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Road Junction Configurations and the Severity of Traffic Accidents in Japan

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Abstract: In many countries, 40–60% of the traffic accidents occur at junctions, making the reduction of junction accidents paramount to achieving UN Sustainable Development Goals. In Japan, the road safety guidelines specify the proximity between junctions and non-perpendicular angles at junctions as the two main risk factors behind junction accidents, yet their impact remains understudied. Using binomial logistic regression models, this study investigates the impact of junction intervals and junction angles on the severity of traffic accidents. The study found that, in general, (1) shorter intervals between adjacent junctions helps reduce the risk of serious accidents, which is the opposite of the current road safety guidelines in Japan, and (2) results from the junction angle analysis were mixed but there was no evidence that the roads should meet at a right angle to reduce traffic accidents. Some types of accidents also returned a non-linear curve, e.g., vehicle-to-vehicle collisions at four-armed junctions involving a driver aged 65 years and over have the highest risk of fatal/serious accidents when adjacent junctions were 32 m apart, and the risk reduces at a shorter or longer interval. These results suggest that the current road safety guidelines require updating to improve road safety around junctions.

Keywords: fatal accidents; logistic regression; non-linearity; road safety; traffic accidents; traffic junctions

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1. Introduction

Road traffic injuries claim 1.3 million lives each year and are known to represent the eighth leading cause of deaths worldwide. They are also responsible for as many as 50 million non-fatal injuries globally and incur economic losses of 1–3% of GDP in each country (World Health Organization, 2022) [1]. Road junctions, in particular, are known to present high risks of traffic accidents due to the complex conflicting traffic movements from different road users, compounded by the fact that roughly 50% of road deaths by cyclists and pedestrians occur at junctions (Huang et al., 2008, Sundfør et al., 2019) [2,3]. Road junctions also trigger traffic congestion and have a prevalence of severe side-impact crashes (Chen et al., 2012) [4]. Identifying the risk factors of road junction accidents and implementing countermeasures would not only alleviate the severity of injuries, but could reduce the number of crashes altogether (Anjana and Anjaneyulu 2015, Sharafeldin et al., 2022) [5,6]. It also aligns with the UN Sustainable Development Goal (SDG) targets 3.6 (halve the number of road death and injuries globally) and 11.2 (provide access to affordable sustainable transport and improve road safety for all age groups), and the recent UN General Assembly resolution on road safety, pledging to reduce 50% of road traffic deaths and injuries by 2030.

In Japan, road junction accidents are considered as a major road safety challenge, responsible for 54% of all road accidents and 46.2% of road accident deaths recorded in Japan in 2020 (Cabinet Office of Japan (2021) [7]. The main risk factors of road junction accidents in Japan are considered to be the configuration of the road junction, especially the distance between the neighbouring junctions (hereafter referred to as the junction interval) and the angle between roads (hereafter referred to as the junction angle). In particular, short junction intervals, including staggered junctions and acute angle junctions, are considered to result in poor visibility and, thereby, induce traffic accidents. For this reason, the design criteria for junctions, "Plans and Designs for Level Crossing", issued by the Japan Society of Traffic Engineers (2018) [8] stipulates that junction angle should be close to a right angle and junction interval should be as long as possible. Similarly, the Priority Elimination Strategy for High Accident-Risk Zones (Ministry of Land, Infrastructure, Transport and Tourism, 2022 [9]) has and will likely continue to treat short junction intervals and staggered junctions, as well as acute angle junctions, as major safety hazards and prioritises their elimination. However, despite the continued focus on these two factors at the national strategy level, their actual impact remains understudied. In otherwards, the causality for the frequent traffic accidents at junctions is often inferred, and it is unclear to what extent these two risk factors will increase the likelihood of accidents. Interestingly, the EU guidelines for road safety recommend the opposite in that they encourage introducing staggered junctions (on the account that four-armed junctions have a higher risk of accidents than three-armed junctions do) (European Commission 2022) [10]. In the case of Japan, before the road safety strategy is set, some key questions should be answered; e.g., how close to a right angle should the junction angle be? What is the recommended junction interval, and is longer junction interval safer? And, more generally, do short junction intervals and acute junctions yield higher risks of traffic accidents when compared with longer junction intervals or non-acute junctions?

Using traffic accident data from the Kyoto Prefecture between 2012 and 2019, this study aims to assess the number of risks presented by these two factors, namely the junction interval and the junction angle, and to investigate whether they affect the outcomes of fatal or serious traffic accidents at road junctions and, if so, what distances or angles present the highest risks and how we might reduce the risk of such accidents.

2. Literature Review

A substantial portion of traffic accidents occur at road junctions, making junctions a major obstacle to building a safe and sustainable urban mobility network (Anjana and Anjaneyulu 2015 [5]). For instance, approximately 40% of traffic accidents in the United States occur at junctions (Zhang et al., 2015 [11]), (Billah et al., 2021 [12]), and more than 20% of all traffic-related fatalities are recorded at junctions (Sharafeldin et al. (2022) [6]). Similarly, around 30% of traffic accidents in Singapore and Canada occur at or near junctions. In the Netherlands, 44% of all registered traffic casualties are attributed to traffic accidents at or near junctions (Chen et al., 2012 [4]). More generally, 40–60% of the road accidents occur at junctions in each EU nation. These figures confirm the high proportion of traffic accidents around junctions globally, and the proportion of accidents around junctions in Japan are, as mentioned earlier, not any better, at 54% of all road accidents and 46.2% of road accident deaths being recorded at junctions (Cabinet Office of Japan 2021) [7].

