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Optimized design of roadside trees based on the risk analysis of occupant injuries in traffic accidents

R. Cheng Y. Pan Y. Huang Q. Xu

Guangxi Key Laboratory of ITS (Guilin University of Electronic Technology), Education Department of Guangxi Zhuang Autonomous Region. Guilin 541004, China
email: xuqi@guet.edu.cn

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Abstract

To reduce occupant injuries in collisions between vehicles and roadside trees, this paper introduces the acceleration severity index (ASI) as an indicator of occupant injury risks and uses the vehicle dynamics simulation software PC-crash to carry out offset crash tests of vehicles and trees along the roadside. The recommended diameter of roadside trees with the minimum ASI is given by collecting various ASI data corresponding to different vehicle departure speeds and slope gradients, and the multivariate models of vehicle departure speeds, slope gradients and diameters of roadside trees, as well as the minimum ASI, are fitted. In the case of the minimum ASI >1, by further adjustment of the diameter of roadside trees, the calculation method of the distance to trees is proposed, and the optimized design schemes of the roadside tree diameter and spacing with the minimum ASI ≤1 for different vehicle departure speeds and slope gradients are given. The results show that the vehicle departure speed is positively logarithmic to the recommended diameter of roadside trees and is positively exponential to the minimum ASI. The slope gradients are approximately positively linearly correlated with the tree recommended diameter and minimum ASI. When the slope gradients are 1:6.5~1:3.5 with a vehicle departure speed of 100 km/h~120 km/h, when the slope gradients are 1:2.5 with a vehicle departure speed of 90 km/h~120 km/h, and when the slope gradients are 1:1.5 with a vehicle departure speed of 80 km/h~120 km/h, the corresponding minimum ASI >1, which indicates that the severity of roadside accidents exceeds the limit that an occupant can endure.

Keywords – roadside tree, diameter and spacing, acceleration severity index, PC-crash, roadside accident

1. Introduction

According to accident investigations and statistical analysis, among the various kinds of road traffic accidents, many collisions between vehicles and roadside trees are attributed to drunk driving, distracted driving or untimely steering, and most of the involved vehicles are cars. Roadside trees, as roadside protection facilities, have a role in greening. However, frequent substantial losses due to vehicle collision with roadside trees cause them to become roadside hazards due to their large growth diameter [12]. To improve driving safety, researchers have been committed to exploring the relationship between roadside accident risk and roadside trees. For example, in terms of the severity of road accidents, Roque et al. [19] collected traffic accident data and concluded that the damage degree of collision between vehicles and trees was twice that of collision with other dangerous objects. Holdridge et al. [10] used a nested logit model to confirm that planting larger-sized trees on both sides of the road tended to lead to fatal roadside accidents. Therefore, Ayati et al. [5] selected roadside trees as an accident risk indicator and constructed a roadside accident severity assessment model based on evidence reasoning. Wu et al. [22] incorporated indices such as roadside tree density, roadside tree spacing and roadside depth into a roadside safety comprehensive evaluation system and determined the roadside safety evaluation standard based on classical set theory. By analyzing the data from two lane rural highways in India, Bandyopadhyaya et al. [6] observed that accident loss has distinct relationship with the road geometry features including distance to off shoulder hazards (e.g. tree), carriageway width, and shoulder width.

In terms of the causes of roadside accidents, Lee et al. [13] analyzed the relationship between the frequency of roadside accidents and roadside characteristics and concluded that the reduction of roadside trees can significantly reduce the incidence of roadside accidents. In addition, Park et al. [17] discovered that increasing the spacing of roadside trees could help reduce the number of roadside accidents by constructing a multiple adaptive regression spline model and generalized nonlinear model. Jalayer et al. [11] proposed that if protective measures are arranged around dangerous objects such as poles and trees, roadside accidents can be effectively reduced by more than 38%. Fitzpatrick et al. [8] utilized a driving simulator to explore the influence of roadside vegetation density on vehicle lateral offset and driver speed selection.

In summary, the relationship between the number, density and spacing of roadside trees and the number and severity of roadside accidents has been analyzed worldwide. However, research on how to design roadside trees to minimize the loss of roadside accidents is still lacking. The author believes that although the setting of roadside trees is contrary to the "tolerant design concept" proposed in the AASHTO roadside design guide [3], based on the notion that roadside trees are widely planted on both sides of roads in China, if roadside trees can have a protective effect similar to guardrails, the existence of roadside trees can effectively prevent runaway vehicles from falling into deep ditches or rivers along sections with steep slopes or gullies on both sides. Therefore, the above views can be regarded as a kind of "seeking advantages and avoiding disadvantages" premise.

Notably, to reduce the loss of collisions between vehicles and roadside fixtures, many researchers have carried out the optimal design of roadside fixtures, such as adopting disassembly energy dissipation measures for roadside lamp poles, line poles and metal fixtures to absorb the energy generated at the moment of collision with vehicles, which can have a good buffering role and reduce accident losses [14, 17, 20]. Therefore, with the above research ideas, if the diameters of roadside trees are properly selected, they can also have a good protective role for runaway vehicles. Actual accident research [4, 23] indicates that when there are deep ditches or rivers on both sides of a road, if the diameters of the roadside trees are too small, runaway vehicles will easily break the trees. Although the collision loss is slight, the vehicles moving forward will eventually rollover or fall, resulting in numerous casualties, so that the loss caused by vehicle rollover is much greater than that caused by collision with roadside obstacles. If the diameters of roadside trees are too large, the collision between runaway vehicles and trees is equivalent to collision with rigid solids, which will still lead to substantial losses. Therefore, to realize the protective effect of roadside trees, further research should be carried out on their diameter design. Considering the high risk of tests involving real vehicles, this paper uses PC-crash simulation software to conduct repeated crash tests between cars and roadside trees with different diameters under the conditions of different departure speeds and road slope gradients and introduces the acceleration severity index (ASI) as a passenger injury risk index to obtain the diameters of roadside trees that can minimize the ASI value. The recommended values of roadside tree diameter and spacing that can ensure an ASI value ≤ 1 are given. The research results can provide guidance for the highway traffic management departments to optimize the design of roadside trees and reduce the losses of roadside accidents.

2. Research variables

2.1. Test parameters

Before the crash test, each test parameter needs to be determined. According to the relevant provisions of China's Code for Highway Alignment Design (JTG D20-2017) [16], the value range for slope gradient, vehicle departure speed and diameter of roadside trees is shown in Table 1.

In addition, the angle at which a vehicle deviates from the travel lane after losing control has a certain impact on the severity of roadside accidents. Notably, many factors determine the angle of the vehicle leaving the lane. As there is currently no relevant research in China, according to the statistical data of roadside accidents in the European "RISER" program, there is a close relationship between the vehicle departure speed and the exit angle in actual roadside accident cases, as shown in Fig. 1 [18]. According to the fitted curves in the figure, exit angles corresponding to different departure speeds can be approximately estimated.

