particular context *(content principle)*
	Motorcycle zones are provided at the front of the traffic lanes to encourage motorcyclists to filter to the front	• Boundaries are managed *(content principle)*
	A sign is used to alert drivers to watch for motorcyclists filtering from behind	• Information is provided where action is needed *(content principle)*

Evaluation workshop materials

Aerial views of the 3D design drawings of each novel design were printed and provided to participants, along with pens and coloured markers for annotations. Further, the design drawings were uploaded onto 27 inch (68cm) Intel Core i7 Lenovo touchscreen tabletop tablets enabling participants to view the designs from varying angles and to zoom in and out to see different levels of detail of the designs. Figure 2 shows participants using the touchscreens and design drawings. In addition, small paper tokens representing different road user types were provided to participants to enable them to create scenarios of road user interactions on the intersection drawings.

Figure 2. Workshop materials

Facilitator guides, consisting of prompt questions and blank space for note taking, were developed to guide workshop discussions. Laptop computers were used to view the guides and for note taking. Audio visual recordings were taken throughout the workshop.

A participant questionnaire was used to gather demographic information, perceptions of alignment against the design goals (e.g. minimising collisions and trauma, maximising efficiency), perceptions of adherence to the values of sociotechnical systems theory (using criteria previously applied to evaluate designs, see Read, Salmon & Lenné, 2015b), and ratings of usability using an adapted version of the System Usability Scale (SUS; Brooke, 1996). Finally, the questionnaire asked participants to rank the three novel designs and the existing design based on preference.

Procedure

The evaluation workshop was held over a full day. The venue was arranged to support group working with participants positioned in small groups (of 5-6 participants), each with a table facilitator.

On arrival, participants were arranged in road user groups, such that there was a driver group, a cyclist group, a motorcyclist group and a pedestrian group. Participants provided written consent, then participants and facilitators each introduced themselves to the group. To encourage participants to think in the mindset of the road user they were representing, they were asked to comment on an aspect of existing road design they either liked or disliked from the perspective of their road user type.

Next, participants were given a short presentation to introduce the issue of collisions between road users and to describe research findings relating to the role of incompatibilities between different road users at intersections (e.g. Salmon et al., 2014a; 2014b). Participants were then provided with an overview of the design aims, the process undertaken to develop the novel designs, and the key features of each design concept. Participants then worked in small groups to discuss each design from the perspective of their road user group (Round 1). All groups considered the concepts in the same order: 1. Self-regulating Intersection; 2. Turning Teams; 3. Circular Concept. Table facilitators guided the group discussions and recorded the outcomes of the discussions. The questions guiding the discussion in Round 1 were:

1. As a [cyclist, pedestrian, driver, motorcyclist], what options do you have to move through this intersection if you were turning right from road X onto road Y (i.e. when approaching from the East and travelling North)?
2. From the point of view of a [cyclist, pedestrian, driver, motorcyclist] turning right at this intersection:
    a) What are the good aspects of the design?
    b) What are the bad aspects of the design? (i.e. Are there potential conflict points with other road users? What errors, if any, do you think could be made in this design?)
3. What improvements or refinements would you make to the design?

After each intersection design was discussed, groups were asked to share one finding with the larger group enabling the sharing of different perspectives within the room.

After Round 1, the groups were re-arranged to include a representative of every road user type. Each intersection design was then discussed from a multi-road user perspective (Round 2). This involved presenting participants with a scenario involving all road users to consider while discussing the designs. The scenario was approaching the intersection in heavy traffic conditions, when traffic lights are red but are about to turn green to allow traffic to proceed.

- The driver is waiting at the front of the traffic queue, in the right-hand turn lane
- The cyclist is approaching the intersection behind the car that is waiting to turn right

- The motorcyclist is approaching behind the cyclist, also wanting to turn right
- Pedestrians are waiting to cross both at the first crossing (i.e. where the car is waiting) and at the road that the other vehicles are turning right into.

Table facilitators posed questions relating to the multi-road user scenario regarding the good and bad aspects of the design, whether the design could assist to support situation awareness amongst road users (e.g. encourage drivers to look where cyclists, motorcyclists and pedestrians may be on the road) and how the design could be improved.

At the conclusion of Round 2, groups again shared one finding with the wider group and then completed the questionnaire items relating to that intersection's alignment against the design goals, adherence to the sociotechnical systems theory values, and usability. After all intersections were discussed, participants completed the demographic questions and the overall preference questions. Participants were then thanked for their input and provided with a gift card to reimburse them for their time.

Data analysis

Raw data from the questionnaires were entered and descriptive statistics were calculated using a statistical software package, SPSS 24.

For the questionnaire items relating to the design goals, percentages for each response were derived. A design goal was determined to be met where more than 75% of participants agreed or strongly agreed that the design aligned with the goal.

The questionnaire items relating to sociotechnical systems theory items were all positively phrased and were given equal weighting. To calculate the percentage of responses (e.g. strongly agree, agree) for each value, the responses for each questionnaire item relating to a value were summed and percentages for each value derived across items. A value was determined to be met where more than 75% of participants agreed or strongly agreed that the design aligned with the value. In addition, given the novelty of applying sociotechnical systems theory in road design, where 50% of participants agreed or strongly agreed, the value was considered to be somewhat met.