The causes of traffic accidents have been studied by many (e.g., Haleem and Abdel-Aty (2010) [13], Penmetsa and Pulugurtha (2018) [14]: Eboli et al. (2020) [15]), and they are mainly classified into four groups:

1. Vehicle-related factors: including lack of maintenance, failure of expendable parts (e.g., brakes, tyres, and lighting), and inherent design limitations (e.g., visibility, rigidity, and manoeuvrability);
2. Road-related factors: traffic volume (Anjana and Anjaneyulu 2015 [5], Kesavareddy et al., 2018 [16]), traffic control type (Billah et al., 2021 [12]), speed limit (Xu et al., 2018 [17]), pavement design and conditions, geometric design (Xie et al., 2013 [18], Zhang et al.,

2015 [11]), light condition (Zubaidi et al., 2022 [19]), insufficient lane and shoulder width, degree of curvature (Bíl et al., 2019 [20]);

3. Driver/road-user-related factors: seat belt usage (Chen et al., 2012 [4]), driving under the influence (e.g., alcohol, drugs), violation of traffic regulations (e.g., speeding, red light violation (Alghafli et al., 2021 [21]), stop sign violation), mental state of and inattention by the driver (Sagberg et al., 2019 [22], Sundfør et al., 2019 [3]), driver's experience and demographic profile (e.g., age, gender, ethnicity (Penmetsa and Pulugurtha (2018) [14]);
4. Environment-related factors: day of the week (Billah et al., 2021 [12]), time of the day (Behnood and Mannering, 2019 [23]), weather condition (e.g., rain, fog, icy condition), reduced visibility.

Zhang et al. (2015) [11] and Makarova et al. (2020) [24] also add "crash characteristics" as the fifth group, which describes a situational setting, such as the manner of collision (e.g., rear-end, head on, hitting an object, dropping an item).

While accidents at or around junctions may be triggered by a number of interrelated factors, this study focuses on junction interval and junction angle as the potential risk factors, both of which belong to the second group of road-related factors (specifically, the geometric design of roads). This is because these two factors represent the key design factors in the road safety guidelines in Japan, yet their impact on accident outcomes remains understudied. The focus on junction interval and junction angle could be partly prompted by the characteristics of the road network of Japan. For instance, Xie et al. (2013) [18] note that Shanghai and other major cities in China have a high density of streets, and this results in short junction interval and increased number of junctions. Given the vast expanse of the major cities in China and the large volume of intra-city traffic, junction interval becomes an important factor to consider for road safety. In contrast, much of the road network in the United States and other parts of the world have longer junction intervals, which could be the reason for less focus on the interval between junctions and how that might affect road safety.

Existing studies on traffic accidents around junctions mainly focus on factors such as the speed of vehicle, as there is a consensus that increase in speed raises crash severity and the likelihood of fatal or serious injuries (Alghafli et al., 2021, Behnood and Mannering, 2019, Ahmed et al., 2018, Asare and Mensah, 2020 [21,23,25,26]). Likewise, increase in traffic volume is known to show positive correlation with crash severity at junctions (Greibe 2003, Anjana and Anjaneyulu 2015, Penmetsa and Pulugurtha 2018) [4,14,27]. However, studies on junction interval and junction angle are few, and their results are less consistent. For instance, Abdel-Aty and Wang (2006) [28] report that increase in junction interval helps reduce traffic accidents. Xie et al. (2013) [18] also confirm that shorter junction intervals increased the likelihood of crashes in China. They suggest that, when planning and rebuilding urban road networks, junctions should be located as far apart as is feasible. Furthermore, Xie et al. (2014) [29] indicatively suggest that a one-kilometer increase in junction interval is expected to reduce the crash frequency by 7.69 cases, annually. The notion of shorter junction interval resulting in higher risks of traffic accidents aligns with the aforementioned safety guidance in Japan. Indeed, there are reports such as "conflicts and interference among different traffic flows are prevalent at intersections" (Zhang et al., 2015 [11]). Sundfør et al. (2019) [3] point out the complex situation around junctions causing distraction to the drivers.

In contrast, Haleem and Abdel-Aty (2010) [13] report that junction interval has a positive correlation with accident rate and suggest that a longer distance between the adjacent junction leads to speeding in between the junctions, thus increasing the risk of accidents. Indeed, Yoshida and Harata (2002) [30] and Hashimoto et al. (2010) [31] assert that a longer junction interval leads to clearer line of sight and results in increased speed of travel. As noted by Archer et al. (2008) [32], driving at higher speed increases the risk of fatal/serious accidents, and longer junction interval may indeed induce this risk. Interestingly, Savolainen and Mannering (2007) [33] conclude that crashes are less severe under wet conditions near the junctions, as drivers may slow down during adverse weather. More generally, Morichi and Hamaoka (1995) [34] suggest that drivers tend to slow down at places where they feel danger which, in turn, helps reduce the accident rate, and it is reasonable to assume that arriving at a junction invariably adds the psychological pressure for the driver to slow down. There are also reports on vehicle-to-bicycle accidents where crashes at non-junction street segments have a 1.31 times higher risk of a severe injury than accidents at junctions do (Asgarzadeh et al. (2017) [35]). The collection of these studies indicates that there are mixed reports on the risks arising from different intervals between junctions.

There are even fewer studies on the impact of junction angles on traffic accidents. Among the few exceptions is a study on vehicle-to-bicycle accident analysis by Asgarzadeh et al. (2017) [35], which reports that the junction angle is the only spatial variable that has a significant association with traffic accidents at junctions. They also note that crashes at non-orthogonal junctions had a 1.37 times higher risk of a severe injury than crashes at orthogonal intersections do (Asgarzadeh et al., 2017) [35]. In addition, Haleem and Abdel-Aty (2010) [13] point out that junctions with a minimal angle of less than 75 degrees have a higher risk of fatal/serious accidents.

Based on these studies, the configuration of junctions, including the junction interval and junction angle, have a complex influence on the driver's situation, and the complex mix of these situations results in the risk of fatal/serious accidents. As such, changes in the junction configuration and their impact on the associated risks of accidents may not be as simple as a monotonic increase or decrease but may, rather, follow a non-linear model.

In fact, many descriptive models have been designed for studying the frequency of accidents and the severity of outcomes, but many of them follow a linear function. These include Poisson models (Miaou 1993 [36], Zewde 2017 [37]), negative binomial models (Alghafli et al., 2021 [21], Srinivas and Venkata, 2011 [38]), the Bayesian hierarchical model (Huang et al., 2008 [2]), logistic regression (Billah et al., 2021 [12], Hsu et al., 2020 [39], Karacasu et al., 2013 [40], Eboli et al., 2020 [15]), log linear regression (Bauer and Harwood, 2000 [41]; Greibe, 2003 [27]), probit models (Garrido et al., 2014 [42], Zhang et al., 2015 [11], Zubaidi et al., 2022 [19]), and logit models (Wu et al., 2016 [43], Anderson and Hernandez 2017 [44], Northmore and Hildebrand 2019 [45]). Others have also adopted a spatial model approach considering the presence of spatial autocorrelation between the incidents (e.g., Poisson spatial model, (Guo et al., 2010 [46]), hierarchical conditional autoregressive (HCAR) model—Xie et al. (2014) [29]). Basu and Saha (2017 [47]) provide a good review on these methods and note that the risk factors and the accident rate are all estimated using a linear model.

