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Research Article
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Vehicle and Pedestrian Safety Assessment at Unsignalized Intersection using Surrogate Safety Assessment Model: A Case Study of Old Sinamangal Intersection, Kathmandu, Nepal

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Abstract

Intersections are one of the key elements of a road network to ensure the safety of the network because intersections have a lot of conflict points. The intersection at Old Sinamangal, Kathmandu is a three legged unsignalized intersection. During peak hours, it handles 3,759 vehicles and facilitates the movement of 318 pedestrians within the same timeframe. Microsimulation software VISSIM was used to model the intersection and Surrogate Safety Assessment model (SSAM) was used to identify location and type of conflicts. The intersection has 3341 number of conflicts in the peak hour among different vehicle types and pedestrians. The conflicts mainly occur where interchanges between vehicle and pedestrian takes place. Among 3341 conflicts at the peak hour, 1469 crossing conflicts, 1518 rear end conflicts and 339 lane change conflicts occur. The alternatives related to regulation of speeds were observed to be more effective in reducing vehicle-vehicle conflict but increased vehicle-pedestrian conflicts, and the alternatives related to grade separation between vehicles and pedestrians i.e. pedestrian bridge was more effective in reducing vehicle-pedestrian conflict. Furthermore, the alternative of shifting pedestrian crossing reduced both vehicle-vehicle and vehicle pedestrian conflicts.

Keywords: Unsignalized Intersection; VISSIM; SSAM; Safety; Conflicts

1. Background

According to a World Health Organization (WHO) report, annual road traffic fatalities have decreased marginally to 1.19 million in 2023, down from 1.3 million in 2018, indicating that road safety initiatives are making a positive difference. However, the cost of mobility continues to remain unacceptably high. The number of road crashes is increasing in the context of Nepal and Kathmandu Valley, which comprises of three district shares 7.8 % to 9.2 % of fatalities and 52.5 % to 60.5 % of crashes of Nepal; based on the crash database for the fiscal year 2007 to 2020 and the total cost of road crashes in Kathmandu Valley for the fiscal year 2020 was calculated a NRs. 1827.67 million. Road crashes in Nepal are caused by numerous factors, such as excessive speeding, poor decision-making by drivers, insufficient driving experience, negligence, improper overtaking, reckless behavior, vehicle overloading, faulty or blinding lights, reluctance to disembark from moving objects (vehicles, motorcycles, humans, or uncontrolled animals), skidding, road surface flaws, level crossings, and obstructions. Road crashes are the primary cause of death for children aged 5-14 and young adults aged 15-29, with an average fatality rate of 27.5 per 100,000 people. Globally, a life is lost on the road every 24 seconds. In Nepal, the fiscal year 2018/19 saw 13,366 road traffic accidents leading to 2,789 deaths, 4,376 severe injuries and 10,360 minor injuries.

Normally, several years of crash data is required to analyze and understand the underlying trend and the factors affecting crashes. Due to unavailability of detailed and reliable crash records, quantification of safety level is limited in developing countries. The data available are not sufficient to conclude the significant factor of the crash. To address the lack of exposure and historical crash data, a surrogate method known as "conflict analysis" has been employed. In this approach, as a measure of the crash potential, traffic conflicts generated from developed model is used. The results obtained from this Surrogate method can be used to simulate alternatives to improve

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safety. The haphazard crossing of the pedestrian can be observed in the intersection under study. Therefore, pedestrian is always exposed to the vehicle which increases potential of crash between pedestrian and vehicle. Additional to pedestrian-vehicle conflict, vehicle-vehicle conflict can also be seen during merging and diverging maneuvers of vehicles primarily due to it being a unsignalized intersection without stop control. Thus, the safety assessment of the intersection is necessary to quantify the conflicts in the intersection and evaluate the alternatives to minimize it. The goal of this study was to evaluate the current state of conflicts (between vehicles and between vehicles and pedestrians) and to propose strategies for enhancing safety at the intersection.