Scoring for the adapted SUS followed the procedure outlined in Brooke (1996), which led to a scores out of 100, with higher scores representing greater perceived usability. In terms of preference rankings, a weighting process was used. All 1st ranks were summed for each concept and multiplied by 4, 2nd ranks were summed and multiplied by 3, 3rd ranks were summed and multiplied by 2, and 4th ranks were summed only. The weighted scores were then summed across all participants to determine a total ranked score out of 80. A second analysis to enable comparison between road user groups involved summing the weighted scores for participants in each group and dividing these by the number of participants in each group (given uneven numbers across groups, including missing data for one motorcyclist for this question). The total possible score for each concept by user group was 4.

The notes recorded by table facilitators in relation to the discussion questions were collated and analysed for positive and negative themes.

Results and discussion

Alignment with design goals

Figure 3 shows the percentages of responses to the questions regarding the alignment of the concepts with the design goals. The criteria of 75% agreement was not met for any of the design goals.

The Self-regulating Intersection, in particular, received poor ratings. In relation to the aim of minimising collisions and trauma, nearly all participants (95%) disagreed that the design would achieve this. Most (74%) participants also disagreed that the Self-regulating Intersection would maximise efficiency and maximise compliance (76%). In contrast, the majority of participants (57%) agreed that the design would appropriately optimise flexibility for road users to traverse the intersection.

The Turning Teams concept received somewhat positive responses with the majority agreeing that the concept would maximise efficiency (62%), compliance (52%) and minimise collisions and trauma (62%).

The Circular Concept received somewhat mixed ratings. The only majority rating related to compliance, where 52% of participants agreed that the design would maximise compliance.

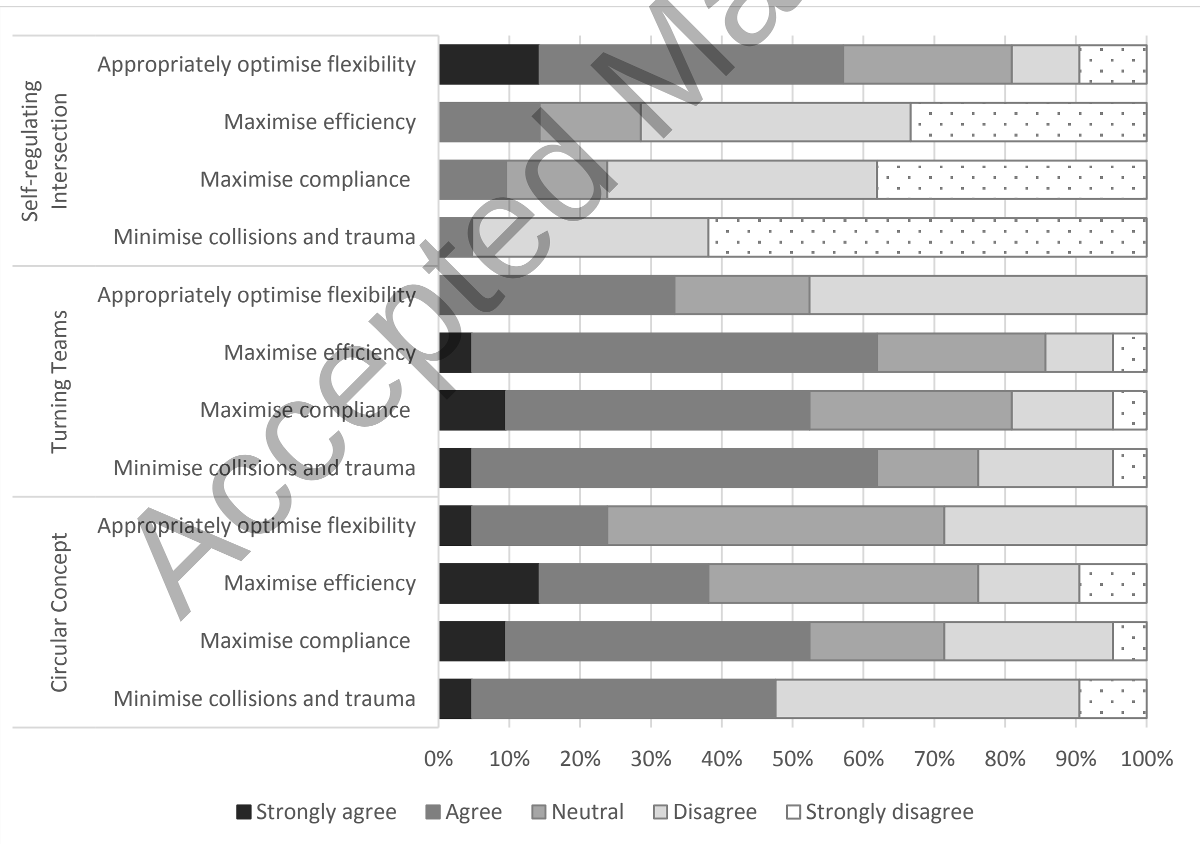


Figure 3. Ratings of concept alignment with the design goals

Given that the overall aim of the designs was to promote safety, we further analysed the ratings in relation to minimising collisions and trauma by road user type. For the Self-regulating Intersection there was little apparent difference between the perceptions of the road user types. All (100%) of the motorcyclists, cyclists and pedestrians disagreed that this design would minimise collisions and trauma. Of the drivers, almost all (80%) disagreed.