In summary, only few studies have looked at the two contributing factors to traffic accidents at junctions focused on in this paper, namely, junction intervals and junction angles. Findings are mixed and occasionally yield conflicting results. Moreover, many studies seem to assume linearity of the situation and adopt a linear model. Based on this gap in the literature, this study will investigate whether the two junction configuration variables have an effect on traffic accidents at junctions, and if they do, what kind of curve or distribution the model take. Separate models will be built for each category of junction configuration and the outcomes.

3. Data and Methodology

3.1. Data

This study focuses on the City of Kyoto, Japan, including the historical town centre as well as the densely inhabited suburban districts, extending to about 15 km wide by 20 km long (Figure 1). The GIS data of the street network and other attributes of Kyoto were taken from Digital Map 5000 (Land Use): Kinki Region 2008 Data assembled by Japan Geographical Survey Institute. The traffic accident data were obtained from Kyoto Prefectural Police and cover all records within Kyoto Prefecture from 2012 to 2019. The data are classified into three groups: fatal accidents, serious injuries, and light/no injuries, and record the date and time of the accident, the traffic rules (e.g., speed limit, stop sign) applicable to that location, and mode of transport of those involved and their demographic profiles. Location of each accident is accurately stored and can be treated as point data in GIS.

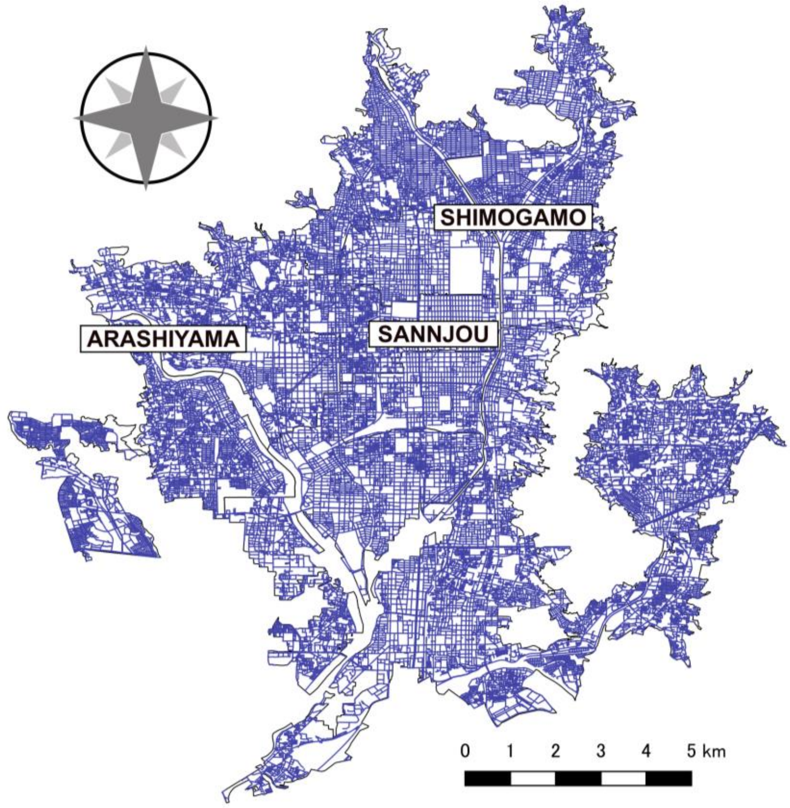


Figure 1. The street network in the city of Kyoto, Japan (Data source: GeoTechnologies Inc., Tokyo, Japan).

The dataset consists of 23,543 cases of traffic accidents recorded at three-armed (T or Y-shaped junctions) or four-armed junctions (+shaped junctions) in Kyoto between 2012 and 2019, excluding motorway accidents, special cases affected by chronic medical conditions of the party involved, and those missing substantial amounts of data. In most cases, the main liable parties were vehicle drivers, and traffic accidents caused by other users were omitted from this study, as non-vehicle drivers may not be affected by the junction interval or junction angle in the same way as vehicle drivers do. To account for the difference between the junction geometry, as well as the combination of the parties involved, the data were classified by the number of arms at junctions, different modes of transport, and the age groups of the other party involved in the accident. Specifically, they were grouped into cases recorded at or around three-armed and four-armed junctions, then classified into four cases of (1) vehicle to vehicle, (2) vehicle to motorcycle, (3) vehicle to bicycle, (4) vehicle to pedestrian, and further divided by the age group of the other party: (i) below 16 (for vehicle-to-bicycle and vehicle-to-pedestrian cases only), (ii) 16 to 64, and (iii) 65 and over, as shown in Table 1. The groups highlighted in yellow in Table 1 have a high rate (10–20%) of fatal/serious injury outcomes out of all junction traffic accidents in that category, and those with orange highlights suffer from very high rates (over 20%) of fatal/serious injury outcomes. The contrast between the vehicle-to-vehicle accidents and the rest of the combinations is clear, as junction traffic accidents involving motor cyclists, bicyclists or pedestrians all have at least 10% serious outcomes, whereas the vehicle-to-vehicle collisions are consistently below 10%. Additionally, all non-vehicle users aged 65 years and over are subject to a 30% or higher rate of fatal/serious injury outcomes, which confirms the high risks for older people at traffic junctions.

Table 1. Classification of traffic accidents and fatal/serious cases at or near junctions. Categories with 10–20% fatal/serious accidents are highlighted in yellow, and over 20% in orange (data source: 1:2500-scale road network data compiled by GeoTechnologies Inc., Tokyo, Japan).