Considering that the height of trees will also affect the severity of roadside accidents, it is necessary to set the height of trees. According to the literature [21], the relationship between the height of a roadside tree and the diameter of a roadside tree is expressed as follows:

$$H = 32.7008e^{\frac{-8.7297}{D}} \tag{1}$$

where H is the height of the roadside tree, m, and D is the diameter of the roadside tree, cm.

2.2. Occupant injury risk index

The acceleration severity index (ASI) is an index used in the European Standard EN 1317-2-1998 to measure the risk of occupant injury during vehicle collision. The ASI has a dimension of 1, and the larger the ASI value is, the more serious the occupant injury is. When ASI>1, it indicates that the accident collision intensity exceeds the maximum tolerance of the human body.

Tab. 1 - Experimental parameters

Test parameters	Values								
Slope gradient	1:6.5		1:5.5		1:4.5	1:3.5	1:2.5		1:1.5
Departure speed (km/h)	40	50	60	70	80	90	100	110	120
Diameter of roadside tree (cm)	5~35								

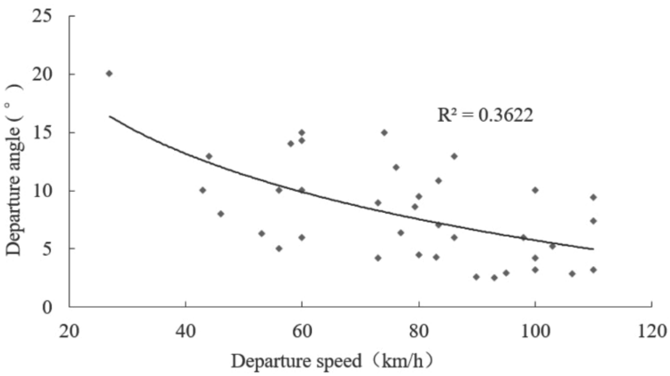


Fig. 1 - Relationship between the departure speed and the departure angle

The ASI is calculated as follows [7]:

$$\mathrm{ASI}(t) = \sqrt{(\bar{a}_x/\hat{a}_x)^2 + (\bar{a}_y/\hat{a}_y)^2 + (\bar{a}_z/\hat{a}_z)^2} \tag{2}$$

where t is the time, s, $\hat{a}_x$, $\hat{a}_y$ and $\hat{a}_z$ are the maximum acceleration tolerance values of the occupant in the longitudinal, transverse and vertical directions, respectively. When drivers and passengers wear safety belts, $\hat{a}_x$ is 12 g, $\hat{a}_y$ is 9 g and $\hat{a}_z$ is 10 g (g = 9.8 m/s^2); $\bar{a}_x$, $\bar{a}_y$ and $\bar{a}_z$ are the maximum values of the 50 ms interval average values of the longitudinal, transverse and vertical accelerations, respectively, of the vehicle centroid position, which can be obtained by low-pass filtering through the vehicle acceleration curves obtained from the crash test. Their calculation formula is expressed as follows [9]:

$$\bar{a}_x = \frac{1}{\omega}\int_t^{t+\omega} a_x \mathrm{d}t \text{，} \quad \bar{a}_y = \frac{1}{\omega}\int_t^{t+\omega} a_y \mathrm{d}t \text{，} \quad \bar{a}_z = \frac{1}{\omega}\int_t^{t+\omega} a_z \mathrm{d}t \tag{3}$$

where a_x, a_y and a_z are the longitudinal, transverse and vertical accelerations, respectively, of the vehicle centroid, and ω is the time interval, which is 50 ms.

3. Simulation test

3.1. Test scenario

As a traffic accident simulation software, PC-crash is widely employed in crash testing and accident modeling. In this paper, PC-crash software is used to establish a two-way, two-lane road model with a subgrade height of 5 m, lane width of 3.75 m and hard shoulder width of 1.5 m. Considering that the number of roadside accidents involving cars is relatively frequent, the collision simulation between cars and trees are carried out. The BMW-116d automobile is selected as the representative model of car, and the tree rigid body model is selected as the road tree model. The tree diameter and tree height can be set by adjusting the parameters of length, width and height of the tree rigid body model. In addition, according to the Code for Urban Road Greening Planning and Design (CJJ75-97) [2], the minimum planting distance of roadside trees is 4 m, and the minimum distance from the center of the tree trunk to the outside of the curb should be 0.75 m. Considering that roadside trees should provide timely and effective protection for vehicles leaving the road, the above values are selected to set the tree model in this test, and the constructed simulation scene is shown in Fig. 2.

Fig. 2 - Test scene

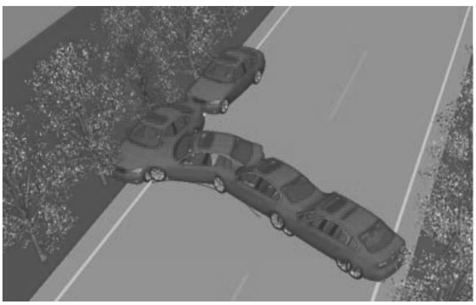
The longitudinal acceleration and transverse acceleration characteristic curves of the car can be obtained by using PC-crash software, and the corresponding ASI value can be calculated according to Formulas (2) and (3). In addition, an investigation of numerous roadside tree collision accidents reveals that the vehicle collision parts are mainly in the front middle and right side, and a front right side collision with the road tree is more common. Therefore, this paper mainly carries out the offset collision test for a collision between the front right side of the car and the roadside tree.

3.2. Test process

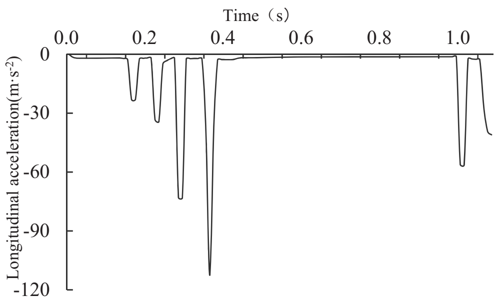
Under the conditions of different departure speeds and slope gradients, repeated crash tests were carried out by adjusting the diameters of roadside trees. The three common collision forms in the test process are described as follows:

(1) When the test vehicle drove into the 1:5.5 slope at a speed of 80 km/h and at an angle of 8° with the carriageway and then had an offset collision with the roadside tree with a diameter of 25 cm and a tree height of 23 m, the motion trajectory and longitudinal acceleration curve of the test vehicle are as shown in Fig. 3 (a) and Fig. 3 (b), respectively. As shown in Fig. 3 (a), the test vehicle did not pass through the tree model after the collision but rebounded to the left and rear, and the motion trajectory was consistent with the operation law of the vehicle during offset collision. According to Fig. 3 (b), the maximum longitudinal acceleration in the collision process is -110.57 m/s^2, and the corresponding ASI is 1.32. These results show that the test vehicle collided with the above size tree model without breaking the tree, and its collision strength exceeded the limit that the occupants can bear.

