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Research Article

Analysis of land-use and POIs contributing to traffic accidents around intersections

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ABSTRACT

In Japan more than half of all traffic accidents occur at or near intersections and many at small intersections where only minor roads cross. A database of all intersections in the built-up area of Kyoto, Japan was created using Open Street Map data, including spatial characteristics such as the presence and types of surrounding facilities. This data was used as explanatory variables to analyze the relation to traffic accidents reported over a period of three years. Presence of traffic signals, pedestrian infrastructure and traffic flow was used as control variable. The results of the analysis suggest that traffic accidents are less likely to occur at intersections where parks are nearby. More accidents occur at medium and small intersections where facilities such as restaurants, supermarkets and convenience stores are nearby. We discuss that the results suggest that visibility but also attention when "briefly hopping into a store" as well as general business of junctions are determinants of accident risks. These results highlight that to reduce the occurrence of traffic accidents at intersections a broader understanding of who passes the junction at what times and the wider land-use characteristics of the vicinity is important.

1. Introduction

Ensuring road safety is crucial. Although both the number of road traffic accidents and the number of road traffic fatalities have been decreasing in recent years, numbers remain too high and ambitious accident reduction targets are missed. In 2022, in the US 42795 fatalities occurred, which is nearly the same as in 2021 [1]. In Japan, 2610 fatalities occurred, which is a 1 % reduction compared to 2021 [2]. Besides the losses in human life, also the impact of non-fatal accidents is significant in terms of loss of physical transport network functionality and other economic side effects [3].

To reduce accident numbers, understanding relationships and causes of accidents are important. Influence of sociodemographics, in particular age have been studied as well as the impacts of road infrastructure such as road layout, traffic signals and pedestrian facilities [4]. Longstanding research has highlighted further the importance of understanding cognitive interactions within motorists and considering visibility fields and obstacles for both road user types [5]. Especially for understanding the accident risk for vulnerable road users at junctions this is an important research field [6,7]. Visibility and interactions of traffic participants are strongly influenced by the land-use along the road space and hence the impact of land-use aspects on traffic safety have also been studied as will be reviewed in the following section.

In Japan as well as other countries, traffic accidents generally tend to occur at intersections and near intersections, accounting, in Kyoto, for more than half of all traffic accidents as our data analysis based on data from Kyoto Police will show [8]. Therefore, to improve road traffic safety, it is important to quantitatively understand accident risk factors at intersections and to implement efficient and effective intersection safety measures. However, a database quantifying the wider spatial characteristics of each intersection has not been sufficiently developed. Although many accidents occur at intersections connected to relatively small roads, such as residential roads, these roads are often not included in databases and are often not included in surveys such as road traffic censuses [9]. As a result, there has not been sufficient research on road accidents based on the spatial characteristics of intersections in residential areas and on minor roads in commercial areas of the city.

With this background, the aim of this study is to quantitatively analyze the relationship between spatial characteristics such as land use and surrounding facilities with accident risk. A particular focus is on

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traffic accidents at small-scale intersections connected to residential roads. By using Open Street Map (OSM) data as our prime data source as well as some government statistics, accident factors at small intersections, which have not been subject to statistical analysis of traffic accident factors, are explored.

2. Literature review on accident risks and the built environment

The relationship between the built environment and accident occurrence has been studied in a wide range of contexts by numerous researchers. Population density has been generally found to be positively associated with accident rates [10,11]. Further commercial land-use and accordingly higher interaction levels of different road users increase the likelihood of an accident occurring [12–14]. Dumbaugh and Li [12], using US data, report that in particular "strip commercial uses, and big box stores" appear to pose accident risks, controlling for a range of other variables. Wedagama et al. [15] show with data from Newcastle-upon-Tyne in the UK that retail-land use is associated with land-use. In contrast to other studies they control for the origin and destination zones of drivers and select zones which are likely the trip destinations. Looking at accident types, the built environment is having disproportionate impact on specific accident types. With Dutch data Asadi et al. [16] show that accidents between vehicles and bicycles show a higher correlation to factors quantifying the built environment than vehicle-to-vehicle crashes. They further report that vehicle-to-bicycle accidents occur in particular in "high urbanity" levels.