Junction Type	Modes of Transport Involved	Age Group	All Cases	Fatal/Serious Cases Count	Fatal/Serious Case Rate
Four-armed junction	Vehicle to vehicle	16–64	3475	147	4.2%
		65 and over	468	34	7.3%
	Vehicle to motorcycle	16–64	3599	752	20.9%
		65 and over	328	130	39.6%
	Vehicle to bicycle	up to 15	237	24	10.1%
		16–64	2640	308	11.7%
		65 and over	499	148	29.7%
	Vehicle to pedestrian	up to 15	107	28	26.2%
		16–64	695	132	19.0%
		65 and over	374	178	47.6%
Three-armed junction	Vehicle to vehicle	16–64	1877	49	2.6%
		65 and over	254	6	2.4%
	Vehicle to motorcycle	16–64	1844	325	17.6%
		65 and over	155	47	30.3%
	Vehicle to bicycle	up to 15	173	25	14.5%
		16–64	1307	141	10.8%
		65 and over	275	88	32.0%
	Vehicle to pedestrian	up to 15	95	26	27.4%
		16–64	479	78	16.3%
		65 and over	246	104	42.3%

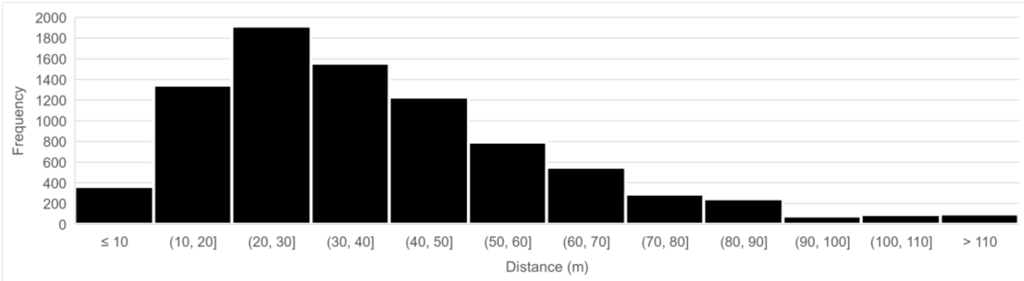
3.2. Binomial Logistic Regression Analysis

3.2.1. Setting the Independent and Dependent Variables

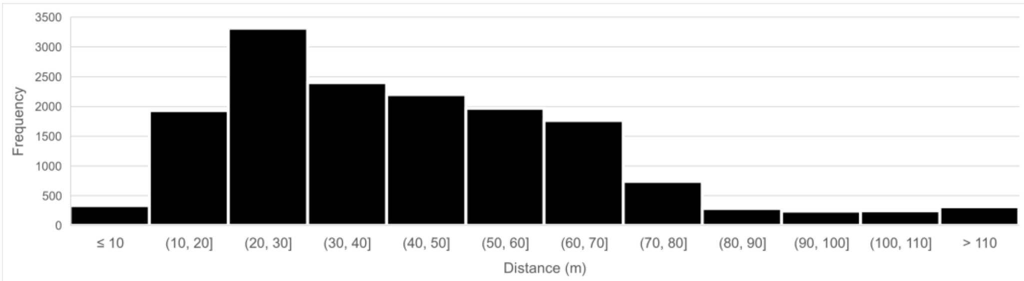
To identify the relevant independent variables for explaining the high risks at junctions, this study carries out binomial logistic regression analysis using R language (compiler ver. 4.0.2). To apply logistic regression, the accident data outcomes were divided into the fatal/serious cases and light/no injury cases. Junction interval and junction angle were obtained by constructing the street network of Kyoto and measuring these attributes with SANET Standalone 1.0 Beta (Okabe et al., 2022) [48] and QGIS 3.10.6. For each junction, the network distance to the nearest neighbouring junction was defined as its junction interval, and the smallest angle at that junction was used as its junction angle. Figures 2 and 3, respectively, show the distribution of junction interval and junction angle for three-armed and four-armed junctions, which are also summarised in Table 2.

These graphs and tables collectively show that while four-armed junctions are nearly as common as three-armed junctions, their distributions, including the central tendencies and other indices, are sufficiently close to each other that many of the risks arising from the difference between the two types of junctions is owed to the topological difference of having three arms or four arms, rather than the difference in the junction angle between them.

To control other covariates and to accurately evaluate the impact of junction configuration on the fatal/serious cases, other variables drawn from the literature were also incorporated into the model. These covariates are summarised in Table 3.

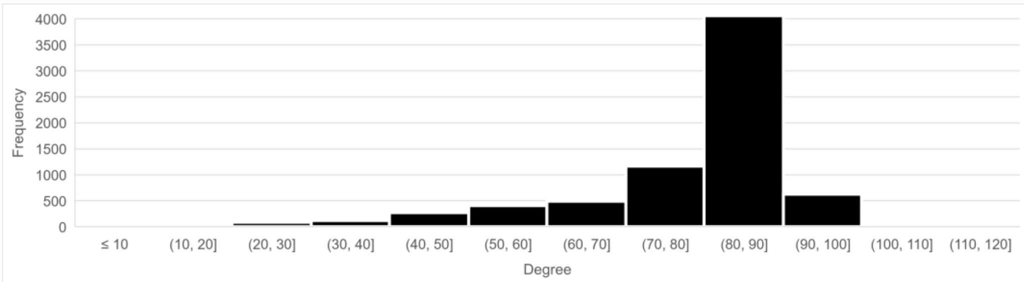


(**a**)



(**b**)

Figure 2. Distribution of junction intervals in Kyoto among (**a**) three-armed junctions, and (**b**) four-armed junctions (data source: 1:2500-scale road network data from GeoTechnologies Inc., Tokyo, Japan).



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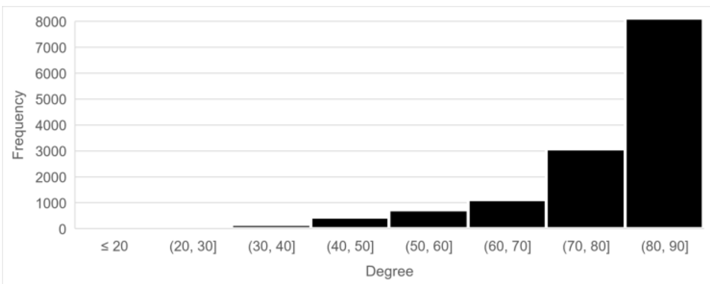


(**b**)

Figure 3. Distribution of junction angles in Kyoto among (**a**) three-armed junctions (min: 6.55 degrees, max: 115.83 degrees), and (**b**) four-armed junctions (min: 10.98 degrees, max: 89.94 degrees) (Data source: 1:2500-scale road network data from GeoTechnologies Inc., Tokyo, Japan).