(2) Other test parameters remain unchanged. If the test vehicle collided with a roadside tree with a diameter of 10 cm and a tree height of 14 m, the motion trajectory and longitudinal acceleration curve of the test vehicle are as shown in Fig. 4 (a) and Fig. 4 (b), respectively. Fig. 4 (a) shows that the test vehicle crossed the tree model after collision and then rolled into the slope. According to Fig. 4 (b), when t= 0.47 s, the maximum longitudinal acceleration generated by the collision between the test vehicle and the roadside tree is 36.72 m/s^2, and the corresponding ASI is 0.31. When t= 1.86 s, the maximum longitudinal acceleration generated by rolling of the test vehicle is 105.38 m/s^2, and the corresponding ASI is 1.27. These result shows that once the vehicle breaks the tree and drives into the slope, the impact force caused by the rolling is obviously greater than that caused by the collision between the vehicle and the above size roadside tree, which often leads to more substantial accident losses.

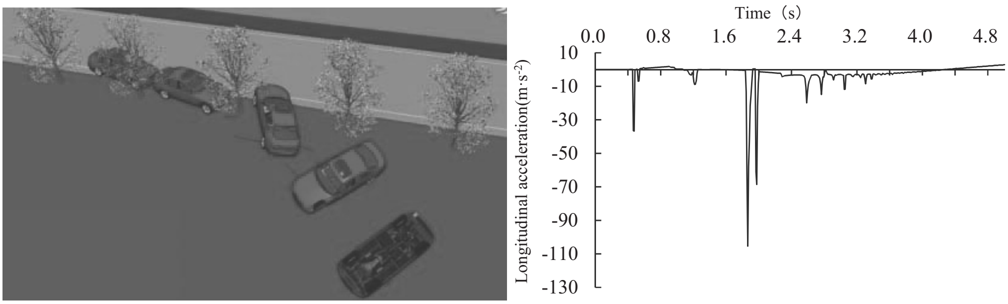


(a) Vehicle collision process



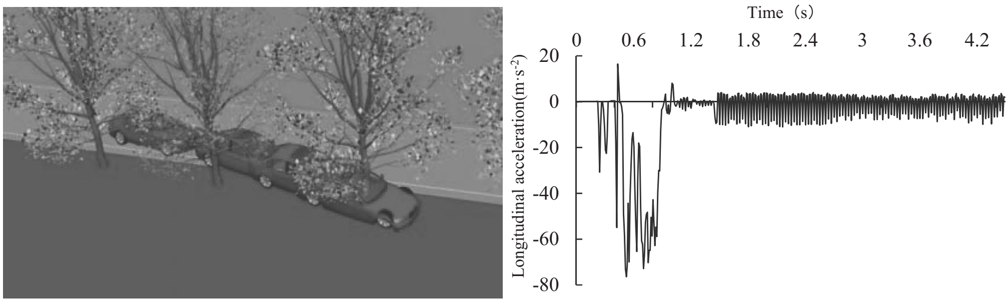
(b) Vehicle longitudinal acceleration curve

Fig. 3 - First collision type



(a) Vehicle collision process (b) Vehicle longitudinal acceleration curve

Fig. 4 - Second collision type



(a) Vehicle collision process (b) Vehicle longitudinal acceleration curve

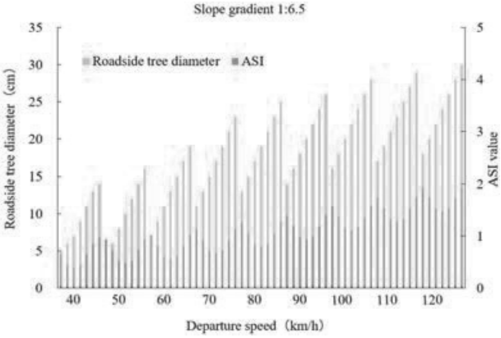
Fig. 5 - Third collision type

(3) Other test parameters remain unchanged. If the test vehicle collided with a roadside tree with a diameter of 20 cm and a tree height of 21 m, the motion trajectory and longitudinal acceleration curve of the test vehicle are shown in Fig. 5 (a) and Fig. 5 (b), respectively. As shown in Fig. 5 (a), the protective effect of roadside trees can intercept the test vehicle (equivalent to the actual accident situation where the vehicle breaks off the tree and then gradually stops), thus avoiding the rollover of the test vehicle when it continues to move forward. According to Fig. 5 (b), the overall longitudinal acceleration tends to decrease during the whole collision process. When the front part of the test vehicle just starts to collide with the tree model, the longitudinal acceleration is large, the maximum value is 71.6 m/s^2, and the corresponding ASI value is 0.87, corresponding to the period before t = 1.2 s. As the test vehicle continues to move forward, due to the buffering and damping effects of the tree model, the test vehicle gradually stops, and the longitudinal acceleration decreases and gradually tends to fluctuate within a small range, corresponding to the period after t = 1.2 s. According to the above analysis, although the roadside tree of the above size can intercept the test vehicle and the ASI value is ≤1, it cannot guarantee that the corresponding ASI value is the minimum value.

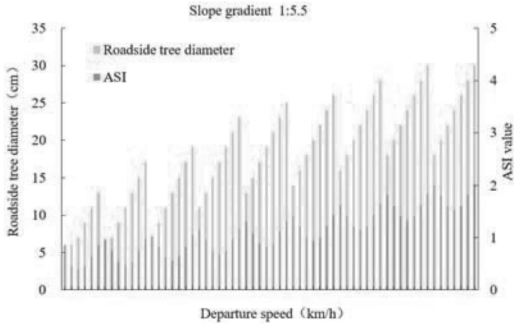
4. Test results

4.1. Results analysis

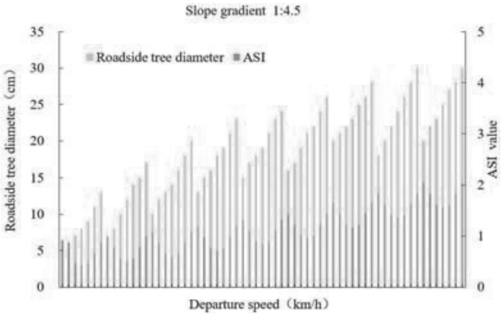
To obtain the roadside tree diameter that can guarantee the minimum ASI value under different traffic conditions, according to the test method in Section 3.2, repeated collision tests were conducted by setting different departure speeds, slope gradients and roadside tree diameters. A total of 378 collision data were collected, as shown in Fig. 6.