Most of the above studies looked at traffic accident rates for traffic analysis zones and used the dominant land-use as well as the variation in land-use as explanatory variables for the number of traffic accidents in these zones. Recent studies have started replacing land-use statistics with point-of-interest (POI) data, which describes point locations of visible, frequently-used or activity-related objects in space [17]. The data have the potential to describe the built-environment better by not building on pre-defined categories. Chung et al. [18] used POI data from Suzhou, China. They confirmed with this the aforementioned effects of population density and commercial land-use and showed that "richness", describing the variation in POIs, impacts traffic safety negatively. Pineda-Jaramillo et al. [19] also used POI data to model traffic likelihood but obtained this from Foursquare records. Accordingly, they could show a positive relation between detailed non-permanent facilities such as the presence of food-trucks on accidents. POI data also lend themselves to analyze the relationship to accidents with machine-learning methods, as there are often many POIs with a wide range of categories [20].

In contrast to the reviewed literature, our study does not look at number of accidents in a wider area but focuses on accidents occurring directly at intersections. In Japan, intersections have long been the subject of traffic accident research as locations where accidents frequently occur. Shiomi et al. [21] and Nishihori et al. [22] have conducted analyses focusing on the relationship between traffic accidents and the geometric structure of intersections, but did not focus on the relationship between facilities around intersections and traffic accidents. The studies of Mitani et al. [23], Furuya et al. [24] and Tabei et al. [25] have investigated the relationship between peripheral facilities and traffic accidents, but their studies were limited to major roads such as national highways and did not focus on narrow roads. Suemasu et al. [26] have focused on street-side facilities on narrow roads and small intersections of school-commuting roads, but the database was created through fieldwork, so the area covered is very limited.

We hence suggest that there is a literature gap with respect to a city-wide analysis of the relationship between small-scale intersection accidents and POIs around these. Our contribution is that we aim to reduce this gap. To achieve this, we have created a database of the built-environment directly adjacent to junctions of all sizes and analyze these with respect to the relation to a multiple year database of accidents. We suggest this complements above reviewed studies using statistical methods for traffic analysis zones and detailed simulations of particular junctions where interactions at junctions are modelled explicitly.

3. Data summary

In this section we provide an overview of the data fused into a database and subsequently used for our analysis. The following four subsections describe the accident data (our dependent variable), intersection information, the POI and land-use information (explanatory variables) as well as traffic signal and traffic flow related information (control variables).

3.1. Traffic accident data

Our analysis area is the main populated area of Kyoto City, Japan. Traffic accident data from 1 January 2017 to 31 December 2019 in the city were included in the analysis. This data is published as open data and opens up a range of analysis possibilities [27,28]. It is important to note that the road accidents covered in this study exclude accidents with property damage only, i.e., only accidents that involve at least one person being lightly injured are included in our analysis. The total number of personal injury accidents in the area over the three years is 21,445. Fig. 1 shows a heat map of road traffic accidents. Traffic accidents are particularly concentrated in Kawaramachi, a busy shopping area in the center of Kyoto City.

3.2. Creation of intersection data and intersection size definition

OSM data were downloaded from Geofabric (https://download.geofabrik.de/) and intersections were defined as locations where road line data from the OSM database intersected. We include all junctions in the study area except for motorway entries and exits. In case several roads intersect within 10 m, we combine these into a single intersection. The total number of intersections in the area was 26,553.