Of these variables, the traffic volume for local streets were substituted with estimates, as actual data are not recorded on this scale. The estimates were derived by applying the local street traffic estimation model (Kobayashi et al., 2018) [49] to Digital Map 5000 (Land Use): Kinki Region 2008 Data assembled by Japan Geographical Survey Institute.

Table 2. Descriptive statistics for junction angles (Data were extracted from the 1:2500-scale road network data compiled by GeoTechnologies Inc., Tokyo, Japan).

	3-Armed Junction	4-Armed Junction
Count	8563	15,744
Mean	80.02	79.32
Median	85.76	84.15
Mode	[85–90]	[85–90]
Standard Deviation	14.15	12.59
Kurtosis	4.16	4.21
Skewness	−2.03	−1.98
Range	109.28	78.96
Minimum	6.55	10.98
Maximum	115.83	89.94

Table 3. Variables considered for the logistic regression models.

Types of Variables	Details
Junction configuration	Junction interval : $[x_i,\ x_i^2,\ x_i^3,\ \log(x_i+1)]$ Junction angle : $[x_j,\ x_j^2,\ x_j^3,\ \log\left(x_j+1\right)]$
Street classes	Dummy variables for prefecture road, national highway, one-way road, bypass, motorway
Street segment features	Dummy variables for bridge, under-path, tunnel, railroad crossing, pedestrian crossing
Facilities (polygon data)	Dummy variables for petrol station, parking lot, bike parking lot
Facilities (point data)	Bus stop, kindergarten, primary school, secondary school, university, park, care home, day care centre
Accident profile	Dummy variables for day/night, rain, snow, accident category, road gradient, raised pavement, gender of party involved, speed limit signage, stop sign
Demographic profile	Local population, proportion of male population, 14 and younger population, 65 to 74 population, 75 and older population, lived locally up to 1 year, lived locally up to 20.y.o lived locally
Junction lighting	Dummy variable for indicating the presence of traffic light
Traffic volume estimates	Ratio of road surface within 1 km grids, residential area within 1 km grids. 1 km number of stations

The junction interval and junction angle were added as linear attributes, as well as their power terms $[x,\ x^2,\ x^3,\ \log(x+1)]$. These transformed configuration variables were then introduced to the model to capture possible non-linear relationship between these risk factors and the accident outcomes. Additionally, dummy variables for street segment types, facilities (points), and facilities (polygons) were assigned by the presence of respective feature within a predetermined straight-line distance of each junction. The threshold distance ranged from 50 m to 200 m, depending on the type and the typical size of the feature.

In terms of the association between junction configuration and other variables, the correlation coefficient between junction interval and other variables converged between −0.17 and 0.14, and, for junction angle, between −0.13 and 0.18. This suggests that the junction configurations are unlikely to act as surrogate variables.

3.2.2. Variable Selection by Stepwise Method

Variables were selected using the stepwise method and selecting those that minimised the Akaike information criterion (AIC). As the number of light/no injury cases (19,637 records) far exceeded those of fatal/serious injury cases (3906 records), weighted logistic regression analysis was adopted to prevent AIC from expecting all accidents to be light/no injury cases. In particular, the log-likelihood for each class of the dependent variables were weighted when estimating the maximum likelihood, and the ratio of the number of minor/no injury cases to that of fatal/serious injury cases was set as the weight for the class of fatal/serious injury cases.

3.3. The Junction Configuration and the Seriousness of the Outcomes

Using the models deemed robust in the previous section, the relationship between junction configuration and the rate of fatal/serious injury cases was examined as follows:

(1) If only one of the forms of variables was selected from $[x,\ x^2,\ x^3,\ \log(x+1)]$ as the independent variable for the junction interval or the junction angle (i.e., if only one variable is selected for that junction configuration), the model has no extreme value. In such a case, the relationship between the junction configuration and the rate of fatal/serious injury cases can be determined by the regression coefficient of the junction configuration—a positive regression coefficient will yield a monotonically increasing function (i.e., the larger the junction configuration value is, the higher the rate of fatal/serious injury cases will be), and a negative regression coefficient will mean a monotonically decreasing function (i.e., the larger the junction configuration value is, the lower the rate of fatal/serious injury cases will be).

(2) If two or more the forms of variables were selected from $[x,\ x^2,\ x^3,\ \log(x+1)]$ as the independent variables for the junction interval or the junction angle, the relationship between the junction configuration and the rate of fatal/serious injury cases cannot be determined solely by the positive and negative value of the regression coefficient. Therefore, the following formula was adopted for the interpretation:

$$M(x) = \exp\left(\beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \beta_4 \log(x+1)\right) \quad (1)$$

where x is the junction interval or the junction angle and $\beta_1,\ \beta_2\ ,\beta_3,\ \beta_4$ denote regression coefficients (which may take the value of 0 if that function was not selected).

In the logistic regression model used in this study, the higher the value of $M(x)$, the higher the rate of fatal/serious injuries, and when $M(x)$ is sufficiently smaller than 1, the fatal/serious injury rate is proportional to $M(x)$. By examining what value of x returns high $M(x)$ value, we can estimate what distance between the neighbouring junctions and what angle between roads will yield the highest rate of fatal/serious injury cases. As a baseline, this study defines a road with junction interval of 50 m and the junction angle of 90 degrees as a standard junction $M(x_{st})$, and calculates $M(x)/M(x_{st})$ as the deviation rate of the respective junction.

3.4. Testing the Robustness of the Model

To ensure that the independent variables selected using the stepwise method are not overfitting the model, this study will carry out a robustness test. The method for robustness testing was determined by reviewing the relevant literature, and it builds on the approach taken by Tonkin et al. (2012) [50]. In their study, Tonkin et al. (2012) [50] prepared a set of data consisting of the training and the test component, applied receiver operating characteristic (ROC) analysis, and measured the total rea under curve (AUC) of the ROC, or the integral thereof, to examine the robustness of the model. If there is a significant difference of 5% or more between AUC for training data and AUC for test data, the model is considered as overfitting.