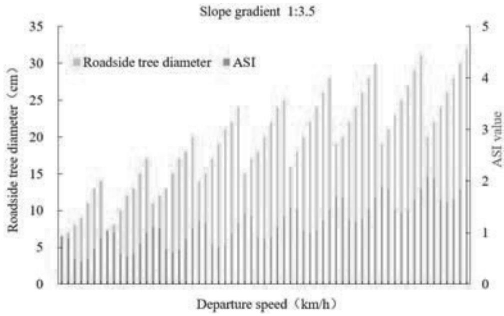
(a) Relationship between roadside tree diameter, ASI value and departure speed in case of slope gradient 1:6.5



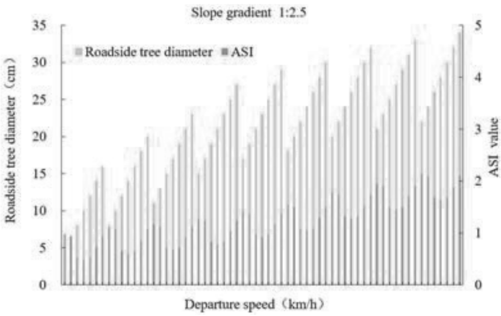
(b) Relationship between roadside tree diameter, ASI value and departure speed in case of slope gradient 1:5.5



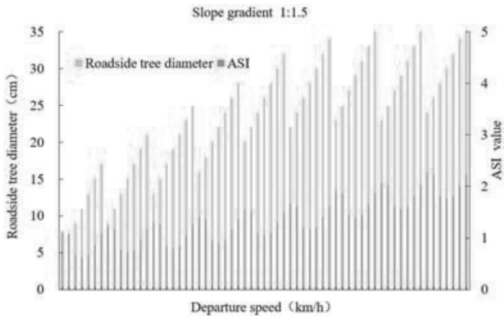
(c) Relationship between roadside tree diameter, ASI value and departure speed in case of slope gradient 1:4.5



(d) Relationship between roadside tree diameter, ASI value and departure speed in case of slope gradient 1:3.5



(e) Relationship between roadside tree diameter, ASI value and departure speed in case of slope gradient 1:2.5



(f) Relationship between roadside tree diameter, ASI value and departure speed in case of slope gradient 1:1.5

Fig. 6 - Test data

As shown in Fig. 6, with an increase in departure speed and slope gradient, the diameter and ASI value of roadside trees generally showed a rising trend, and compared with the slope gradient, departure speed had a more significant impact on the test results. In addition, with an increase in roadside tree diameter, the corresponding ASI value decreased and then increased under various experimental conditions. Therefore, according to Fig. 6, the recommended roadside tree diameter that ensures the minimum ASI value for different departure speeds and slope gradients, as well as the corresponding ASI value, can be preliminarily screened.

To achieve quantitative analysis of recommended roadside tree diameter and more accurate and intuitive research results, it is necessary to further explore the relationship model between the departure speed, slope gradient, and recommended roadside tree diameter and the minimum ASI value. According to the results shown in Fig. 6, a preliminary analysis of the relationship between each variable should be carried out. The results are detailed as follows.

(1) Relationship between the departure speed and the recommended tree diameter

By analyzing the relationship between departure speed and the recommended value of roadside tree diameter (as shown in Fig.7), it can be concluded that departure speed is approximately positively logarithmically correlated with the roadside tree diameter, that is, with an increase in departure speed, the recommended value of roadside tree diameter gradually increases, but the increase in amplitude decreases.

(2) Relationship between the slope gradient and the recommended tree diameter

By analyzing the relationship between slope gradient and recommended value of roadside tree diameter (as shown in Fig. 8), it can be concluded that slope gradient and recommended value of roadside tree diameter are approximately positively linear, that is, with an increase in slope gradient, the recommended value of roadside tree diameter presents an overall increasing trend.

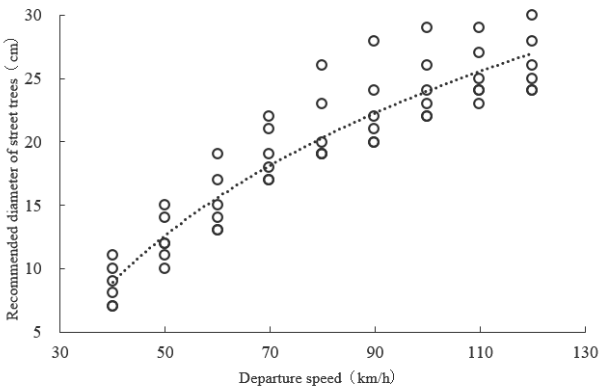


Fig. 7 - Relationship between the departure speed and the recommended diameter of trees

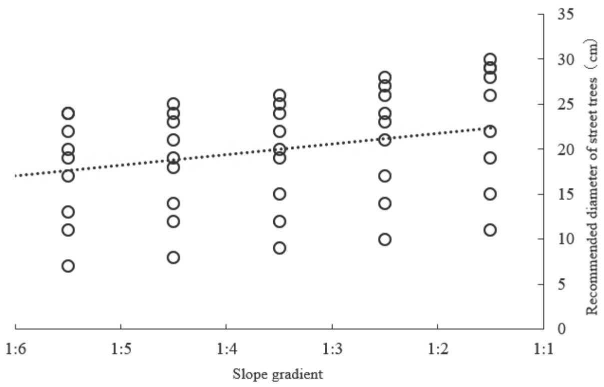


Fig. 8 - Relationship between the slope gradient and the recommended tree diameter

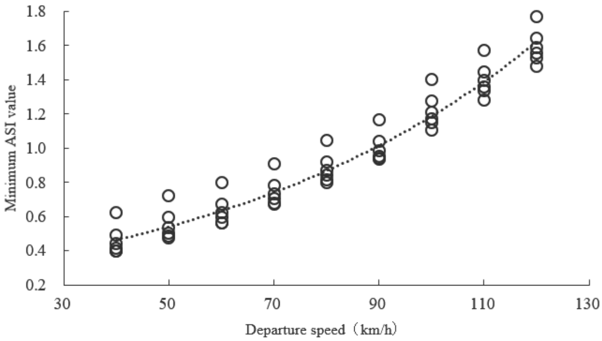


Fig. 9 - Relationship between the departure speed and the minimum ASI

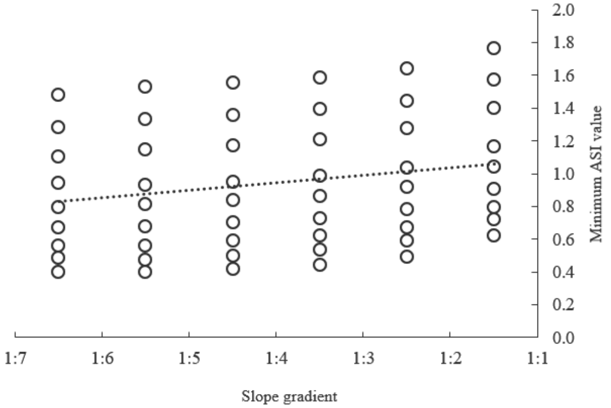


Fig. 10 - Relationship between the slope gradient and the minimum ASI

(3) Relationship between the departure speed and the minimum ASI value

By analyzing the relationship between departure speed and the minimum ASI value (as shown in Fig. 9), it can be concluded that departure speed and the minimum ASI value are approximately and exponentially positively correlated, that is, with an increase in departure speed, the minimum ASI value gradually increases, and the increase range becomes increasingly larger.