For the Turning Teams intersection, the results were more varied. Interestingly, driver and cyclist groups provided similar ratings. The majority (80% of drivers, 83.33% of cyclists) agreed that the design would minimise trauma and collisions. For both motorcyclists and pedestrians, only 40% agreed that the design would minimise trauma and collisions. Therefore, the positive ratings for this measure overall were mainly driven by the ratings of drivers and cyclists.

Finally, for the Circular Concept, all drivers (100%) and most cyclists (66.6%) disagreed that the concept would minimise collisions and trauma. In contrast, all pedestrians (100%) and most motorcyclists (60%) agreed with this item. The positive ratings for this measure overall then were mostly driven by ratings of pedestrians, and to some extent motorcyclists.

Alignment with sociotechnical systems theory

In relation to alignment with sociotechnical systems theory, the percentages of responses across all participants for each of the values is shown in Figure 4. For all concepts, the criteria of 75% agreement was not met for any of the values.

The Self-regulating Intersection was poorly rated in relation to respecting individual differences and being responsible to all stakeholders. However, the Humans as asset value was somewhat met with more than 50% positive ratings being received.

For the Turning Teams concept, the following values were considered to be somewhat met: Technology as a tool to assist humans, Respect for individual differences, and Responsibility to all stakeholders. However, in contrast to the Self-regulating Intersection, there were just over 50% negative ratings for the value of humans as assets.

Finally, in relation to the Circular Concept, only one value – Technology as a tool to assist humans – could be considered to be somewhat met, achieving 62% agreement. This concept also received more neutral ratings that the other concepts suggesting that there may be less certainty about its impact on road user behaviour.