This study adopts a similar method and only uses, in subsequent analyses, the models that clear the robustness test. Data is divided into the training data (80%) and the test data (20%) for each accident type to verify whether the model obtained from the training data had sufficiently high accuracy to predict the test data. In the weighted logistic regression analysis, the ratio of the number of minor injury accidents to that of fatal/serious injury accidents was set as the weight for the "fatal/severe injury accidents" class. Table 4 shows the AUC of the training data and test data obtained for each accident type, and the *p*-value from the hypothesis test of AUCs. The models with an asterisk after the *p*-value are considered overfitting (5% significance of AUC), and the models in grey are not tested as they had no junction configuration variables selected in the stepwise process as their independent variable.

Table 4. AUC with training data and test data of each accident type and the *p*-value for test of AUC. The models considered overfitting (5% significance of AUC) has an asterisk next to the *p*-value, and the models greyed out did not include any junction configuration variables as its independent variable.

Junction Type	Modes of Transport Involved	Age Group	AUC with Training	AUC with Test Data	*p*-Value
Four-armed junction	Vehicle to vehicle	16–64	0.84	0.75	0.153 *
		65 and over	1	0.59	0.000 *
	Vehicle to motorcycle	16–64	0.67	0.66	0.862 *
		65 and over	0.85	0.75	0.123 *
	Vehicle to bicycle	up to 15	1	0.57	0.000 *
		16–64	0.70	0.66	0.351 *
		65 and over	-	-	-
	Vehicle to pedestrian	up to 15	0.92	0.51	0.002 *
		16–64	0.80	0.71	0.178 *
		65 and over	-	-	-
Three-armed junction	Vehicle to vehicle	16–64	0.93	0.61	0.027 *
		65 and over	-	-	-
	Vehicle to motorcycle	16–64	0.74	0.70	0.325 *
		65 and over	-	-	-
	Vehicle to bicycle	up to 15	1	0.51	0.000 *
		16–64	0.81	0.72	0.150 *
		65 and over	0.88	0.68	0.011 *
	Vehicle to pedestrian	up to 15	1	1	incalculable
		16–64	0.86	0.80	0.324 *
		65 and over	-	-	-

3.5. Likelihood Ratio Test

Existing studies on the relationship between the junction configuration and the rate of fatal/serious injury cases tend to use a single variable for each junction configuration. In cases where two or more independent variables are set for the same junction configuration, this study tests the suitability of the model using the likelihood ratio test. For each model that has two or more independent variables of the junction configuration (hereafter a full model), a model with a single independent variable of the junction configuration is built, where possible, by reducing the junction configuration variable to one and the model with the maximum likelihood (hereafter a reduced model) is used for comparison. The likelihood ratio test exploits the tendency where, under the null hypothesis that "all independent variables that exist in the full model and not in the reduced model will have a regression coefficient of 0", twice the difference of the log likelihoods of both models follows X^2 distribution with the degree of freedom that equates to the difference in the number of parameters. If the likelihood is significantly increased as a result of the analysis, it is considered that the setting of multiple variables for the junction configuration was appropriate.

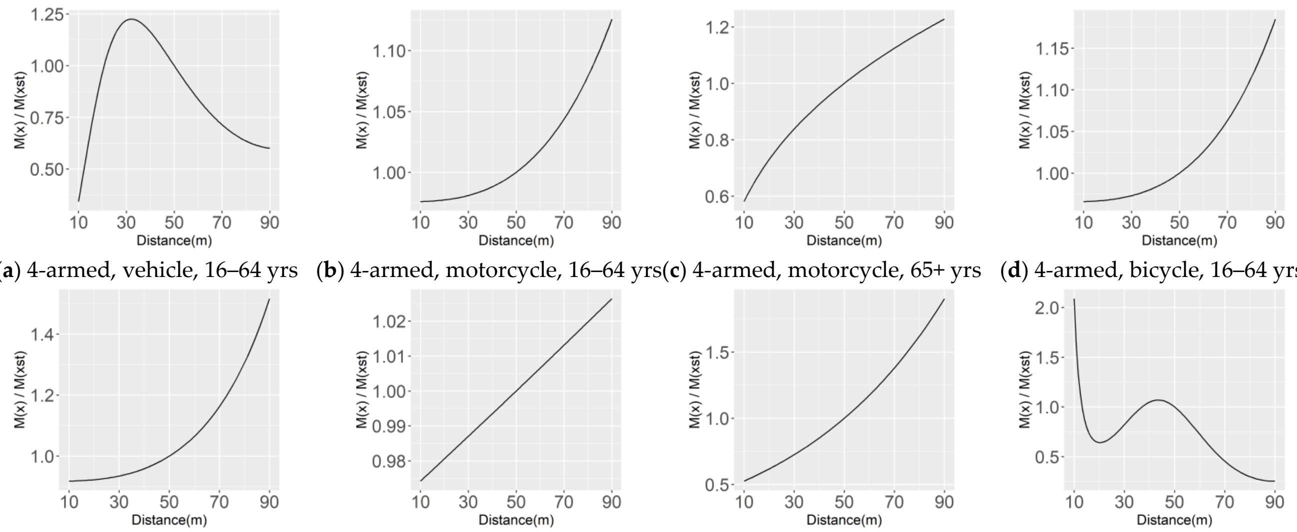
4. Results

4.1. Impact of the Junction Interval

Table 5 and Figure 4 show the results of the analysis on the relationship between the junction configuration and the rate of fatal/serious injury cases.

Table 5. The relationship between the junction interval and the rate of fatal/serious injury cases. Models that deviate from the standard monotonic increment pattern are highlighted.

Junction Type	Modes of Transport	Age Group	Relationship	Extreme Value
Four-armed junction	Vehicle to vehicle	16–64	Single Peak	Max. at 32 m
	Vehicle to motorcycle	16–64	Monotonic increase	N/A
		65 and over	Monotonic increase	N/A
	Vehicle to bicycle	16–64	Monotonic increase	N/A
	Vehicle to pedestrian	16–64	Monotonic increase	N/A
Three-armed junction	Vehicle to motorcycle	16–64	Monotonic increase	N/A
	Vehicle to bicycle	16–64	Monotonic increase	N/A
	Vehicle to pedestrian	16–64	One Peak and One Valley	Min. at 20 m Max. at 43 m
Three-/Four-armed junctions	All accidents	All age	Monotonic increase	N/A



(**a**) 4-armed, vehicle, 16–64 yrs (**b**) 4-armed, motorcycle, 16–64 yrs (**c**) 4-armed, motorcycle, 65+ yrs (**d**) 4-armed, bicycle, 16–64 yrs (**e**) 4-armed, pedestrian, 16–64 yrs (**f**) 3-armed, motorcycle, 16–64 yrs (**g**) 3-armed, bicycle, 16–64 yrs (**h**) 3-armed, pedestrian, 16–64 yrs

