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Evidence for designing safer intersections for pedestrians using data analytics, video processing, and simulation

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1. Introduction

The historical emphasis on vehicle-focused benefits in intersection design has led to a standard of design that can negatively impact pedestrians by causing delay, putting their safety at risk or deterring them from walking. We hypothesise that intersection design plays a role in driver and pedestrian behaviour and that that combination of design and behaviour has important implications for safety. We should design roads that make it safe and easy for vulnerable road users to use intersections.

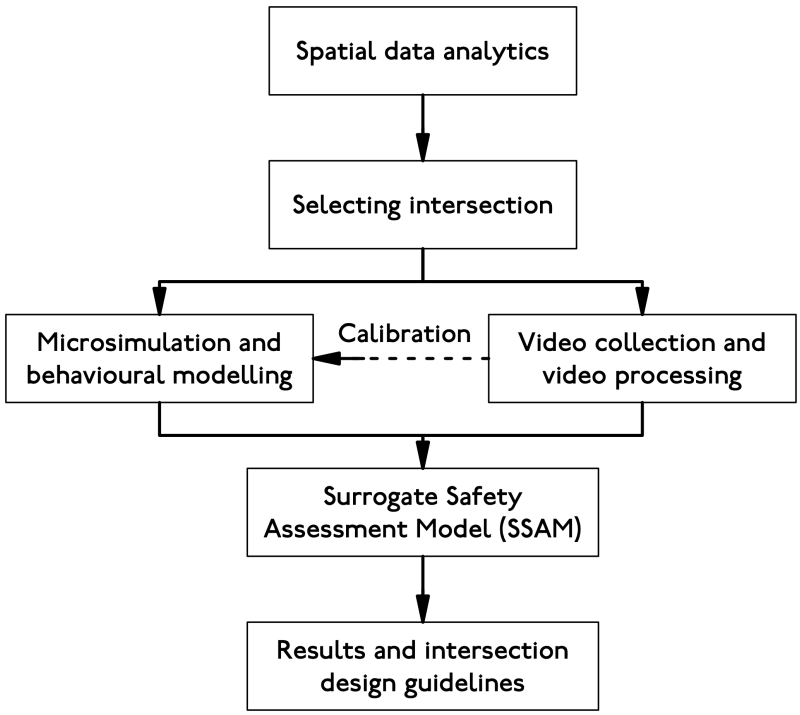
This paper introduces a wider project that aims to build the evidence for intersection design as an important factor in reducing vehicle-pedestrian road trauma. Here, we investigates the relevant factors and attributes, including adjacent land use patterns, road designs, footpath designs and signal timings, that historically contribute to safer intersections. This analysis is used to determine the locations to collect video footage of Australian intersections. The video provides and empirical basis for exploring alternative intersection designs. The status quo will be enriched with microsimulation of hypothethical alternatives. The real and hypothetical alternatives will be evaluated with safety and behavioural modelling to support the hypothesis that behaviour is an important link between design and safety outcomes.

First, this submission explains an overview of the larger project's methodologies and innovations. Second, it presents preliminary results regarding a spatial analysis of historical crashes and the design of the video data collection. Third, we will discuss the anticipated results from the larger project.

2. Methods

This research offers an innovative perspective because it combines large-scale analytics with microsimulation and behavioural modelling to better capture the pedestrian-vehicle-infrastructure system. Moreover, it leverages studies performed elsewhere (Carter et al., 2006; Prajapati, Advani, and Parida, 2018) to investigate the impact of intersection design on pedestrian safety in an Australian context. Figure 1 illustrates the conceptual flowchart of the study's analytical and methodological steps. Each aspect of the methodology is presented here, and the following section presents results primarily associated with the spatial data analytics.