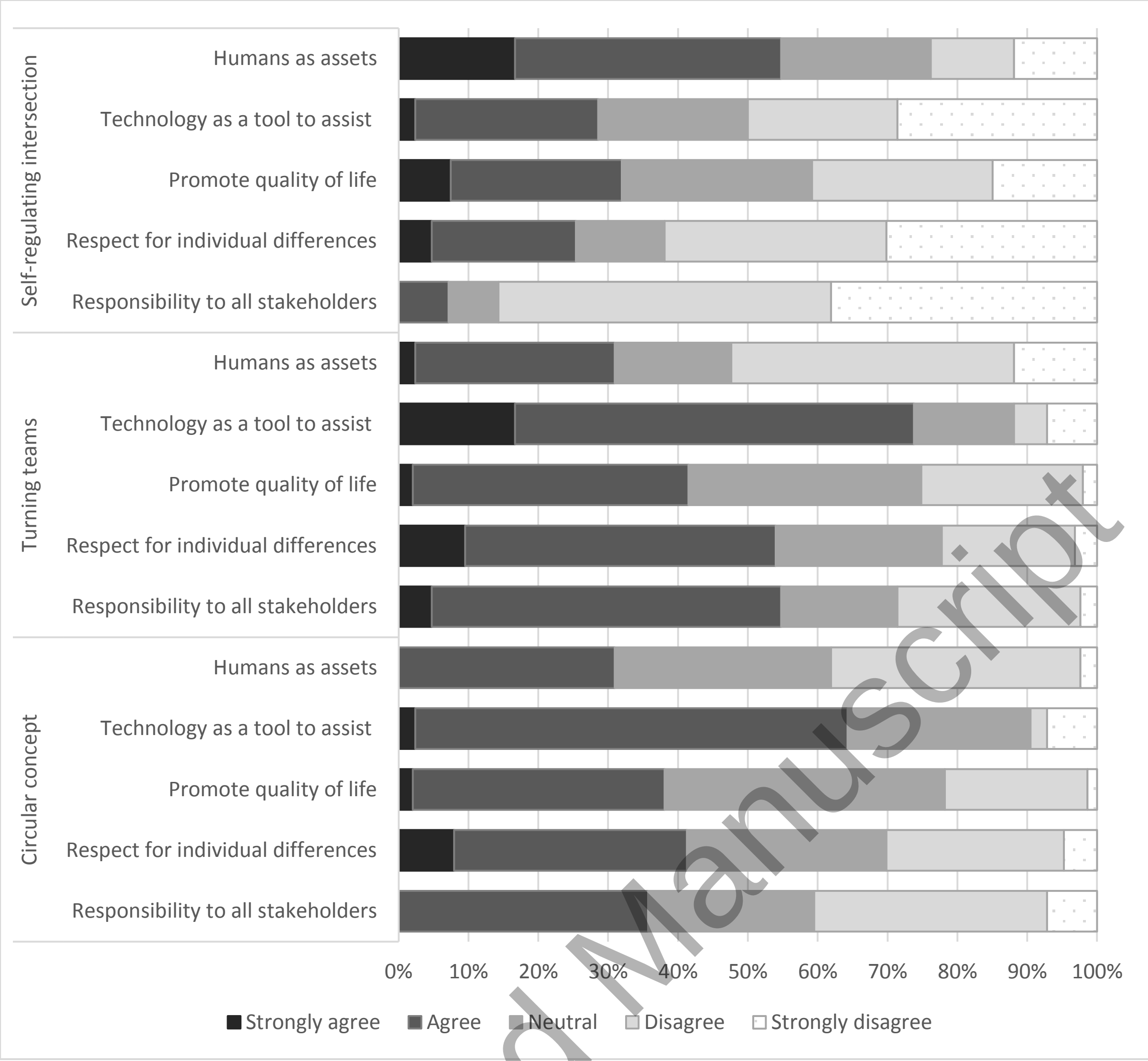


Figure 4. Ratings of concept alignment with the sociotechnical systems theory values

Perceived Usability

System usability scale

On average, participants rated the Turning Teams concept (M = 69.89, SD = 17.53) and Circular Concept (M = 60.60, SD = 23.14) as higher in perceived usability than the Self-regulating Intersection (M = 25.48, SD = 16.76).

When considering the SUS scores by road user type, it can be seen in Figure 5 that they were fairly consistent, with the Self-regulating Intersection ranked lowest across all road user types.

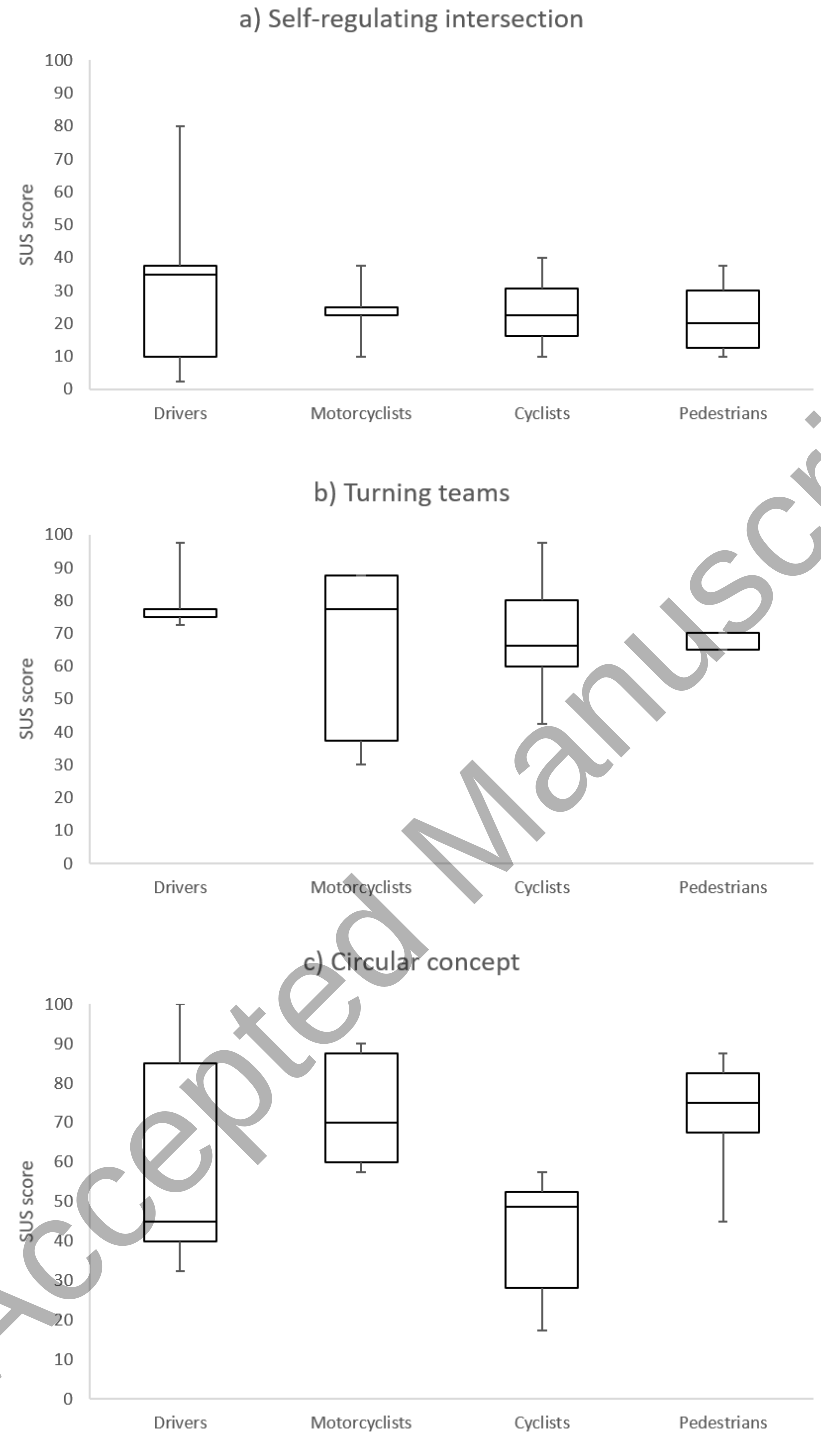


Figure 5. Box plots showing SUS scores by road user type for: a) Self-regulating Intersection; b) Turning teams; and c) Circular Concept. Drivers, *n* = 5; motorcyclists, *n* = 5; cyclists, *n* = 6; pedestrians, *n* = 5.