(4) Relationship between the slope gradient and the minimum ASI value

By analyzing the relationship between the slope gradient and the minimum ASI value (as shown in Fig. 10), it can be seen that the slope gradient is approximately positively correlated with the minimum ASI value, that is, with an increase in the slope gradient, the minimum ASI value shows an overall increasing trend.

4.2. Model building

According to the analysis of the recommended values of departure speed, slope gradient and roadside tree diameter in Fig. 7 and Fig. 8, it is preliminarily determined that the relationship model of the three variables should be a combination of logarithmic function and linear function. Therefore, SPSS software was selected in this paper to conduct regression analysis of the test data. By comparing the correlation coefficients of functions under different linear conditions, the optimal expression of the recommended value model of roadside tree diameter was determined as follows:

$$D_S = 16.456\ln(v) + 0.22N - 56.696 \quad (4)$$

where D_S is the recommended diameter of the roadside tree (cm), v is the vehicle departure speed (km/h), and N is the slope gradient (°).

The above model shows that the recommended value of roadside tree diameter has a binary nonlinear relationship with departure speed and slope gradient and that the goodness of fit R^2 of the model is 0.982. According to the analysis of departure speed, slope gradient and minimum ASI value shown in Fig. 9 and Fig. 10, it is preliminarily determined that the relationship model of the three variables should be a combination of exponential function and linear function. SPSS software was also selected for regression analysis of the data, and the optimal expression of the minimum ASI value model was determined as follows:

$$\mathrm{ASI}_{\min} = 8.866\times10^{-5}v^2 + 0.009N + 0.159 \quad (5)$$

where $\mathrm{ASI}_{\min}$ is the minimum ASI value.

The above model shows that the minimum ASI value has a binary quadratic nonlinear relationship with departure speed and slope gradient and that the goodness of fit R^2 of the model is 0.987. According to Model (4), the recommended values of roadside tree diameter corresponding to different departure speeds and slope gradients can be accurately calculated. However, as shown in Fig. 6, Fig. 9 and Fig. 10, with an increase in departure speed and slope gradient, the minimum ASI value corresponding to the recommended values of some roadside tree diameters exceeds 1, that is, accident severity exceeds the limit that passengers can tolerate. The reason is that the rigidity of the roadside tree model is too large due to its large size. Therefore, it is still necessary to adjust the diameter of the roadside tree to make its ASI value ≤1 based on the calculation results of Model (4). However, the reduction in the diameter of the roadside tree will lead to the test car directly crossing the tree model, which will lead to a rollover accident. Therefore, it should be guaranteed that the second adjacent roadside tree can intercept the test car moving forward and make the ASI value ≤1 in the whole collision process. Further consideration should be given to setting the diameter and spacing of roadside trees.

4.3. Optimization scheme of roadside tree setting

Let Model (5)>1; it is calculated that when the slope is 1:6.5~1:3.5, the departure speed is 100 km/h~120 km/h; when the slope is 1:2.5, the departure speed is 90 km/h~120 km/h; and when the slope is 1:1.5 and the departure speed is 80 km/h~120 km/h, the corresponding minimum ASI value is >1. The following scenario shall be adjusted according to the setting scheme of roadside trees under the above test conditions. According to the crash test, the direction of the test car will not change much after it passes the first roadside tree. Therefore, to ensure that the second roadside tree can be stopped by the test vehicle, the maximum distance L'_{max} allowed between the vehicle and the roadside tree in the offset collision should be greater than the maximum distance L_{max} allowed between the front middle position of the vehicle and the roadside tree in the collision, as shown in Fig. 11. Therefore, to ensure that vehicles in two collision modes can be intercepted by the second roadside tree, the distance between roadside trees should be calculated according to L_{max} as follows:

$$L_{\max} = \frac{W - D}{2\sin\alpha} \quad (6)$$

where L_{max} is the maximum allowable roadside tree spacing (m); W is the width of the car (m), 1.8 m; D is the diameter of the roadside tree (m); and α is the vehicle exit angle (°).

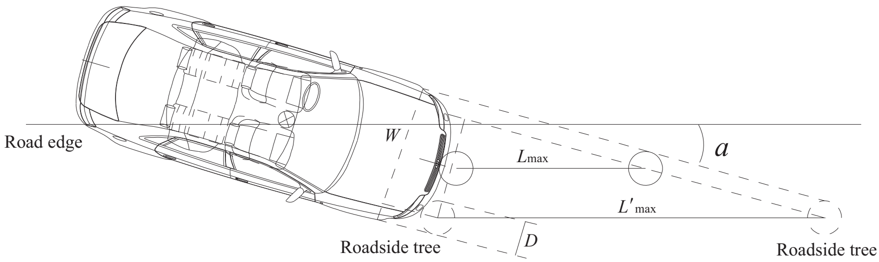


Fig. 11 - Allowed maximum spacing of trees

Tab. 2 - Setting scheme of the tree diameter and spacing (Unit: m)

Slope	Running speed of outermost lane (km/h)								
	40	50	60	70	80	90	100	110	120
1:6.5	0.06 (*L*≥4)	0.10 (*L*≥4)	0.13 (*L*≥4)	0.15 (*L*≥4)	0.17 (L≥4)	0.19 (*L*≥4)	0.18 (7.75≥*L*≥4)	0.19 (9.29≥*L*≥4)	0.20 (9.18≥*L*≥4)
1:5.5	0.06 (*L*≥4)	0.10 (*L*≥4)	0.13 (*L*≥4)	0.15 (*L*≥4)	0.18 (*L*≥4)	0.20 (*L*≥4)	0.18 (7.75≥*L*≥4)	0.19 (9.29≥*L*≥4)	0.20 (9.18≥*L*≥4)
1:4.5	0.07 (*L*≥4)	0.11 (*L*≥4)	0.14 (*L*≥4)	0.16 (*L*≥4)	0.18 (*L*≥4)	0.20 (*L*≥4)	0.19 (7.75≥*L*≥4)	0.20 (9.18≥*L*≥4)	0.21 (9.18≥*L*≥4)
1:3.5	0.08 (*L*≥4)	0.11 (L≥4)	0.14 (*L*≥4)	0.17 (*L*≥4)	0.19 (*L*≥4)	0.21 (*L*≥4)	0.20 (7.65≥*L*≥4)	0.20 (9.18≥*L*≥4)	0.22 (9.06≥*L*≥4)
1:2.5	0.09 (*L*≥4)	0.13 (*L*≥4)	0.16 (*L*≥4)	0.18 (*L*≥4)	0.20 (*L*≥4)	0.20 (6.56≥*L*≥4)	0.19 (7.65≥*L*≥4)	0.21 (9.06≥*L*≥4)	0.23 (9.06≥*L*≥4)
1:1.5	0.12 (*L*≥4)	0.16 (*L*≥4)	0.19 (*L*≥4)	0.21 (*L*≥4)	0.17 (5.75≥*L*≥4)	0.18 (6.56≥*L*≥4)	0.20 (7.65≥*L*≥4)	0.22 (9.06≥*L*≥4)	0.24 (8.95≥*L*≥4)

Note: values without brackets are tree diameter; values within brackets are tree spacing, its minimum spacing is selected according to the provisions of Code for Planning and Design of Urban Road Greening (CJJ75-97) [2].