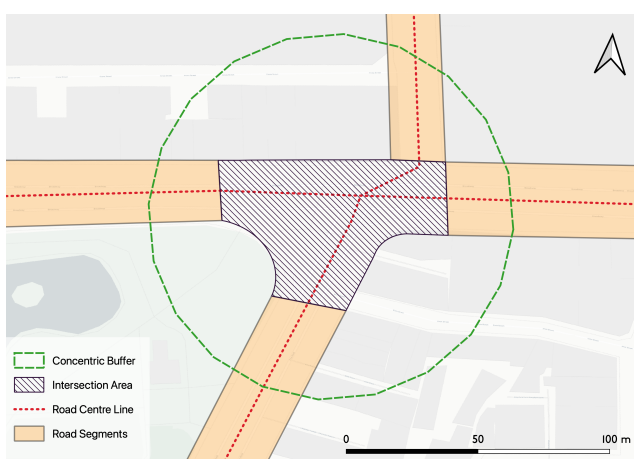
Figure 1: Conceptual framework diagram



2.1. Spatial data analytics

Road network topology, road segment length, traffic flow, density of non-signalised intersections, number of lanes, and adjacent land use are positively associated with traffic crashes (Guo et al., 2017; Barua, El-Basyouny, and Islam, 2016). Intersection area is the region where two or more intersecting streets share a common space. This area is captured by overlapping the road segments' right-of-way in GIS. We use the intersection area and a spatial buffer to capture the associated crashes and land use attributes of each intersection as illustrated in Figure 2. Accidents are assigned to intersections according to their coordinates and the buffers drawn around each intersection. When two intersections are close together, a collision may be attributed to both.

Figure 2: Broadway-City Road showing the intersection area and spatial buffer from the intersection centroid



2.2. Video processing

The video processing has three main steps: detecting, tracking and calibrating the objects' positions. YOLO (You Only Look Once) is a well-known object detection library trained on the COCO dataset which includes persons, cars, bicycles, motorcycles, buses, trucks, trains, traffic lights, and stop signs. After detecting each object with YOLO in each video frame, DeepSORT tracks the objects. Using computed features of each object's bounding box, DeepSORT tries to find similar objects in subsequent frames. The result is a set of the frame-by-frame trajectories of each object. Camera calibration is the final step which corrects the projection in the camera's field of view. We match fiducial points in the footage to satellite images. This transforms the pixel coordinates into a well-known projection such as the World Geodetic System 1984 (WGS84).

2.3. Traffic Simulation

Microsimulation is used to explore hypothetical scenarios and unobserved conditions based on baselines from video data analytics. An approach that explores unobserved conditions is essential for testing the benefits of novel technologies and designs that have not been built yet in Australia. Most microsimulation packages are not suited to model crashes or near misses, especially for pedestrians. The video data will validate how serious this shortcoming is when moderated with surrogate safety measures.

VISSIM is one of the most popular traffic simulation softwares. In this research, a key output of the simulation is to provide the trajectory files for both vehicles and pedestrians to be fed into the safety models. To the best of our knowledge, VISSIM is the only commercial traffic simulation software that integrates with the safety modelling software.

2.4. Surrogate Safety Assessment

To reduce road trauma, surrogate safety indicators proactively model conflict events that may be realised into crashes rather than assessing historical crashes. The Surrogate Safety Assessment Model (SSAM) is a US Federal Highways Administration conflict detection model commonly used for vehicle-vehicle conflicts and can be adapted for pedestrian-vehicle conflicts. It supports time-based surrogate safety measures including time to collision (TTC) and post-encroachment time (PET) which are more adaptable to a pedestrian-vehicle conflict. Vehicle-vehicle, pedestrian-pedestrian, and vehicle-pedestrian conflicts should be modelled separately to accommodate the variation in the size of the moving object. This software is used in this project to evaluate the safety level of a given intersection in real and simulated situations.

3. Data

A combination of data sources is used to ensure coverage across the study elements. Intersections with particularly high and low pedestrian crash rates are flagged for observation using observations of crashes using the NSW Road Crash data (NSW Centre for Road Safety, 2020).

This allows us to identify intersections in Greater Sydney Area with the highest fraction of crashes that involve a pedestrian, the highest number of pedestrian crashes, and the lowest rates of pedestrian crashes controlling for pedestrian counts. This safety-outcome led approach for intersection selection is complemented by a survey of the traffic calming measures used in the Australian context (Steinmetz and Aumann, 2017).

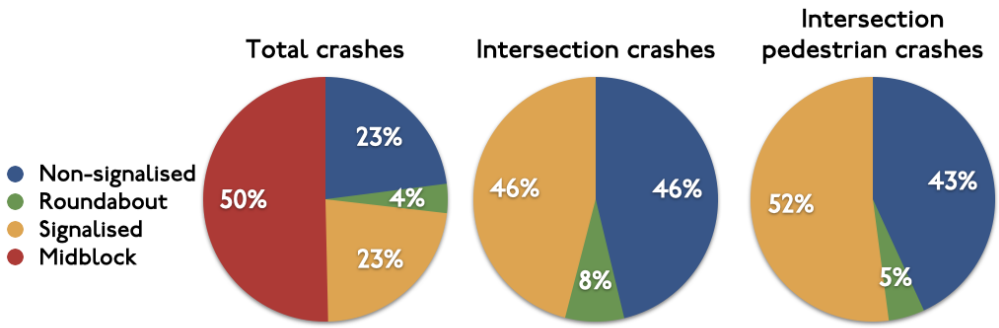
The intersection selection directs the collection of video. Through the video processing methodology, we extract trajectories of multiple types of road users. Additionally, geometric design, inclusion of design elements like roadabouts, sliplanes and islands and information about the phasing and land use are included in the analysis.