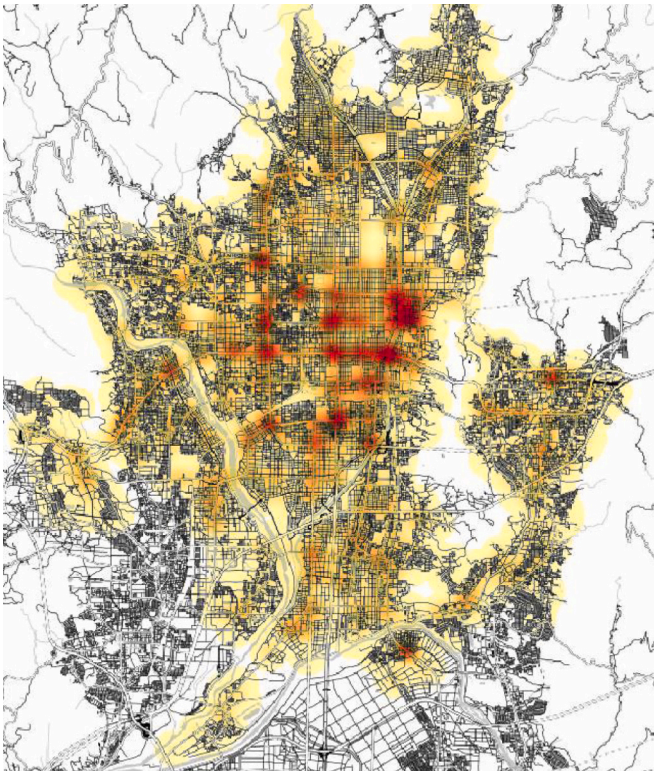

Fig. 1. Heat map of road traffic accidents in Kyoto City.

We distinguish types of intersections according to the types of roads that intersect: Noting that many smaller urban Japanese roads allow two-way traffic but do not have a clear lane marking, we distinguish three types of intersections. Major intersections were defined as intersections where two (or more) roads cross which both have clear lane markings. Medium intersections are those where only one road has a clear lane marking and minor roads are those where no road has a lane marking. One might split especially large intersections into further subgroups, considering junction diameter and number of lanes per direction, but, in this analysis, we aim to focus on the difference between any kind of major intersection to those on small roads. Fig. 2 shows these three types of intersections. We note that the number of large intersections, even with this broad categorization, is much smaller than the number of medium and small intersections: There are 762 large intersections, 5916 medium intersections and 19,875 small intersections in our database. Traffic accidents records were then linked to the intersections. We define an accident as occurring at a junction if the recorded location is within 30 m of the intersection. The 30 m definition is also used by the police in Japan [29] and generally appears to be reasonable to define whether an accident is likely to have a relationship with the traffic and infrastructure present at the junction. We also note, that we found that the 30 m radius from the central point of the junction area reflects the locally-largest junctions in the investigation area.

3.3. POI data, land-use and population density data

In the next data preparation step, Points Of Interest (POI) such as parks, schools, restaurants, supermarkets, convenience stores, bus stops, stations, parking lots were also extracted from the OSM database. The traffic signals and pedestrian crossings were linked to the intersections. The POI data on the presence or absence of nearby facilities such as restaurants and supermarkets were linked to the intersection based on the same 30 m rule, as in the case of traffic accidents. Furthermore, all intersections were classified as being located in a residential, commercial or industrial area. This information was obtained from the Japanese Ministry of Transport Land and Infrastructure [30]. Further, population density variables of 100 m × 100 m mesh areas of Kyoto were obtained [31]. The population density, illustrated in Fig. 3, of the mesh in which the junction is located was then also associated with the junction.

3.4. Traffic signals, pedestrian crossings and traffic volume data

As “control variable” we further extract traffic signals and pedestrian crossing information from OSM. Through map matching we associate this information also with the junctions. We note that we only include information as to whether the junction has these elements or not, but not details as to how many signal heads and how many sides of the junctions have dedicated pedestrian crossings. We further approximate traffic volume information. As there are no junction specific traffic volume information we utilize loop detector information if these are near the junction. The data are available from JARTIC [32]. We use again the 30 m threshold and take the cross-sectional volume observed from the detector over a month. If there are multiple detectors we utilize only the highest volume. Clearly this is a rough estimate and can be improved in further analysis by considering the temporal profile of the flow as well as creating a better estimate of the junction flow through, for example, the creation of a simulation based on the readings. We also note, that of the 26,553 intersections covered by this study, the number of intersections with vehicle detectors within a 30 m radius is only 1124. In the subsequent analysis we hence create models for all junctions, ignoring traffic volume information, and for the subset of junctions with traffic flow information.