Figure 4. Relationship between the junction intervals and the rate of fatal/serious injury cases for each accident type corresponding to Table 5: (**a**) 4-armed junctions, vehicle-to-vehicle (victim 16–64 years old) (maximum risk at 32 m); (**b**) 4-armed junctions, vehicle-to-motorcycle (victim 16–64 years old); (**c**) 4-armed junctions, vehicle-to-motorcycle (victim 65+ years old); (**d**) 4-armed junctions, vehicle-to-bicycle (victim 16–64 years); (**e**) 4-armed junctions, vehicle-to-pedestrian (victim 16–64 years old); (**f**) 3-armed junctions, vehicle-to-motorcycle (victim 16–64 years old); (**g**) 3-armed junctions, vehicle-to-bicycle (victim 16–64 years old); and (**h**) 3-armed junctions, vehicle-to-pedestrian (victim 16–64 years old) (risks: local minimal at 20 m and local maximal at 43 m).

1. Almost all models, including the model that examined all accident types together, showed a monotonic increase of the rate of fatal/serious injury cases. This owes to the fact that, during the stepwise selection process, only the linear junction interval variable (x) came through for most accident types (and the remaining terms in the forms of x^2, x^3, $\log(x+1)$ were not adopted as the independent variable). As the regression coefficient was positive and significant (α = 0.01), the entire data increased monotonically. For this reason, we can conclude that, in general, the longer the distance between junctions, the more likely it will lead to fatal or serious injury accidents.
2. One of the two exceptions was the model for [vehicle-to-vehicle collisions at four-armed junctions with the other party aged 16–64], which followed a square curve with a single peak, reaching the highest risk at a junction interval of 32 m, and subsequently showing a distance decay.
3. The other exception was the model for [vehicle-to-pedestrian accidents at three-armed junctions with the other party aged 16–64], which followed a cubic function with one valley or the lowest risk at 20 m and one peak or the highest risk at 43 m.

Both of the two exceptions (Figure 4a,h) have their respective peak around the 30–40 m range, which, according to Figure 2, is the most frequent range of junction interval. This means, unfortunately, that the cases where adjacent junctions are separated by the most common interval are the range where the risk of fatal/serious injury outcomes is the highest for the corresponding types of traffic accidents.

4.2. Impact of the Junction Angle

Table 6 and Figure 5 show the relationship between the junction angle and the rate of fatal/serious injury cases obtained from the analysis.

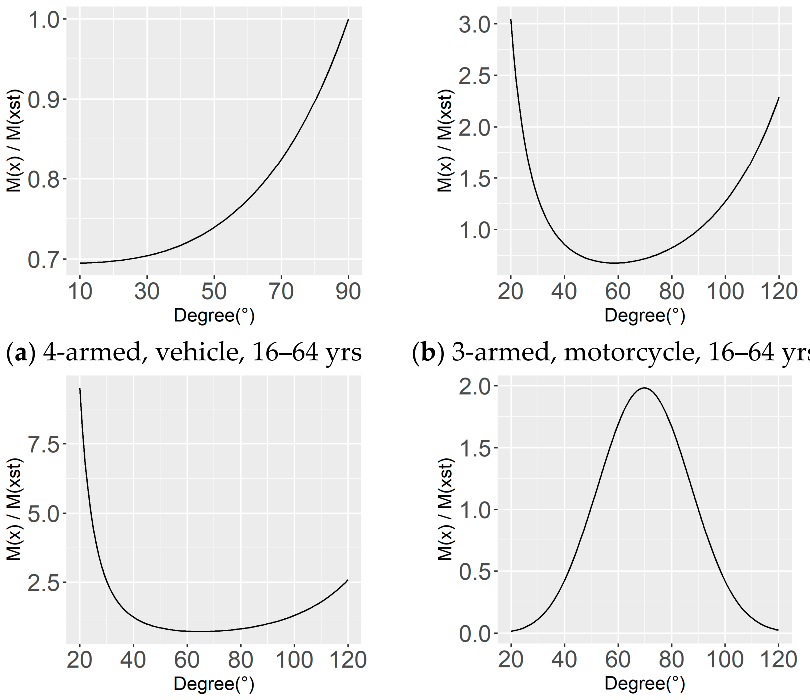
Table 6. The relationship between the minimum junction angle and the rate of fatal/serious injury cases. Models that deviate from the standard monotonic increment pattern are highlighted.

Junction Type	Modes of Transport	Age Group	Relationship	Extreme Value
Four-armed junction	Vehicle to vehicle	16–64	Monotonic increase	N/A
Three-armed junction	Vehicle to motorcycle	16–64	U-shaped curve	Min at 59°
	Vehicle to bicycle	16–64	U-shaped curve	Min at 65°
	Vehicle to pedestrian	16–64	Single peak curve	Max at 70°

As highlighted across Figure 5a–d, the results are quite mixed.

1. In the case of [vehicle-to-vehicle accidents at four-armed junctions with the other party aged 16–64], the rate of serious outcomes monotonically increases; i.e., the larger the smallest junction angle, the higher the risk of serious outcomes for the accident.
2. For the models of [vehicle-to-motorcycle accidents at three-armed junctions with the motorcyclist aged 16–64 years old] and [vehicle-to-bicycle accidents at three-armed junctions with the motorcyclist aged 16–64 years old], a U-shaped curve was derived with the lowest risk of fatal/serious accidents at the junction angles of 59 degrees and 65 degrees, respectively.
3. In contrast, in the case of [vehicle-to-pedestrian accidents at three-armed junctions with the pedestrian aged 16–64], a single-peak curve was observed with the fatal/serious injury rate reaching the maximum at 70 degrees.

According to Figure 3, the three extreme values of 59, 65, and 70 degrees are at the lower end of the distribution of junction angle for three-armed junctions. If we truncate the rare cases with smaller junction angles and consider the righthand side of the distribution only, these can be reduced to one case of a monotonic decrease and two cases of monotonic increase. The diverse and somewhat contradicting results across different accident types suggest that the results are more mixed and less conclusive for the junction angles than they were for the junction intervals, which makes it challenging to provide a safety guideline for designing a safe junction angle.