Preference

In relation to preference ratings, across all road user groups (with the highest possible score being 80), the Circular Concept received the highest score at 67, followed by Turning Teams at 63, then the Existing Intersection at 38 and the Self-regulating Intersection at 32.

Figure 6 shows the weighted preference scores by concept and road user type. Drivers gave higher preferences to the Turning Teams and Circular Concept designs, motorcyclists and pedestrians gave highest preferences to the Circular Concept while cyclists gave highest preferences to the Turning Teams concept.

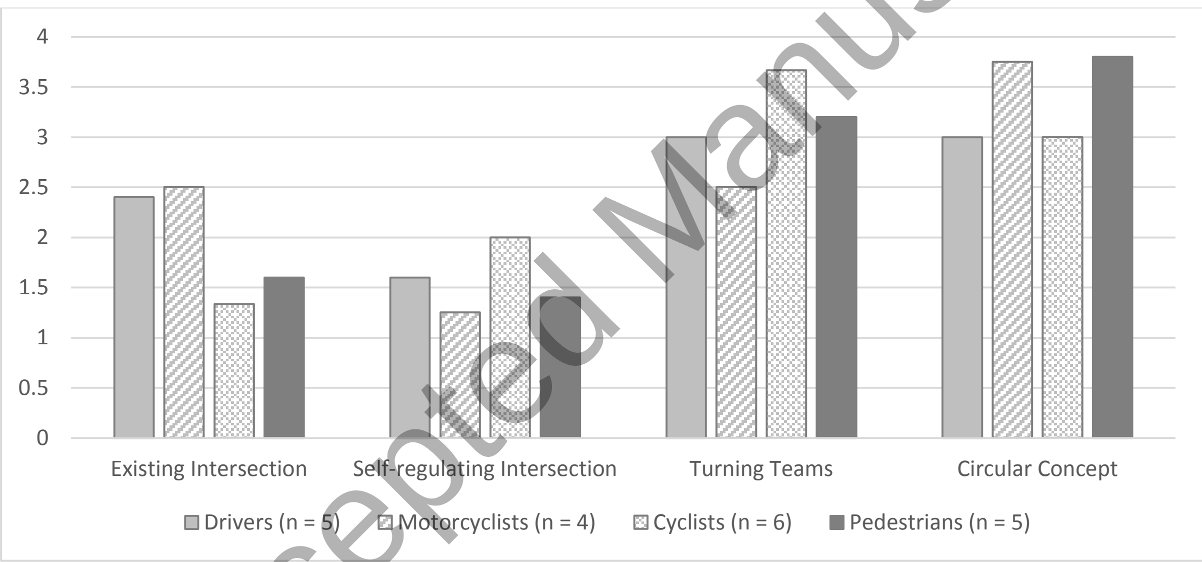


Figure 6. Weighted preference scores for the intersection concepts by road user type.

Positive and negative aspects of the designs

The themes arising from the participant feedback provided during discussions in Round 1 of the workshop are summarised in Tables 4 and 5. All concepts received both positive and negative comments.

Positive comments

Table 4 provides the frequency of positive comments provided in relation to each design. The frequency of comments (*f*) is reported, rather than the frequency of participants making the comment, as they arose within group discussions and involved either explicit or tacit agreement from other group members.

The results indicate key differences exist in the needs and preferences of different types of road user. Positive comments by drivers tended to focus on certainty (f = 3) and efficiency (f = 3). Other road users tended to focus more on safety-related matters (motorcyclists f = 6; cyclists f = 3; pedestrians f = 7). Interestingly, pedestrians were the only group to comment on the user experience (f = 4). This may be because it takes more time for a pedestrian to traverse an intersection than other road users.

Across all road user types, the Circular Concept received the most positive comments of the three designs (f = 17), followed by the Turning Teams design (f = 14) and then the Self-regulating Intersection (f = 10).

Negative comments

Table 5 provides the frequency of negative comments provided in relation to each design. When considering the negative aspects of the designs, drivers tended to comment on matters relating to safety (f = 10) and certainty (f = 5) and motorcyclists most frequently commented on safety (f = 7). Both cyclists and pedestrians tended to comment on safety (cyclists f = 6; pedestrians f = 11) and efficiency (cyclists f = 4; pedestrians f = 4). There were also particular concerns for road user groups, such as motorcyclists being concerned about the paint on the road in the Turning Teams concept being slippery in wet weather.

Overall, the Self-regulating Intersection received the most negative comments of the designs (*f* = 26), followed by the Circular Concept (*f* = 19) and the Turning Teams concept (*f* = 17).

Overall, only 28% of the comments made regarding the Self-regulating Intersection were positive, while 45% of comments made regarding the Turning Teams intersection were positive, and 47% of comments made in relation to the Circular Concept were positive.