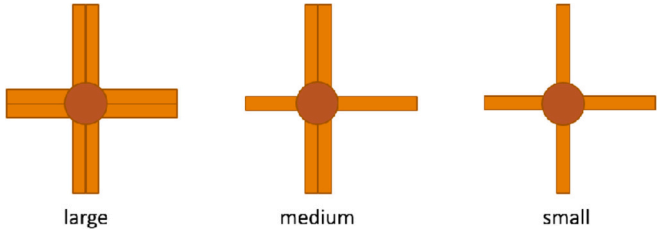

Fig. 2. Types of intersections distinguished in this study (Junctions with e.g., 3 lanes on one road and one lane on the other are also classified as large).

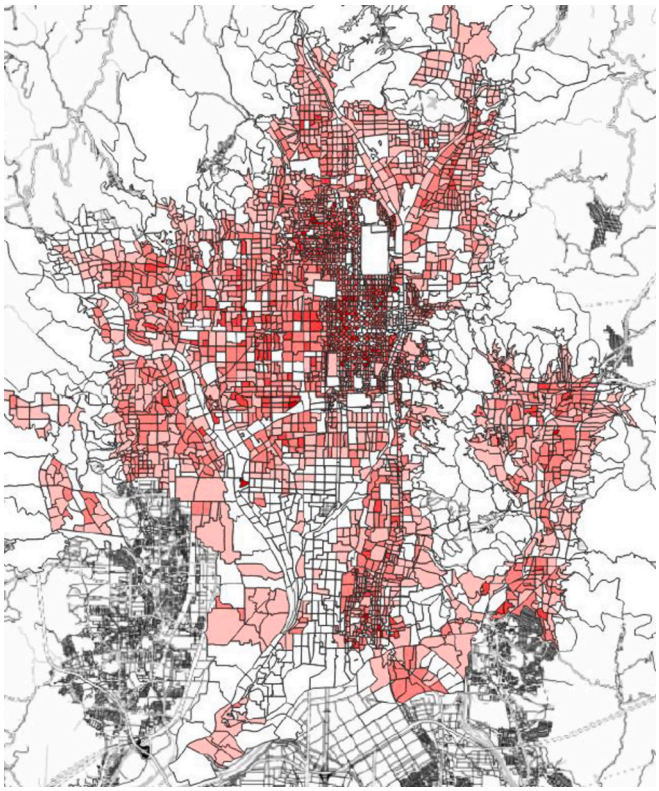

Fig. 3. Population density per basic unit district.

4. Descrptive analysis and regression analysis

We utilize the constructed database to derive descriptive statistics and by employing regression analysis to understand which factors are associated with the likelihood of an accident occurring. We consider all of the afore introduced variables as potential explanatory variables. We conduct analysis for specific junction types and specific types of accidents and report the results in the following. We tested different types of model formulations, including linear and ordinal regression. Since, however, there are a large number of junctions without any accidents occurring in the three years for which we hold data, we report in the following results of a binomial logistic regression. Results of alternative models do not appear to provide deeper insights.

4.1. All intersections

In this first analysis, all intersections were included. We hence include dummy variables for the junction types “large” and “medium” with small as reference. After dropping some types of POI categories, the correlation coefficients between the explanatory variables reported in the results were all below 0.3, hence we conclude that that the problem of multicollinearity is not significant. The results of the analysis as well as descriptive statistics of the accident distribution are presented in Table 1. The degree of model fit is not high, indicating a high

Table 1
Negative binominal regression on all intersections ($N = 26{,}553$).