4. Preliminary results

4.1. Historical data analysis

More than 80,000 intersections in the Greater Sydney area, including roundabouts, signalised, and non-signalised intersections, are investigated by analysing historical crash records (1996 to 2019) (NSW Centre for Road Safety, 2020). About 50% of crashes occur around intersections. More than 90% of intersection collisions belong to signalised and non-signalized intersections, and signalised intersections account for more than 50% of pedestrian crashes.

Figure 3: Total, intersection, and pedestrian crash rates in Greater Sydney Area for roundabouts, signalised, and non-signalised intersections. Values account for historical crash records from 1996 to 2019



The crash data is spatially joined to the intersections and then intersections are ranked by the number of pedestrian-involved crashes. Table 1 shows top 5 intersections by pedestrian crash rates for each type of intersection.

Table 1: Top 15 intersection pedestrian crash rates (by intersection area) for three intersection types

ID	Intersection Type	Location (street names)	Suburb	Total crashes	Pedestrian crashes	Pedestrian crash ratio	Rank
564	Signalised	Oxford - Bourke	Darlinghurst	275	116	42%	1
261	Signalised	Pitt - Eddy	Sydney	210	87	41%	2
258	Signalised	Elizabeth - Foveaux	Sydney	238	76	32%	3
563	Signalised	Oxford - Crown	Darlinghurst	188	76	40%	4
560	Signalised	Oxford - Liverpool	Sydney	217	75	35%	5
58976	Non-signalised	Jamison - George	Sydney	82	58	71%	1
57320	Non-signalised	Railway Sq.	Haymarket	44	33	75%	2
57470	Non-signalised	Oxford - Pelican	Darlinghurst	91	27	30%	3
58959	Non-signalised	Barrack - George	Sydney	37	26	70%	4
57705	Non-signalised	Darlinghurst - Springfield	Potts Point	37	25	68%	5
4367	Roundabout	Barbara - Harris	Fairfield	33	12	36%	1
6740	Roundabout	Everton - Mosely	Strathfield	18	10	56%	2
3801	Roundabout	South - William	Granville	25	10	40%	3
6618	Roundabout	Kensington - Gray	Kogarah	34	8	24%	4
6420	Roundabout	Plowman - Glenayr	Bondi Beach	63	8	13%	5

The total number of crashes and total number of pedestrian-involved crashes are aggregated by five concentric spatial buffers around the intersections (10, 20, 50, 75 100 metres). Land use attributes including population, employment and number of surrounding schools have been aggregated for the same areas. Table 2 shows a sample of the analysis based on highest total crash counts. Similar tables have been generated for the highest pedestrian crash counts, highest pedestrian crash rate and for counts normalised by exposure (for a limited sample of intersections with pedestrian counts). Examples of the analysis for a signalised, unsignalised and roundabout intersection respectively are shown in Figure 4a, Figure 4b, and Figure 4c.