Table 4. Positive discussion points relating to each of the three intersection designs. Frequency of themes are denoted by *f*.

	Drivers	**Motorcyclists**	**Cyclists**	**Pedestrians**
Self-regulating Intersection	Certainty (*f* = 1) • E.g. Bus lanes	Safety (*f* = 2) • E.g. Slow traffic speed Efficiency (*f* = 1) • E.g. Maintains flow	Safety (*f* = 2) • E.g. Safety refuge	Certainty (*f* = 1) • E.g. Defined path for pedestrians Safety (*f* = 1) • E.g. Removing pedestrians from the intersection Efficiency (*f* = 1) • E.g. One phase of lights, minimising waiting User experience (*f* = 1) • E.g. Visually attractive, would make you walk more
Turning Teams	Certainty (*f* = 1) • E.g. Designated lanes (bus lanes, right hand turn lane, cyclist lane Safety (*f* = 1) • E.g. Median strip comes out to separate traffic Efficiency (*f* = 1) • Can travel at	Safety (*f* = 1) • E.g. Filtering lanes a reminder to drivers that motorcyclists might filter	Certainty (*f* = 2) • E.g. Clarity of position / lane through shading Efficiency (*f* = 1) • E.g. Lanes present quickest way through intersection	Safety (*f* = 2) • E.g. Prevents pedestrians running into the intersection (compared to Self-regulating Intersection) Certainty (*f* = 2) • E.g. Markings for pedestrians let them know where to go Efficiency (*f* = 1) • E.g. One phase of lights User experience (*f* = 1)

	normal speed (compared to Self-regulating Intersection Compliance (f = 1) • More control over traffic (compared to Self-regulating Intersection)			• E.g. Feel safer because of additional separation provided by cycle lane
Circular Concept	Efficiency (f = 2) • E.g. Able to handle the traffic Certainty (f = 1) • E.g. Motorcycle boxes	Safety (f = 3) • E.g. No surface changes Efficiency (f = 1) • E.g. Gives priority to motorcyclists Certainty (f = 1) • E.g. Simple design	Safety (f = 1) • E.g. Separation of bicycles from cars Flexibility (f = 1) • Potential option to use the bus lane (if able to do so without a fine)	Safety (f = 4) • E.g. Path is far back from the road, good for families, situations of cyclists falling User experience (f = 2) • E.g. Cafes reduce pedestrians needing to cross the road and makes it a friendly environment Efficiency (f = 1) • Pedestrian paths are shorter, pedestrians not encouraged to run through middle of intersection

Table 5. Negative discussion points relating to each of the three novel intersection designs

	Drivers	Motorcyclists	Cyclists	Pedestrians
Self-regulating Intersection	Safety (*f* = 4) • E.g. Filtering lights can cause nose-to-tail collisions if users are unfamiliar Certainty (*f* = 3) • E.g. Confusion about exit lanes and lane position, lead to 'cutting people off' Efficiency (*f* = 2) • E.g. Long distance and time to traverse intersection	Safety (*f* = 4) • E.g. Change in gradient at safety zone a hazard for two-wheelers Compliance (*f* = 2) • E.g. Lack of compliance when traffic volumes low (e.g. night time) Efficiency (*f* = 1) • E.g. Reduces efficiency and capacity of the road	Safety (*f* = 3) • E.g. Lack of separation Certainty (*f* = 2) • E.g. Too much choice in route	Safety (*f* = 4) • E.g. The refuge and vehicles travelling slower would encourage pedestrians to run into the middle Efficiency (*f* = 1) • E.g. Location of bus stops means you must cross the road to get to the bus
Turning Teams	Certainty (*f* = 1) • E.g. Some potential for confusion with knowing your lane within the intersection Efficiency (*f* = 1) • E.g. Long distance to cross Practicality (*f* = 1) • E.g. Cost of blue paint	Efficiency (*f* = 2) • E.g. Width of cycle lane and filtering lane reduces lanes for traffic and affects throughput Safety (*f* = 1) • E.g. Paint on the road would reduce grip, especially in wet weather Practicality (*f* = 1) • E.g. Maintainability of the paint on the road	Efficiency (*f* = 1) • E.g. Traffic light phasing would take too long, leading to lots of waiting Practicality (*f* = 1) • Questioned whether the colour on the bitumen would last in the long term	Safety (*f* = 4) • E.g. Distance for pedestrians to travel increases likelihood that they will cross dangerously in the middle Efficiency (*f* = 2) • E.g. Light phasing could lead to long waiting times leading to pedestrians running across the road Flexibility (*f* = 1) • E.g. Lack of choice in route Practicality (*f* = 1) • E.g. Would be confusing and difficult for police to control traffic if traffic lights failed
Circular Concept	Safety (*f* = 3) • E.g. Cyclists won't want to wait at red	Safety (*f* = 2) • E.g. No hard / engineering barrier to	Safety (*f* = 3) • E.g. Angles of the turns onto the	Safety (*f* = 3) • E.g. Sharing between pedestrians and cyclists

light and will cut across traffic Certainty (f = 1) • E.g. Confusing to have the cycle lane in the middle, instead of on the left Compliance (f = 1) • E.g. Cyclists could use the motorcycle box while motorcyclists are filtering up	protect cyclists using median stop Certainty (f = 1) • Lack of lane guidance for drivers exiting intersection Compliance (f = 1) • E.g. Cars may use motorcycle box	crossing (e.g. 90° turn) is a problem if approaching at speed Efficiency (f = 3) • E.g. Have to wait for pedestrian phase of traffic lights	may be dangerous Efficiency (f = 1) • E.g. Having one cycle of lights means a long distance to cross

Comparison of concepts

Table 6 summarises the results, using shading to indicate where concepts received more positive evaluation results in comparison to the other concepts.