2. Literature Review

A traffic conflict occurs when two or more road users, typically motor vehicles, interact in a way that forces one or both drivers to take evasive actions, such as braking or swerving, to prevent a collision. According to Amundsen and Hyden (1977), a traffic conflict arises when road users approach each other in time and space in a manner that poses a risk of collision unless their movements are altered. In other words, a conflict could result in a crash unless one of the involved parties adjusts their speed, changes direction, or accelerates/decelerates to avoid an accident. Prajapati et al. 2022 highlighted that microscopic simulation tools like VISSIM offer a detailed approach, capturing individual driver interactions with the environment and other vehicles, as well as specific link behaviors or driver class characteristics. Their study utilized VISSIM to simulate traffic flow on the Ekantakuna-Satdobato section of Kathmandu Ring Road by calibrating various parameters, demonstrating its effectiveness in modeling the heterogeneous traffic conditions of the Kathmandu Valley. Tiwari, H (2015) investigated 10 major black spots in the Kathmandu Valley to analyze the relationship between road accidents, traffic volume, and speed. The study found that crashes are significantly influenced by factors such as vehicle speed, local traffic volume, and the proportion of two-wheelers on the road.

Habtemichael & Picado-Santos (2013) determined that the most critical parameters affecting the safety of simulated vehicles in VISSIM include CC1 to CC5 for the car-following model, the 'Safety distance reduction factor' for the free lane-changing model, and 'Lane changing position' and 'Maximum deceleration of trailing vehicles' for the necessary lane-changing model. Most of these parameters were also found to influence the travel time in the simulation. The study concluded that the values of these parameters significantly affect the aggressiveness or defensiveness of simulated vehicles, thereby impacting both the safety and operational efficiency of the simulated traffic.

The calibrated parameter values for driving behavior recommended by Siddharth and Ramadurai (2013) for Indian heterogeneous traffic conditions were initially used as a reference. These parameters were adopted as a baseline for determining the calibrated values for the model, as driving behaviors in India and Nepal are somewhat similar. Acharya (2020) identified that the primary cause of traffic congestion in the New-Baneshwor area was due to high traffic volumes exceeding the intersection's capacity. The study utilized VISSIM to simulate the traffic and signal timing under current conditions. The VISSIM model was calibrated and validated using the GEH (Geoffrey E. Havers) statistic for traffic volume and regression analysis for travel time. The study proposed various alternatives to enhance intersection performance by implementing modifications in the calibrated and validated VISSIM model.

Huang et al. (2013) investigated whether the VISSIM simulation model and SSAM (Surrogate Safety Assessment Model) could provide reliable estimates of traffic conflicts at signalized intersections. In their study, they gathered 80 hours of traffic data and recorded traffic conflicts at ten signalized intersections. The simulated conflicts generated by VISSIM and identified by SSAM were compared to the conflicts observed in the field. The researchers proposed a two-stage process to calibrate and validate the VISSIM simulation models. They found that this two-stage calibration method improved the accuracy of the simulated conflicts compared to real-world conflicts. Stevanovic et al. (2012) developed linear regression model to analyze the relationship between simulated and observed conflicts. The results indicated a reasonable correlation between the simulated and observed rear-end and total conflicts. SSAM generated surrogate safety measures by identifying, classifying, and evaluating traffic conflicts within the simulation in the study. Gettman et al. (2008) examined the relationship between simulated conflicts and actual crashes at 83 four-leg urban signalized intersections and discovered a significant correlation between the two. Additionally, a more recent study by Dijkstra et al. (2010) also confirmed a statistically significant relationship between observed crashes and simulated conflicts.

Astarita et al. (2019) conducted microsimulation studies to assess typical intersection scenarios and concluded that combining microsimulation with surrogate safety measures is a reliable and consistent approach for evaluating the safety of various intersection designs. Similarly, Vasconcelos et al. (2014) reached comparable conclusions when evaluating three standard intersection layouts: a four-leg priority intersection, a four-leg staggered intersection, and a single-lane roundabout.

VISSIM offers two approaches for simulating pedestrians. The first is a default method that applies general rules to model pedestrian behavior, while the second treats pedestrians similarly to vehicles by adjusting various parameters to replicate their behavior. Using the car-following algorithm for pedestrian modeling is a recent advancement, and its effectiveness was demonstrated by calibrating VISSIM to accurately predict established pedestrian speed-flow relationship by Ishaque & Noland (2009).