By further adjusting the diameter of the roadside tree, repeated collision tests were carried out under the test conditions with a minimum ASI value >1. Combined with the calculation results of Model (4) and Formula (6), the design scheme of roadside tree diameter and spacing that can ensure the minimum ASI value ≤1 in the whole collision process was determined, as shown in Table 2. Considering that the departure speeds of vehicles should not be selected as the standard design speed, and that in general, vehicles leaving the exit lane run on the outside lane, the running speed of the outermost lane is set as the speed of a vehicle leaving the lane, as shown in Table 2.

5. Discussion

To verify the effectiveness of the proposed scheme, this paper select 10 typical roadside accidents involving car speed, slope gradient, tree diameter and tree spacing. As can be seen from Table 3, for accidents 1, 3, 5, 7 and 8, the diameter and spacing of roadside trees are in the general range of Table 2 under the conditions of corresponding departure speeds and slope gradients, leading to minor or moderate consequences, with ASI less than 1. On the contrary, for accidents 2, 4, 6, 9 and 10, the diameter or spacing of roadside trees is not in the range of Table 2, That results in serious or fatal consequences, corresponding to ASI greater than 1. Therefore, the effectiveness of the proposed scheme can be validated.

Tab. 3 - Analysis of typical cases

No.	Departure speed (km/h)	Slope gradient	Tree diameter (m)	Tree spacing (m)	Accident Severity
1	63	1:6.5	0.14	6.0	Minor
2	81	1:4.5	0.30	7.3	Fatal
3	55	1:2.5	0.15	4.0	Minor
4	60	1:1.5	0.26	5.1	Serious
5	99	1:6.5	0.18	6.6	Moderate
6	72	1:4.5	0.33	8.4	Serious
7	68	1:5.5	0.14	5.0	Minor
8	91	1:2.5	0.20	6.5	Moderate
9	100	1:3.5	0.16	10.0	Fatal
10	80	1:3.5	0.25	5.8	Fatal

By reviewing the research results of this paper, we conclude a positive exponential correlation between the departure speed and the minimum ASI, which is consistent with most of the other researches. For example, in literature [1], speed is positively and exponentially correlated with accident severity; At the same time, we also obtain a positive linear correlation between slope gradient and the minimum ASI, which conforms to relevant provisions of the AASHTO roadside design guide [3] and the China's Specifications for Highway Safety Audit (JTG B05-2015) [15]. However, other valuable research results proposed in this paper have not been found in previous literature, including the quantitative design of roadside tree diameter and spacing to reduce accident injuries, which breaks through the macroscopic qualitative analysis of roadside tree diameter in previous studies.

Whereas, this paper did not carry out the trend analysis between the tree spacing and the severity of accidents as described in the literature [17] and [22]. In addition, we did not consider the influence of tree strength on accident consequences on account of the limitations of PC-crash software either. These will be the research directions in the future.

6. Conclusion

Selecting ASI as the occupant injury risk index, under the conditions of different departure speeds and slope gradients, the repeated collision test between a car and roadside trees with different diameters is carried out by using PC-crash simulation software. The recommended value model of roadside tree diameter and the corresponding minimum ASI value model are constructed, and the optimal design scheme of the diameter and spacing of roadside trees corresponding to different running speeds and slope gradients is given and verified.

The research results provide guidance and a reference for highway traffic management departments to optimize the design of roadside trees in the future. For example, for roads with roadside trees planted on the side of the road, the running speed of the outermost lane can be determined according to Table 2 by measuring the diameter, spacing and slope gradient of the roadside trees, and then the corresponding speed limit measures can be proposed based on the design speed of a road section. For newly built or rebuilt highways, the appropriate diameter and spacing of roadside trees can be determined according to the slope gradient and road running speed according to Table 2, and then the appropriate varieties can be selected for planting based on the diameters of different types of adult trees.

Although this research has made some innovative achievements, there are still the following deficiencies. For example, in view of the limitation of the PC-crash simulation software, the influence of the intensity of roadside trees on accident severity cannot be considered. Therefore, we plan to combine with finite element software in further research, and carry out accident collision analysis under different tree strength by building models with different materials.

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References

1. Aarts, L., Van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis & Prevention*, 38(2), pp. 215-224.
2. Academy of Urban Planning & Design of China (1997), *Code for Urban Road Greening Planning and Design (CJJ75-97)*, AUPDC, Beijing.
3. American Association of State Highway and Transportation Officials (2012). *Roadside design guide (fourth edition)*, AASHTO, Washington D. C.
4. Armah Z, A., Wiafe, I., Koranteng F, N,. Owusu, E. (2022). Speed monitoring and controlling systems for road vehicle safety: a systematic review. *Advances in Transportation Studies: an international Journal*, 56(4), pp. 3-22.
5. Ayati, E., Asghar S, A., Moghaddam A, M., et al. (2005). Introducing roadside hazard severity indicator based on evidential reasoning approach. *Safety Science*, 50(7), pp. 1618-1626.
6. Bandyopadhyaya, R., Ujjwal, J. (2018). A guideline for assessment of level of service of safety for two lane rural highways using road and roadside features. *Advances in Transportation Studies: an international Journal*, 45, pp. 33-42.
7. EN. *Road restraint systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers*. 1998.
8. Fitzpatrick C, D., Harrington C, P., Knodler Jr, M. A., et al. (2014). The influence of clear zone size and roadside vegetation on driver behavior. *Journal of Safety Research*, 49, pp. 91-97.
9. Guozhu, C., Rui, C., Yulong, P., Liang, X., Weiwei, Q. (2020). Severity Assessment of Accidents Involving Roadside Trees Based on Occupant Injury Analysis. *PLoS One*, 15(4): e0231030, doi: 10.1371/journal.pone.0231030.
10. Holdridge J, M., Shankar V, N., Ulfarsson G, F. (2005). The crash severity impacts of fixed roadside objects. *Journal of Safety Research*, 36(2), pp. 139-147.
11. Jalayer, M., Zhou, H. (2013). Evaluating the safety risk of roadside features for rural two-lane roads using reliability analysis. *Accident Analysis & Prevention*, 93, pp. 101-112.
12. Kutela, B., Avelar R, E., Geedipally S, R. (2012). Prediction of occurrence and severity of run-off-roadway crashes on rural two-lane roadways using Bayesian networks. *Transportation Research Record*, 2676(3), pp. 371-384.
13. Lee, J., Mannering, F. (2005). Impact of roadside features on the frequency and severity of run-off-roadway accidents: an empirical analysis. *Accident Analysis & Prevention*, 34(2), pp. 149-161.
14. Lord, D., Brewer M, A., Fitzpatrick, K., et al. *Analysis of roadway departure crashes on two lane rural roads in Texas*. Texas Transportation Institute, 2011.
15. Ministry of Transport of the People's Republic of China (2015), *Specifications for Highway Safety Audit (JTG B05-2015)*, MTPRC, Beijing.