Table 2: Top crash rates by spatial buffers from intersection centroids

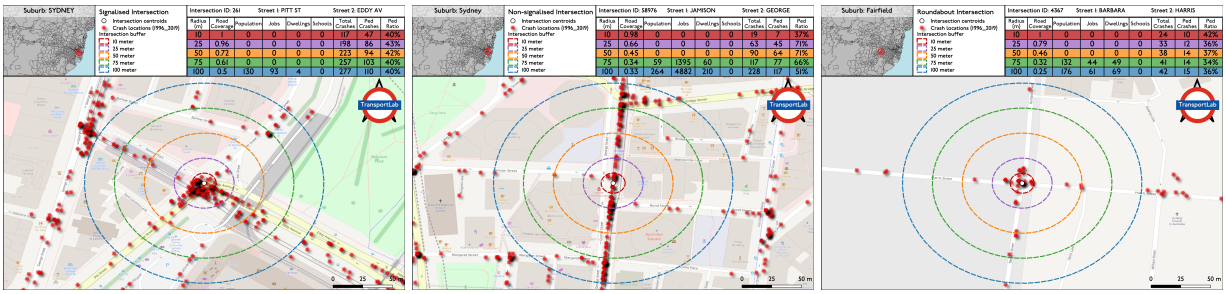
ID	Intersection type	Buffer radius [metre]	Population density [ppl/km^2]	Job density [jobs/km^2]	Location (street names)	Suburb	Road coverage [%]	Total crashes	Pedestrian ratio [%]
38	Signalised	10	0	0	South Dowling - Fitzroy	Surry Hills	100%	287	1%
299	Signalised	10	0	0	Botany - Bourke	Alexandria	100%	244	2%
39	Signalised	10	0	0	Botany - Mcevoy	Alexandria	100%	213	5%
78	Signalised	10	0	0	Elizabeth - Mcevoy	Waterloo	100%	206	1%
54	Signalised	10	0	0	Gardeners - O'Riordan	Mascot	100%	205	1%
38	Signalised	25	0	0	South Dowling - Fitzroy	Surry Hills	83%	316	2%
149	Signalised	25	0	0	Hume Hwy - Woodville	Lansdowne	100%	284	1%
299	Signalised	25	0	0	Botany - Bourke	Alexandria	94%	275	3%
439	Signalised	25	0	0	Cleveland - South Dowling	Redfern	93%	263	2%
1201	Signalised	25	0	0	Cumberland Hwy - Cabramatta	Cabramatta West	100%	261	2%
38	Signalised	50	9,310	16,790	South Dowling - Fitzroy	Surry Hills	49%	342	2%
149	Signalised	50	0	0	Hume Hwy - Woodville	Lansdowne	95%	336	1%
52335	Non-signalised	50	0	0	Eastern Distributor - South Dowling	Surry Hills	39%	333	2%
439	Signalised	50	0	0	Cleveland - South Dowling	Redfern	61%	309	4%
4328	Roundabout	50	0	0	Polding - Smithfield	Fairfield West	78%	305	0%
149	Signalised	75	0	0	Hume Hwy - Woodville	Lansdowne	82%	461	1%
14571	Non-signalised	75	0	0	Hume Hwy - Woodville	Villawood	55%	378	1%
1428	Signalised	75	0	0	Silverwater - Western Motorway	Silverwater	53%	374	0%
38	Signalised	75	9,125	16,745	South Dowling - Fitzroy	Surry Hills	47%	357	2%
439	Signalised	75	0	0	Cleveland - South Dowling	Redfern	43%	356	3%
280	Signalised	100	6,727	5,623	William - Palmer	Woolloomooloo	48%	576	11%
57655	Non-signalised	100	9,660	8,955	Eastern Distributor - Barnett	Darlinghurst	45%	558	11%
57708	Non-signalised	100	8,863	4,986	Eastern Distributor - Palmer	Woolloomooloo	48%	546	12%
149	Signalised	100	0	0	Hume Hwy - Woodville	Lansdowne	64%	530	1%
55743	Non-signalised	100	0	0	Church - Junction	Granville	26%	523	1%

The correlation between crashes and local attributes is measured to investigate how land use attributes and design elements affect the crash rates. Table 3 illustrates the correlation between crash rates and other attributes as a preliminary predictor of what contributes to dangerous intersections.

Table 3: Correlation between crash rates and relevant parameters within 100m of each intersection

	Total crashes	Pedestrian crashes	Ped. crash ratio
Population density	0.22	0.28	0.18
Job density	0.20	0.35	0.12
Dwelling density	0.26	0.33	0.20
Schools	0.05	0.05	0.07
Road coverage	0.35	0.23	0.06
Total crashes	1	0.65	0.17

Figure 4: Intersections with high pedestrian crash rate in 25 metres radius



(a) Signalised **(b)** Non-signalised **(c)** Roundabout

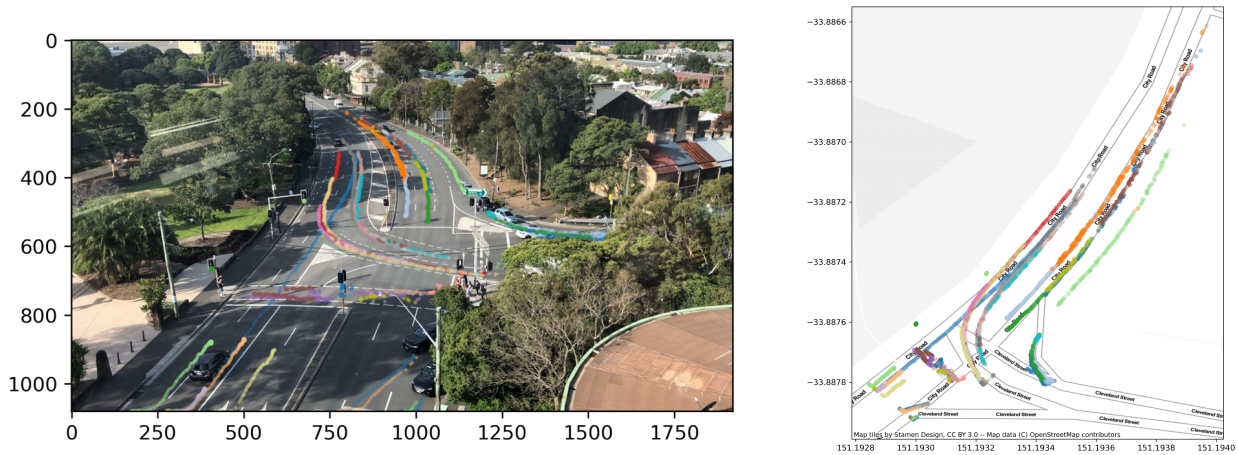
4.2. Image processing, microsimulation and behavioural modelling