The Turning Teams intersection received the most positive evaluation results. It gained the highest ratings in relation to three of the four design goals, and four out of the five sociotechnical systems values. Based on the positive comments provided in the evaluation, end users appeared to perceive that the concept met user goals such as safety and efficiency, which could be interpreted to support the values of technology or infrastructure as a tool to assist humans and of responsibility to all stakeholders (i.e. other road users and the community for safety; and economic stakeholders regarding efficiency). In addition, the value of respect for individual differences was seen as promoted by this concept whereby cyclists and motorcyclists were provided with formalised flexibility to traverse the intersection. The Self-regulating Intersection was also rated the highest in relation to perceived usability measured by the SUS, and second highest of the other usability measures. General areas of improvement for the concept are improving its alignment with the humans as assets value, and supporting the appropriate optimisation of flexibility for road users.

Specific areas for improvement arising from the workshop discussions included clearer delineation of lanes once road users have entered the intersection, the use of a non-slip material for the lane colouring (to improve grip for cyclists and motorcyclists), and optimisation of the traffic light phasing to balance priority for different users.

The Circular Concept received the second most positive evaluation results. It gained the highest ratings in relation to ranked preference and the proportion of positive comments made during the workshop. It was ranked second in relation to three out of the four design goals, all of the sociotechnical systems values, and for the SUS. It was however ranked last in relation to appropriate optimisation of flexibility for road users, which relates to the fact that it creates very clear pathways for each user, without the ability for them to choose between options. In relation to sociotechnical systems theory, similarly to their reactions to the Self-regulating Intersection, most end users perceived that the concept supported the value of technology as a tool to assist humans, relating to their positive comments about the design providing safety, efficiency and, to a lesser extent, a sense of certainty. While pedestrians noted in their positive comments that the design promoted user experience, interestingly the design elements associated with improving the user experience for pedestrians and cyclists (e.g. the addition of gardens, cafes, BBQ and seating areas) did not translate into high overall ratings of the extent to which the value of promote quality of life was supported. Specific areas for improvement arising from the workshop discussions included the potential for confusion around the centre cycling lane and the lack of barriers to protect cyclists. Further, that cyclists may not comply with use of the shared path and would cut across to merge into traffic, potentially using the motorcycle box which could lead to coming into conflict with motorcyclists. Cyclists in particular noted that there would be inefficiencies in needing to wait for the pedestrian phase of the traffic lights. There were also concerns regarding the potential for conflicts between cyclists and pedestrians on the shared path. Thus, participants suggested that this design had shifted the concern about conflicts between drivers and cyclists, to conflicts between cyclists and motorcyclists, and between cyclists and pedestrians.

The Self-regulating Intersection received the poorest evaluation results overall. It was ranked last in relation to three of the four design goals, four out of five of the sociotechnical systems values, and in all measures of perceived usability. However, it was ranked first in relation to appropriately optimising flexibility and the Humans as assets value. This intersection received the least positive comments and most negative comments of all the designs. Concerns included the lack of separation between user types, the uncertainty about where road users would be, the likelihood of confusion about positioning on the road, the impact on throughput due to the reduced speeds through the intersection and questioning how the intersection would be able to self-regulate at times of low traffic flow. Participants considered congestion arising from the slower speeds required to safely enter the intersection a problem, and potentially this was perceived as trading off efficiency too much for the potential safety gains. The design also received the lowest perceived usability ratings, and the lowest overall preference score across all road users, indicating a lack of user acceptance for the design.

Further, participants did not perceive the design to align with the sociotechnical systems theory values. While participants did provide some positive ratings of the design against the humans as assets value (i.e. that it provided flexibility for users), they did not perceive the design to demonstrate responsibility to all stakeholders (i.e. they considered that this flexibility would create negative consequences). Participants were concerned that road users, left to make their own decisions and choices, would make unsafe decisions. This lack of trust in other road users to behave appropriately was an interesting outcome of the discussions and was also reflected in the participant ratings which suggested that this design would not meet the design goals of minimising collisions and trauma, or of compliance. These findings raise some interesting considerations regarding the notions of autonomy or self-organisation associated with the sociotechnical systems approach when designing public spaces. The Self-regulating Intersection provided higher levels of autonomy and latitude for decision making to end users, which is uncommon in road transport regulation. It appears that the views of the end users in this study reflect the current approach to controlling road user behaviour which is compliance-based with enforcement employed to deter non-compliance. Given the novelty of the Self-regulating Intersection, it is likely that it would take some time for end users to become familiar with the approach and to build trust that it would work safely.