		Dummy = 1			Dummy = 0		
	coefficient	percentage of accidents	Number of junctions with accidents	Number of junctions with no accidents	percentage of accidents	Number of junctions with accidents	Number of junctions with no accidents
intercept	−2.347 **						
park	−0.118 **	12.6 %	202	1395	16.0 %	3987	20,969
school	0.010	17.4 %	220	1041	15.7 %	3969	21,323
restaurant	0.044 **	43.4 %	588	768	14.3 %	3601	21,596
supermarket	0.073 **	44.5 %	94	117	15.5 %	4095	22,247
convenience store	0.033 **	58.3 %	275	197	15.0 %	3914	22,167
bus stop	0.078 **	46.1 %	483	564	14.5 %	3706	21,800
parking	0.060 **	24.6 %	978	3003	14.2 %	3211	19,360
station	0.059	53.8 %	28	24	15.7 %	4161	22,340
traffic signal	0.280 **	78.2 %	886	247	13.0 %	3303	22,117
pedestrian crossing	0.082 **	55.4 %	690	555	13.8 %	3499	21,809
commercial area	0.446 **	45.5 %	1559	1864	11.4 %	2630	20,500
industrial area	0.316 **	18.0 %	738	3363	15.4 %	3451	19,001
residential area		9.9 %	1892	17,137	30.5 %	2297	5227
major intersection	1.391 **	68.8 %	524	238	14.2 %	3665	22,126
medium intersection	1.250 **	40.3 %	2383	3533	8.8 %	1806	18,831
small intersection		6.5 %	1282	18,593	43.5 %	2907	3771
population density	-1.066×10^{-6}						
AIC	32,201						
BIC	32,332						
likelihood ratio chi-square	9572**						

*:$p < 0.05$, **:$p < 0.01$

randomness as to where accidents occur. Clearly, the model does not have sufficient goodness of fit to be used for forecasting purposes but we suggest that for explanatory purposes the model is appropriate since we obtain a number of statistically significant factors. We note that a low model fit has also been found in other models and that for example Greibe [33] also discusses that "modelling accidents for road links is less complicated than for junctions, probably due to a more uniform accident pattern and a simpler traffic flow exposure or due to lack of adequate explanatory variables for junctions."

For example, there are 1597 junctions that have a park located nearby. At 12.6 % of these we find that an accident is occurring. For the junctions that do not have a park nearby, we find that at 16 % of these there are accidents. From the descriptive statistic we can observe some significant differences between junctions with and without certain attributes. At 43.4 % of the junctions with a supermarket an accident is occurring, but only at 14.3 % of the junctions without a supermarket this is the case. Similar large differences can be found for "convenience store", "bus stop" and "station". We also find large differences as to whether an accident has occurred or not for land-use variables. The parameter estimates generally confirm those trends. We find that the parameter for station is not significant, which is though not surprising given the low number of samples with a train station nearby. Also, for our "control variables" traffic signal and pedestrian crossing we find that at those junctions with this road infrastructure more accidents occur. Clearly this is an endogenous effect as signals and crossings are installed at junctions with higher risks.

4.2. All intersections with traffic volume and monthly accident data

As shown in previous section, the control measures are significant and missing traffic flow information might have led to an overestimation of the parameter estimates shown in previous section. We hence show here the results with traffic volume. As afore discussed, we can only conduct this analysis for a small subset of the junctions. In particular there are no small intersections in the analysis as vehicle detectors are not installed on single lane roads. In order to use the total monthly traffic volume aggregated per month as an explanatory variable, the presence of traffic accidents per intersection was also recounted per month. This hence leads to a binomial logistic analysis with 36 months of data at 1124 sites. For comparison, the same sample was also analyzed excluding traffic volume from the explanatory variables. The results of these analysis are presented in Table 2.

Comparing the results with and without traffic volume, the signs of all coefficients are the same, although traffic volume is significant.

Table 2
Logistic regression on all intersections with traffic volume ($N = 1124$ junctions × 36 months).

	With traffic volume	without traffic volume
intercept	−3.79 **	−3.53 **
park	−0.21	−0.27
school	0.20 *	0.16
restaurant	0.19 **	0.16 **
supermarket	0.19	0.16
convenience store	0.06	0.02
bus stop	−0.13 *	−0.15 *
parking	0.07	0.09
station	0.30	0.25
traffic signal	0.66 **	0.65 **
pedestrian crossing	0.06	0.10
commercial area	0.21 **	0.26 **
industrial area	0.35 **	0.41 **
major intersection	0.49 **	0.52 **
population density	-2.16×10^{-6}	-2.26×10^{-6}
traffic volume	6.33×10^{-7} **	
Adjusted R2	0.04	0.04

*:$p < 0.05$, **:$p < 0.01$

Compared to the results in the previous section, the signs are different only for bus stops, since small intersections are not included in the sample. To note is further that supermarket and convenience store are now not significant anymore in this model where mainly large junctions are included. We elaborate on this further in the next section where we report separate models for the three junction types.