16. Ministry of Transport of the People's Republic of China (2017), *Design Specification for Highway Alignment (JTG D20-2017)*, MTPRC, Beijing.
17. Park, J., Abdel-Aty, M. (2015). Assessing the safety effects of multiple roadside treatments using parametric and nonparametric approaches. *Accident Analysis & Prevention*, 83, pp. 203-213.
18. RISER. (2005). *Guidelines for Roadside Infrastructure on New and Existing Roads*, Roadside Infrastructure for Safer European Roads, Deliverable 6. 5th Research Framework Programme "Growth", European Commission, Brussels.
19. Roque, C., Jalayer, M. (2018). Improving roadside design policies for safety enhancement using hazard-based duration modeling. *Accident Analysis & Prevention*, 120, pp. 165-173.
20. Wang X, H. (2022). Traffic accident data classification algorithm based on decisión tree. *Advances in Transportation Studies: an international Journal*, 1, pp. 37-46.
21. Wei, J. (2014). Relationship between DBH and tree height. *Journal of Hubei Minzu Universily (Nature Science Edition)*, 32(2), pp. 190-192.
22. Wu, D., Lin, Y., Lin G, C. (2016). Roadside safety evaluation based on fuzzy logic theory. *Journal of Guizhou University (Nature Sciences)*, 33(1), pp. 122-126.
23. Zou, Y., Tarko A, P., Chen, E., et al. (2014). Effectiveness of cable barriers, guardrails, and concrete barrier walls in reducing the risk of injury. *Accident Analysis & Prevention*, 72, pp. 55-65.

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Comparison of different calibration methods in modelling the unsignalized intersection using VISSIM with vehicular flow as the fitness measure

N.M. Hasain M.A. Ahmed S. Jena H.R. Khan

Department of Civil Engineering – National Institute of Technology Silchar, Silchar, 788010, Assam, India
email: mohamed_rs@civil.nits.ac.in; maa@civil.nits.ac.in; suprava@civil.nits.ac.in; 007haroon@gmail.com

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Abstract

With the increasing attention towards microsimulation of transportation facilities, the calibration methods for simulation have been widened over the last decade, especially with advancements in computational power. Different methods of calibration exist in the literature. Hence, there is a need to compare different calibration methods for heterogeneous traffic conditions. Two unsignalized intersections (I-1 and I-2) were considered for the study. PTV VISSIM was used as the simulator and the intersections were modelled with data extracted from the field. The Vehicular flow was considered as the performance measure. Six driving behaviour parameters out of twelve were found to be sensitive in the model using the one-way ANOVA test. The range for each parameter was set. Three methods, namely manual calibration (trail & error method), automated calibration (Genetic Algorithm (GA) method) and partially manual calibration (trial & error and GA method), were used in calibrating the model. In manual calibration, 150 sets of parameters were sampled. The lowest Root Mean Square Normalised Error (RMSNE) value was found on both intersections after 1500 runs of simulation. The genetic algorithm was used with MATLAB for automated calibration and the models were calibrated through the Component Object Model (COM) interface. The objective function was defined and converged after the 49th and 32nd generation for intersections I-1 and I-2, respectively. The partially manual calibration used multiple regression models to find the optimal values for the parameters using the GA toolbox in MATLAB. The calibrated results from each method were compared with their merits and demerits.

Keywords – genetic algorithm, COM interface, automated calibration, latin hypercube sampling, MATLAB

1. Introduction

With the growing economy, the ability to own a private vehicle increased along with the complexity of the traffic on the road network. This makes road transportation difficult to manage, especially in developing countries with heterogeneous traffic conditions, where there exists a shortage of lane discipline among the users and lane markings on the road [1-3]. This paved the way for microsimulation for transportation and traffic management. But, with the lack of simulation tools and processing power in the past, the use of microsimulation was not adopted by most researchers. However, with the recent advancement in computational power, the simulation of the traffic facilities provides a better tool for traffic studies and management. Also, other advantages of using microsimulation are cheaper, easier and faster than field implementation [4]. This led to increased attention on the microsimulation to establish a newer traffic facility and improve the existing facility for evaluating the changes in traffic. However, the simulated model should be calibrated to replicate the actual field condition. The calibration involves adjusting various parameters and characteristics available in the model and reducing the error between a field variable and the corresponding simulated variable [5]. Earlier, researchers used models for the traffic study with default parameters rather than calibrating. The reason behind using the default parameter values is the lack of clarity on the procedures and the complexity of the calibration process of the simulated model [6]. However, this leads to unreasonable results with more significant errors from field values. Hence, the calibration of the simulated model becomes a significant role in using microsimulation for transportation studies [5]. Various methods have been adopted to calibrate the simulated model along with different micro simulators in the past. Some of the major simulators were Verkehr In Stadten SIMulation (VISSIM), AIMSUN and Paramics. These micro simulators were extensively used in traffic safety using surrogate safety measures [7-10]. Jayasooriya et al. used VISSIM to calibrate and validate the urban intersections manually with the vehicular flow as a measure of effectiveness. They used GEH statistics and got most of the values under the acceptable level [11]. A similar study was done to model the urban area with Wiedemann 74 car following model [12]. Dutta et al. modelled three unsignalized intersections using VISSIM. The authors sampled the sensitive parameters using the Latin Hypercube Technique (LHS) and used the trial & error method to calibrate the model [13]. Similar studies have calibrated the model with respect to vehicular volume and validated the same with space mean speed [14, 15].

Several other attempts were made to automate the calibration and validation process with optimization algorithms. Kim et al. used travel time as the performance measure by developing a statistically based objective function and automated the calibration with the help of the genetic algorithm (GA) [16]. Park et al. used the genetic algorithm (GA) to model the unsignalized intersection using VISSIM and CORridor SIMulation (CORSIM) [4]. Mathew and Radhakrishnan calibrated the signalized intersection for heterogeneous traffic conditions using the VISSIM. They used the genetic algorithm (GA) with a population size of 10 chromosomes with stopped delay as the objective function [1]. Other methods, like GEH statistics between field volume and the simulated volume were used to calibrate the microsimulation model [17, 18]. Siddharth and Ramadurai used the GA tool in MATLAB and automated the calibration process to a certain extent using the Component Object Model (COM) interface in VISSIM. They used the elementary effect and ANOVA to find the sensitive parameters to be calibrated [19]. Also, both regression analysis and optimization algorithms were done in the past for the calibration process. Park and Schneeberger calibrated twelve signalized intersections in Germany manually using VISSIM with travel time as the measure of effectiveness. The sensitive parameters were identified and sampled using the sampling technique. The optimum values were identified with the help of a linear regression equation developed with travel time as the dependent variable [5]. Park and Schneeberger calibrated a road section in a highway using VISSIM. They used a partially manual calibration method by sampling the parameters using LHS Technique and developed a regression model. They used the developed models to further optimize the parameters using Microsoft Excel Solver [5]. In 2003, Park and Qi followed a similar approach, but instead of Microsoft Excel Solver, they used the GA algorithm to optimize the parameters with the help of a regression equation [6]. A similar study was conducted by Maheshwary et al., where they used the LHS technique for sampling and generated a linear regression equation from the data generated with the trial and error method. Then the generated equation was used as the fitness function in the genetic algorithm (GA) and optimal values were found for the sensitive parameters [2]. Maheshwary et al. also presented a methodology for a vehicle class-based calibration of the simulated model for heterogeneous traffic conditions. The LHS technique was again used to collect the data for developing the regression equation and the Genetic Algorithm (GA) was used for optimization [20]. A similar study was conducted by Bhattacharyya et al. at both intersections and midblock sections with the LHS technique, regression equation and GA optimization technique [21]. Several other studies have also compared various neural networks using MATLAB and Component Object Model (COM) interface for the simulation of urban roundabouts [22].