Strengths, limitations and future research

This study represented a first step in evaluating novel intersections designed based on the sociotechnical systems approach. Key strengths of the work included the theory-driven approach to the development of the novel intersection designs and the engagement of end users in a structured process to evaluate the designs. Gaining input from different road user groups was important to draw out the different needs and preferences that need to be balanced in designing road environments. Further research should explore and document the full set of diverse needs associated with different road users. This would support road designers to better take account of all user groups in design and is particularly pressing given the projected increase in active transport modes such as cycling. Such work could also consider the needs of more highly automated vehicles as 'road users', to support intersection designs for effective and safe interactions with existing road users. For example, just as Salmon et al (2014a; 2014b) found that drivers were not expecting cyclists and motorcyclists and were not aware of their different intersection behaviours, without appropriate design intervention it is likely that fully automated vehicles will not either.

Table 6. Ranking of intersections based on participants ratings across all criteria. Shading is used to highlight the highest ranking concept for each criteria.

	Evaluation criteria	Self-regulating Intersection	Turning Teams	Circular Concept	Existing intersection
Design goals	Minimise collisions and trauma	3rd	1st	2nd	-
	Maximise efficiency	3rd	1st	2nd	-
	Maximise compliance	3rd	1st	2nd	-
	Appropriately optimise flexibility	1st	2nd	3rd	-
Sociotechnical systems theory values	Humans as assets	1st	3rd	2nd	-
	Technology as a tool to assist humans	3rd	1st	2nd	-
	Promote quality of life	3rd	1st	2nd	-
	Respect for individual differences	3rd	1st	2nd	-
	Responsibility to all stakeholders	3rd	1st	2nd	-
Perceived usability	SUS scores	3rd	1st	2nd	-
	Ranked preference	4th	2nd	1st	3rd
	Percentage of positive comments	3rd	2nd	1st	-

It is acknowledged that the order of presentation of the design concepts may have influenced the results. Participants evaluated the Self-regulating Intersection concept first and this design received the poorest evaluation results. Given that it could also be considered the most novel of the new design concepts, participants may have been more critical than if it had been introduced after one or both of the other new designs. Further individually-based evaluations, using questionnaires or interviews would provide the possibility of randomising the presentation of the concepts to negate potential order effects.

Further, given that this evaluation was conducted as a desktop exercise only, with relatively low sample sizes in each road user group, further investigation of the designs providing end users with opportunities to interact with the intersection environments, either physically, through prototypes, or virtually, using simulation and virtual reality approaches is required prior to recommendations being made regarding real world implementation. For example, different road user types could be interacting in the same environment at the same time within a distributed simulation. Based on the behavioural patterns identified, computational modelling methods such as Agent-Based Modelling could then be used to test how a population of users might interact with one another within these novel road environments, including how behaviour might adapt over a longer period. This is important given that novel designs may improve behaviour in the short-term, however as users adapt to the road environment and to how other users are behaving, unintended consequences may emerge.

Additionally, more traditional traffic modelling and simulation would be useful to answer questions regarding efficiency and throughput, based on more detailed design of aspects such as traffic light sequencing. This could assist to allay concerns of drivers and motorcyclists that lower speeds lead to less throughput, which may not be the reality.

Finally, future research should further explore the application of sociotechnical systems theory to public spaces such as the road system. It may be that elements of the theory, such as promoting autonomy, may need to be reconsidered to better apply to the road context. It is also likely that higher level systemic changes are required, such as to the philosophy behind road safety management in general, before more specific changes to the physical road environment aligned with sociotechnical systems theory can be successfully implemented. Indeed, it may be the case that we cannot fix fundamental conflicts between road users only through the physical design of the intersection. For example, at a single intersection it may be impossible to balance the safety and user experience needs of vulnerable pedestrians with the efficiency needs of high volumes of motorised road traffic. Instead, interventions at wider levels of the system such as policy intervention to decrease reliance on road vehicles through urban planning, and to increase the uptake of public transport may provide more sustainable solutions.

Conclusion

It has been argued that considering all road user needs in intersection design is a key requirement for preventing intersection collisions. Following a design process that sought to create intersection design concepts to optimise interactions between different forms of road users, the aim of this paper was to describe the evaluation of three intersection designs. We invited representatives of four end user groups to comment on and rate the intersections.

The evaluation process identified two novel intersection designs (Turning Teams and the Circular Concept) that show promise in preventing collisions between different road user types. Importantly, this study has demonstrated the utility of applying the sociotechnical systems approach in intersection design for the first time. In particular, it has showed that the CWA-DT can produce designs that are generally acceptable to users and that end users will actively engage in evaluations of proposed designs. It is the participatory nature of the sociotechnical systems approach that provides much of its strength, and improving user participation in road transport design processes will provide benefits, and, over time, should help the road transport system to shift towards designs more aligned with sociotechnical systems thinking. It is recommended that, where not already in place, road transport agencies consider adopting formal participatory processes during road design processes to better understand and incorporate end user perspectives.

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