4.3. Models by intersection type and accident category

To further understand differences by type of intersection we further construct separate negative binominal regression models for small, medium and large intersections. In addition, for each junction type, we run three models, one for all accidents at this junction, one for accidents without pedestrian involvement and one for accidents with vehicle and pedestrian involvement. The results of all nine models are presented in Table 3.

We firstly note that the model fit indicates that accidents at larger junctions are slightly better explainable than accidents for medium and small junctions. This is not surprising since due to the larger likelihood of accidents at large junctions, the distribution of accidents at large intersections is less random compared to medium and small intersections. At small junctions more random, difficult to explain factors occur. We then note that "traffic signals" has the expected positive sign for all models. The largest coefficients are observed for small junctions. This is understandable, since at small junctions, precisely at those that are accident prone traffic lights will be installed, whereas at larger junctions having traffic lights is the norm. Pedestrian crossings are not significant for the large junctions but are for the medium and small junctions. Surprisingly for medium-sized junctions the main significance occurs for "vehicle-to-vehicle accidents". For small junctions, in line with expectations, the largest significant effect is observed for person and vehicle accidents. The variables traffic signals and pedestrian crossing show that they are in place at the junctions of most risk. Whether or not they help to reduce accidents we can not conclude.

The most consistent variable is "commercial area". This highlights that most of the accidents occur in downtown Kyoto as illustrated with Fig. 1. Higher accident rates are associated with more active areas of the city which is not surprising. Industrial area is also significant, though not at the same level as commercial area.

We now turn to the POIs associated with the junctions. For large junctions we observe that few POIs are significant. Only parks are negatively associated with all and vehicle-to-vehicle accidents and restaurants are positively associated with vehicle-to-pedestrian accidents. The negative effect of park is replicated in the models for the medium sized junctions but the variables are not significant for small junctions.

In contrast, restaurants, convenience stores, and supermarkets are positively associated with accidents, but only for medium-sized and even more so for small junctions. Especially restaurants are associated with more vehicle-and-pedestrian accidents which provides further evidence that it is the increased pedestrian flow in the vicinity of such facilities that is an accident hazard. Supermarkets and convenience stores have a significant effect also for vehicle-to-vehicle accidents which is possibly explainable by considering that such shops are associated with increased parking traffic. It is also found that car parks are positively associated with accidents and the same reasoning might apply: Car parking facilities indicate more interaction of pedestrians and cars as well as the presence of traffic merging maneuvers which may be the reason for the car park parameters being positive and significant. These trends are found at medium and small intersections but not for large junctions. Finally, we note that bus stops are also associated with more accidents of all, vehicle-to-vehicle and person-to-vehicle but only for mid-sized junctions.

5. Disucssion

We suggest the above presented results confirm some findings and lead to a number of new results. In line with our literature review and Fig. 1, Table 1 shows that junctions in commercial areas are more prone to accidents whereas junctions in residential areas are less likely to have seen an accident in the years 2017–2019. Controlling for land-use we find that our continuous variable population density is not significant. Further, significantly more accidents are observed at major and medium sized junctions compared to small junctions. Overall, the results illustrate how commercial activities near the intersection and with it the likelihood that drivers need to pay attention to possibly un-attentive shoppers or persons coming from restaurants increases the accident likelihood. These findings confirm those reports in the literature for pedestrian-vehicle accidents [34] but we show that there is also an impact on vehicle-vehicle accidents. We note that among the POI types, convenience store and supermarket have higher parameter estimates. Especially, convenience stores are very common in Japan and are visited frequently. As they are designed to be in easy access locations, often

Table 3
Negative binominal regression on each size intersections.