The analysis of historical intersection crashes provides value evidence regarding factors that contribute to pedestrian road trauma. It is also used to support the selection of key intersections for video collection and analysis. This section details preliminary progress towards the subsequent analysis.

4.2.1. Video processing

The videos are processed to extract information about the intersection attributes as well as the counts and trajectories of vehicles and pedestrians.

Figure 5: Left: A sample of trajectories at City Road and Cleveland St from the position of the camera. Trajectories measured in pixel space will have a non-linear relationship with speed over the field of view due to the projection. Right: The deprojection to an orthographic view and conversion to physical coordinates (degrees or metres) allows the calculation of speeds and detour distances

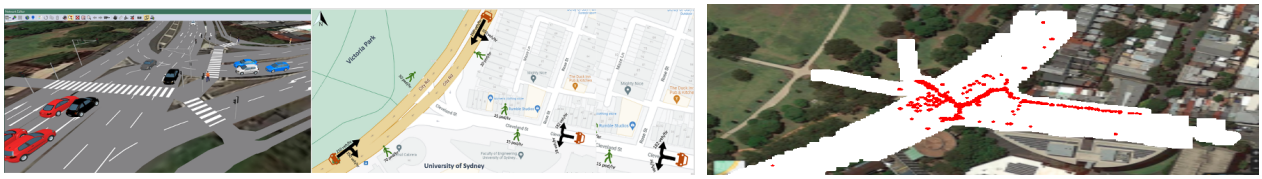


(a) Original **(b)** Deprojected

4.2.2. Simulation

In the simulation phase of the study, the T-intersection of City Road and Cleveland St. is modeled in Vissim software. The simulation has to make all feasible paths explicit, including paths that might be unintended by the designers (such as a pedestrian crossing outside the crosswalk). The map of the simulated intersection with the assigned traffic flow is illustrated in Figure 6.

Figure 6: Perspective (left) and top (middle) views of the City Rd and Cleveland St. T-intersection simulated in VISSIM. Conflict points location determined by SSAM (right). Red points are the crossing conflict points for Cleveland-City Rd intersection simulation



(a) Simulation Set-up **(b)** Conflict Points

4.2.3. Behavioural and safety modelling

Real and simulated trajectories allow us to record behaviours that were not intended by the intersection designer. These include vehicles encroaching or blocking the intersection, vehicles or pedestrians entering the intersection against the red light and pedestrians crossing outside the crosswalk. We supplement this behavioural analysis with the persona framework (Pruitt and Grudin, 2003) to capture the variation between users. Our observations show that people with prams and people in groups behave differently, and have different speeds and reaction times. The classification of users might reveal specific behavioural characteristics.

From the safety modelling perspective, SSAM is used to identify conflict points. Figure 6b shows conflict points identified in 60-min of simulated trajectories of the City Road and Cleveland St intersection. Moving forward, the safety model will be calibrated using video trajectories and conflict training data based on observed conflicts. For example, a one-hour pilot observation of this intersection resulted in three near-miss events, so smaller threshold values of TTC and PET should be found such that the number of pedestrian-vehicle conflicts and their hot-spots best fit the collected videos.

5. Discussion and conclusion

This submission gives the overview of an on-going project establishing an Australian evidence base for more pedestrian oriented and safer intersection designs. We briefly present the four-part methodology (spatial analysis, video processing, microsimulation and safety/behavioural modelling). The results presented here focus on the spatial analytics of historical crash data motivating the selection of video collection sites. Alone they demonstrate the complexity of and patterns in the factors that determine intersection safety. On-going data collection and analysis will contribute insights on the relationships between the infrastructre and operational design of the intersection, road users' behaviour and safety outcomes.

Acknowledgment

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