With limited studies conducted on the heterogeneous traffic condition, several different methodologies for calibrating the simulated model were followed. One may get confused regarding the selection of the calibration method for the simulated model. Hence, there is a need to evaluate the existing calibration methods and compare them. So, this study tries to compare the different calibration methods existing in the literature. The objectives of the study are 1) to calibrate the simulated model using three methods of calibration, namely a) manual calibration using sampling technique and trial & error method, b) automated calibration using Genetic Algorithm (GA) in MATLAB through the COM interface and c) partially manual calibration using sampling technique, trial & error method and genetic algorithm and 2) to compare the three calibration methods concerning complexity, speed and accuracy. The proposed methodology of the work was presented in the methodology section. The case study section explains the data collection, modelling of the study area and the identification of the sensitive parameter to be calibrated. The detailed procedures for each adopted calibration procedure are discussed in the calibration section. The next section consists of the validation and visualization of each method, followed by results and discussion. The final section discusses the conclusion of the study.

2. Methodology

The study objective is to compare the commonly used calibration methods in simulating traffic facilities in terms of speed, accuracy and complexity. VISSIM software has been selected to model the study area. VISSIM is preferred over the other software due to its simplicity and ability to represent the heterogeneous traffic nature with a slight adjustment in the driving behaviour [19].

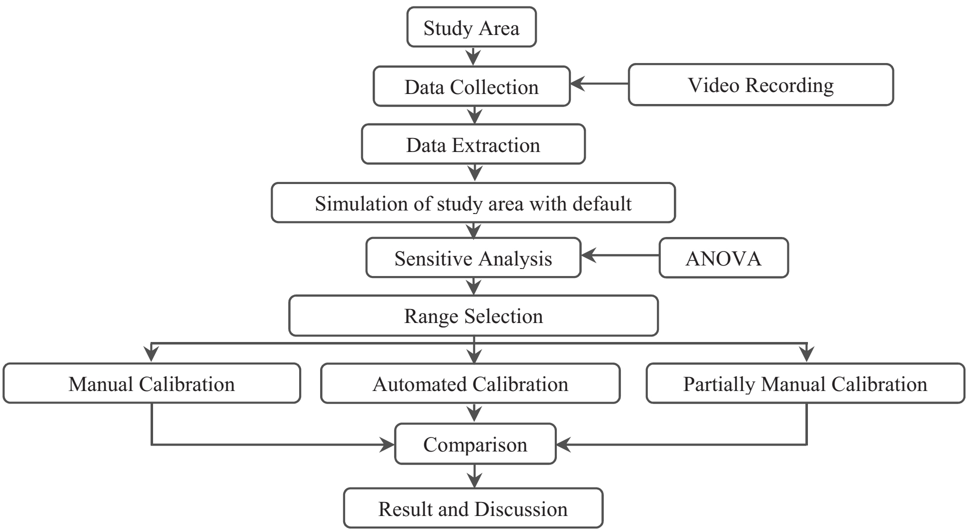

Fig. 1 - Methodology of the study

The first step was selecting the study area, followed by the data collection using video recording. The necessary data were extracted from the recorded video and the study areas were modelled using the VISSIM software with default parameters. Then the sensitivity analysis was conducted using the one-way ANOVA test and the sensitive parameters were identified. The range for each sensitive parameter was set and also used as the search space for the genetic algorithm. Then the simulated model was calibrated using each of the methods considered. The next step was to manually calibrate using the trial & error method after sampling the parameters. The second method uses GA with the COM interface. This method is fully automated. The final method was calibrating with the trial & error method and the genetic algorithm. This method was considered as partially manual calibration. Figure 1 shows the detailed methodology of the study.

3. Case study

3.1. Data collection

Most of the intersections in India are unsignalized. The unsignalized intersections are also considered to be more complex to simulate due to the complex vehicle manoeuvres in the road network [23, 24]. Two three-legged unsignalized intersections were selected in Guwahati, Assam. One near Assam State Zoo (I-1 intersection) and the other near the Gauhati Commerce College (I-2 intersection). The major road for I-1 is four-lane divided and for I-2 is two-lane undivided. Both the intersections have an undivided two-lane minor road. The peak hours were identified by visual observation of the traffic flow in the city, particularly at each intersection. The study was conducted during peak hours from 9.00 AM to 10.30 AM. The camera was placed on top of a tall three-storied building to cover a larger area. Further, additional data such as spot speeds for different types of vehicles, geometric data of the intersections were collected from the site. The other necessary data such as vehicular flow in each intersection leg, turning volume and vehicular composition were extracted from the recorded video from the site. The study considered six types of vehicles - motorized two-wheeler, cars, motorized three-wheeler (auto-rickshaw), minivan, bus, and truck.

3.2. Modelling the intersection

PTV VISSIM has been used as the simulator in the present study. The data of the first 3600 seconds of the study area were used for modelling. For simulation, the input data, such as the number and width of lanes, the vehicular volume, the vehicular composition, the percentage of the turning volume in each approach and the speed of vehicles approaching the intersection, were given in VISSIM software. By default, only a few types of standard vehicles could be represented in VISSIM [1]. Other vehicular types, including motorized three-wheelers (auto-rickshaw), are not readily available in the software and were included manually in .v3d format. Time intervals of 300 seconds were created in the model to improve the accuracy. The vehicular volume and the vehicular composition were given as the input variables for each specified time interval. VISSIM software, in default, represents homogeneous traffic with lane discipline. However, the vehicular movements in developing countries are heterogeneous and follow no lane discipline. Changing the driving behaviour parameters in the model help to achieve heterogeneous traffic movement. The changes made were a) allowing the vehicle to move anywhere in the lane instead of only in the middle of the lane, b) setting the general behaviour of the drivers to the free-lane selection, c) allowing vehicles to overtake the other vehicle on both left and right sides and d) making the vehicles to queue in the diamond pattern in the model [1, 13]. The vehicular flow was considered as the