	large intersection			medium intersection			small intersection		
	all	person and vehicle	vehicle and vehicle	all	person and vehicle	vehicle and vehicle	all	person and vehicle	vehicle and vehicle
intercept	−0.715 **	−1.462 **	−0.320 **	−1.070 **	−1.865 **	−0.557 **	−2.614 **	−3.377 **	−1.823 **
park	−0.152 *	0.014	−0.101 **	−0.122 *	−0.179	−0.074 **	−0.193 *	0.212	−0.030
school	−0.006	−0.082	0.005	0.001	0.007	−0.020	0.013	0.190	−0.018
restaurant	−0.006	0.150 *	0.001	0.057 *	0.226 **	0.028 **	0.180 *	0.687 **	0.030
supermarket	−0.003	0.148	−0.020	0.083 *	0.259 **	0.040 *	0.613 **	0.955 **	0.345 **
convenience store	−0.021	0.033	−0.006	0.051	0.236 **	0.025 *	0.488 **	0.752 **	0.316 **
bus stop	0.011	0.094	0.022	0.106 **	0.194 **	0.050 **	0.251	0.422 *	0.224 **
parking	−0.020	0.021	−0.006	0.082 **	0.172 **	0.037 **	0.292 *	0.053	0.118 **
station	−0.048	0.231	0.525	0.022	0.189	0.528	0.198	0.323	0.078
traffic signal	0.335 **	0.547 **	0.152 **	0.265 **	0.385 **	0.013 **	0.534 **	0.584 **	0.366 **
pedestrian crossing	0.027	0.115 *	0.018 *	0.122 **	0.160 **	0.066 **	0.623 **	0.583 **	0.406 **
commercial area	0.206 **	0.267 **	0.091 **	0.391 **	0.475 **	0.232 **	1.052 **	1.316 **	0.817 **
industrial area	0.153 **	0.059	0.079 **	0.262 **	0.081	0.185 **	0.413 **	0.338 **	0.318 **
population density	-1.342×10^{-6}	5.511×10^{-7}	-5.145×10^{-7}	1.928×10^{-6}	2.612×10^{-6}	-3.33×10^{-6}	5.616×10^{-6}*	-3.920×10^{-6}	7.352×10^{-6}**
sample size	778	778	778	5838	5838	5838	19,937	19,937	19,937
AIC	3071	1808	4338	14,516	8260	22,380	14,185	7592	25,914
BIC	3136	1873	4403	14,610	8354	22,474	14,296	7702	26,024
likelihood ratio chi-square	238**	117**	276**	908**	588**	1215**	769**	701**	1327**

*:$p < 0.05$, **:$p < 0.01$

directly at intersections and with wide doors to easily enter and leave our results suggest that this easy access can encourage accidents by unattentive shoppers when entering or leaving the shop. This hypothesis should, however, be investigated further with additional data. In support of our analysis, we note that Otsuka [35] also discussed a relation of accidents with the presence of convenience in a study of accidents around Shinjuku, Tokyo.

From Tables and Table 3 we find that a key factor of significance is the presence of parks near the junction. Noteworthy is, however, that the significance of parks for vehicle-and-vehicle accidents but not for vehicle-and-person accidents. This might suggest that it is not the park itself that improves safety but possibly the visibility due to fewer buildings and the calmer atmosphere of junctions with adjacent parks that reduces accidents. We suggest hence that including factors related to "field-of-view" would be a natural next step to improve the model fit.

We similarly find that also for some other factors more detailed variables should be created. Regarding car parking for example, the reported signs appear reasonable but it is difficult to explain why the sign is not significant for large junctions. We suggest that a reason may be the lack of separation between pedestrians and vehicles on single-lane roads in Japan but to confirm this, detailed information on lane markings should be considered. Other "deeper factors" could be related to the type of activities that are associated with the car parking place. For example, others have reported that activities such as "dressing-up" or "drinking-eating-smoking" while waiting at junctions are associated with accident risks [36]. These activities will be more present for drivers leaving car-parking near, for example, fast-food restaurants.

Similarly, our results for bus stops where only significant parameters are found for mid-size junctions, deserve further investigation with additional data. A possible explanation is that at larger junctions the bus stops are likely more protected with separate bus bays and at small junctions the bus frequency and pedestrian volume is likely lower, possibly explaining these results. We further remind that at medium size intersections roads of different size cross so that cars might not sufficiently appreciate the changing driving conditions and the presence of larger vehicles on the more major roads which might be an alternative explanation.