(**a**) 4-armed, vehicle, 16–64 yrs (**b**) 3-armed, motorcycle, 16–64 yrs
(**c**) 3-armed, pedestrian, 16–64 yrs (**d**) 3-armed, motorcycle, 16–64 yrs

Figure 5. Relationship between the minimum junction angle and the rate of fatal/serious injury cases for each accident type corresponding to Table 6: (**a**) 4-armed junctions, vehicle-to-vehicle (victim 16–64 years old) (monotonic increase); (**b**) 3-armed junctions, vehicle-to-motorcycle (victim 16–64 years old) (minimum risk at 59°); (**c**) 3-armed junctions, vehicle-to-bicycle (victim 16–64 years) (minimum risk at 65°); and (**d**) 3-armed junctions, vehicle-to-pedestrian (victim 16–64 years old) (minimum risk at 70°).

The mixed results are also confirmed by the analysis performed using the aggregates of all data (without distinguishing the number of arms at junction, the mode of transport or the age group) in that none of the junction angle variables were adopted during the stepwise selection and, therefore, no analysis was conducted. Instead, it suggests that no significant relationship exists between the junction angle and the rate of fatal/serious injury cases.

4.3. Likelihood Ratio Testing

Table 7 shows the results of likelihood ratio tests for models with two or more junction configuration variables. All models were significant ($\alpha = 0.05$). These results validate the decision to use multiple variables when deciding on the function that best fits the models of the junction configurations.

Table 7. Results of likelihood ratio test (* significant at $\alpha = 0.05$).

Junction Type	Modes of Transport	Age Group	Deviation	*p*-Value
Four-armed junction	Vehicle to vehicle	16–64	55.6	0.000 *
Three-armed junction	Vehicle to motorcycle	16–64	19.1	0.000 *
	Vehicle to bicycle	16–64	8.9	0.003 *
	Vehicle to pedestrian (junction interval)	16–64	17.2	0.001 *
	Vehicle to pedestrian (junction angle)	16–64	12.4	0.000 *

5. Discussion

The analyses carried out in the previous section drew several interesting patterns of associations between the types of accidents and the risks of fatal or serious outcomes for the accidents. These were highlighted across Tables 5 and 6, and Figures 4 and 5. In terms of the junction intervals (Table 5 and Figure 4), the overall tendency was that of monotonic increase; i.e., the longer the distance between the adjacent junctions, the higher the risk of serious accidents. The literature suggests that longer junction interval leads to increase in travel speed, while frequent encounter with junctions alerts the drivers to reduce speed and pay attention to the changing conditions. At the same time, there were two exceptions which would align with other reports in the literature on the challenges arising from the poor visibility at the junctions and the need to make decisions fast in a complex situation, which allegedly increases the risk of accidents—it may have been indeed disorienting and hard to see all directions for pedestrians at a three-armed junction.

As stated earlier, the two exceptions (Figure 4a,h) had their respective peaks at 32 m and 43 m, respectively, which roughly overlap with the mode of the junction intervals (Figure 2). The fact that certain types of vehicle-to-vehicle accidents and vehicle-to-pedestrian accidents reach their highest risk of fatal/serious injuries at the most common junction interval is worrying. More importantly, the overall tendency of monotonic increase for junction intervals identified in this study is in direct contradiction with the current road safety guidelines in Japan, where longer junction intervals are recommended on account of “a short interval between junctions is (considered) dangerous.”

In terms of the junction angles (Table 6 and Figure 5), the results were much more mixed, with different types of accidents returning different outcomes. The analysis using all data also found no significant relationship between the road angles at junctions and the rate of fatal/serious injury cases. While the outcomes are inconclusive, it does not support the popular consensus among the relevant literature where junctions with angles close to 90 degrees are safer and help reduce the rate of fatal/serious injury cases—a notion that aligns with another policy currently effective in the road safety guidelines in Japan. However, the outcomes from this study suggest that there is no robust argument to adhere to the current guidelines on junction angles.

There are several limitations that could be improved with follow-up studies. For instance, this study focused on the configuration of junctions and the traffic accident data from Kyoto, Japan. Applying the same research framework to datasets from other cities and regions would help improve the robustness of findings. any notable difference in the outcomes from two cites or regions would benefit a closer investigation, as they could help tease out the underlying risk factors, too. Further study on junction intervals and angles using more data across Japan would help deliver a clear set of recommendations for the road safety guidelines. In addition, given the scope of the analysis, this study adopted logistic regression modelling and pursued the broader understanding of the risks incurred by the junction intervals and junction angles. In doing so, a comprehensive set of factors were brought in for possible addition to the model. However, the dataset was missing the temporal element and the weather conditions at the time of each accident. By incorporating additional environmental and other local risk factors, we may be able to finetune the model. Finally, this study measured the risk of traffic accidents by the seriousness of the outcomes (i.e., fatal or serious injuries) and the proportion thereof. This decision was based on the priorities set by the current road safety guidelines. However, depending on the scope of the study, it may be sensible to use other criteria such as the frequency or the total count of junction traffic accidents, which would help reduce the overall volume of junction accidents. Such a decision requires further debate on what constitutes a safer road environment and urban society, and how we might best achieve it.

6. Conclusions

This study investigated how two of the main factors used for the configuration of road junctions in Japan—namely, the distance between adjacent junctions, and the angle the roads meet at junctions—affect the risks of serious accidents. Contrary to the existing safety guidelines, this study identified different patterns of risk curves across different types of accidents which could not be described by a simple monotonical increase or decrease and, in some cases, an extremum or a peak existed. The presence of such global and local extrema means that a nonlinear model would be more effective in explaining the distribution, and it may be indeed worthwhile reflecting on the current design practice of junctions in Japan in that respect. Furthermore, given that different countries and regions have different guidelines for safe junction designing, the non-linearity may be also applicable to countries other than Japan; and further studies using data from other countries would be beneficial.

As described at the beginning, traffic accidents that occur at junctions are often regarded as minor, as vehicles are considered to approach junctions at a reduced speed. Nevertheless, over 40% of fatal or serious traffic accidents occur around junctions, and reducing this risk is a priority for building a safer and sustainable society. In this sense, findings from this study contribute to the current debate over the junction intervals and the junction angles by offering useful evidence for reviewing the existing design standards for junctions.

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