6. Conclusions

In this study, a database of junctions, the infrastructure of the intersection links and the build environment in the vicinity of these junctions was created for Kyoto Japan. The database includes all intersections of the main built-up area of Kyoto including minor ones. Besides some government information on land-use characteristics our main data source has been Open Street Map and the various Points of Interest that are recorded in there. We then merge this data with an existing database of accidents involving injuries for the years 2017–2019. We conducted regression analysis with whether an accident had occurred at a junction using these spatial characteristics as explanatory variables. Separate models for intersections of different scale as well as for accidents with and without pedestrian involvement are reported.

The results showed that it is indeed important to distinguish intersections according to their scale as we find significant differences in the models. Some POI groups are only associated with more accidents at medium and small-scale junctions.

We aim to control for the general accident likelihood of a junction by considering the presence of traffic lights, pedestrian crossings and traffic volume. Given these "control variables" we showed that the presence of parks near a junction is associated with less accidents and that supermarkets, convenience stores and restaurants are associated with more accidents. The results highlight that it is not only the volume of passing traffic and the road infrastructure that determine accidents, but also the interaction of vehicles and pedestrians at the intersection which in turn depends on the facilities around the intersection that has an impact on the occurrence of traffic accidents at intersections. We discuss that the significance of restaurants, in particular for accidents involving pedestrians, suggests that attention after leaving restaurants could be one reason. Convenience stores are places where people "quickly-drop-in" and possibly do not pay sufficient attention to traffic.

To explain the safety enhancing effect of parks, in further analysis we obtained Google streetview pictures of several junctions with no accidents occurring and those with many accidents occurring. Though we have not yet carried out a formal analysis of these pictures we suggest that for the many narrow streets of Kyoto, parks are often associated with higher visibility possibly explaining the results.

In general, we acknowledge that further research with detailed data on the accidents occurring at the junctions is needed to confirm these hypotheses and to draw urban planning conclusions and to suggest traffic safety improvement strategies. Moving the public locations associated with more accidents away from the junctions is unlikely to be a feasible solution, nor in many cases desired. Possibly rather the junction details at intersections with these facilities need specific attention.

To enable such analysis the here reported study should be continued in various directions besides those already mentioned. For one, in the current study only the public available accident database is used, in a more detailed non-public database from Kyoto Police, accident details are provided and have been obtained now. Then regression models for specific times of day and more specific accident types such as "rear collision accidents" could be conducted. In the present study we also did not pay attention to the role of cyclists. Further, our database could clearly be improved by considering additional junction details such as the specific layout, and direction specific traffic volumes.

A limitation of our study is the low R-squared value of our model, which suggests that our model explains a relatively small proportion of the variance in traffic accident data. This low value is partly due to the rare and random nature of accidents, especially at smaller junctions, which complicates predictive accuracy. Although the model's explanatory power could potentially be improved with more advanced techniques or additional data, such as Surrogate Safety Measures (SSM), the inherent randomness of traffic accidents remains a significant challenge.

Furthermore, in terms of policy implications, we remind that one has to be careful with cause and effect conclusions from our study as we discussed, among others, for our observed effects with respect to the presence of a park around the junction. In other words, policy makers can use our results as indicators which type of POIs generally positively or negatively influence accident risks, but they still need to carefully consider the very local factors that provide a deeper explanation.

Nevertheless, the findings suggest several potential measures for improving road user safety at junctions. For instance, careful design and placement of signage near restaurants and convenience stores could mitigate the risks associated with these high-traffic areas. Implementing measures such as clearer warnings for pedestrians and vehicles, particularly near POIs [37], and regulating quick drop-in practices at convenience stores could contribute to safer intersections. These findings are also in line with our observations. Additionally, we discussed that visibility is a likely factor explaining some of our findings. Hence reducing distracting advertisements and enhancing visibility at crossings could further decrease traffic accident rates. To confirm this, however, further analysis with more detailed consideration of street furniture and visibility fields is required.

CRediT authorship contribution statement

Satoshi Nakao: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Koshi Sawada:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Andreas**

Keler: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jan-Dirk Schmöcker:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

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