Abukauskas et al. (2013) investigated road safety enhancements at at-grade intersections. The study focused on conventional intersections in Lithuania featuring left-turn deceleration and waiting lanes on main roads. Driving speeds were measured at three different locations, and changes in speed and the frequency of traffic conflicts were analyzed. The study found that after implementing safety measures, which led to a reduction in actual driving speeds, the likelihood of traffic conflicts in the intersection area significantly decreased.

The research by Pin et al. (2015) showcased the application of automated traffic conflict analysis for conducting before-and-after safety assessments. The aim was to perform a time-series safety evaluation for an intersection in Surrey, British Columbia, Canada, where various pedestrian-related safety measures were implemented. These measures included protected-only left turns, pedestrian countdown timers, crosswalk realignment, crosswalk repositioning, and the use of drop-down sidewalks. The results revealed a significant reduction in both the frequency and severity of pedestrian conflicts at the intersection after the treatments were applied. This study highlights the effectiveness of surrogate safety indicators in diagnosing pedestrian-related safety issues and evaluating intersection countermeasures.

3. Study Area

The unsignalized intersection at Old Sinamangal in Kathmandu was selected for this study. Although the intersection has four legs, the western leg carries a very low traffic volume (0.011% of vehicles), making its impact negligible compared to the other legs, and it has therefore been excluded from the analysis. The Jadibuti (South Leg) and Sanothimi (East Leg) legs each have a total width of 14 meters (two lanes, each 7 meters wide), while the Kadaghari (North Leg) leg is 12 meters wide (two lanes, each 6 meters wide). The footpaths around the intersection vary in width from 1.7 meters to 3 meters. The layout of the intersection is presented in figure 1.

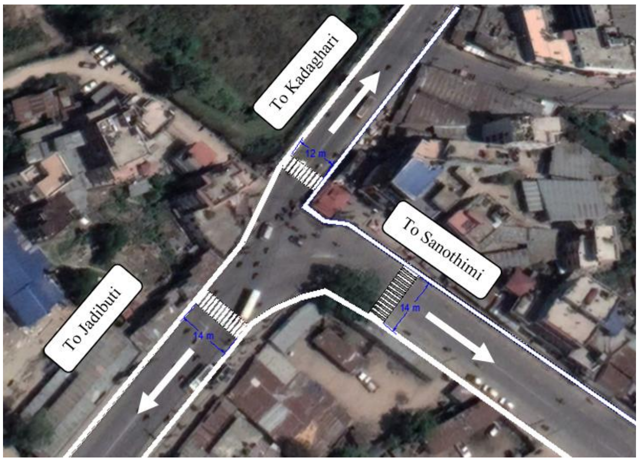

Figure 1 Old Sinamangal Intersection

4. Methodology

Traffic volume data was collected through a videographic survey conducted over three days—May 9, 10, and 11, 2023—during peak hours from 8:00 AM to 10:30 AM and 4:00 PM to 6:30 PM. These peak hours were recommended by Tiwari et al. [20] in their study on optimizing performance at signalized intersections through signal coordination in two intersections in Nepal. Pedestrian counts were also recorded during the identified vehicular peak hours. The intersection's geometry was determined through field measurements, and vehicle and pedestrian speeds were measured using a radar gun. The collected data was then used to create a traffic model in PTV VISSIM-2023. Connectors and nodes were utilized to replicate the intersection's geometry, and vehicle volumes and speeds were assigned based on the survey results. Driving behavior parameters were adjusted to align the simulated traffic volume, queue length, and speed in VISSIM with the field data [10]. The model was calibrated using two days of traffic data (speed, queue length, and volume) by applying GEH Statistics and RMNSE values. Once the model was sufficiently calibrated, validation was performed using the third day's data for speed, queue length, and volume. GEH Statistics were used to validate traffic volume, while RMNSE values were used to validate speed and queue length.

Once the base model in VISSIM was calibrated and validated, the trajectory for the existing scenario and other safety improvement alternatives was generated as a direct output. SSAM (Surrogate Safety Assessment Model) was employed to analyze the trajectory file and quantify the number of conflicts between pedestrians and vehicles, which were classified as rear-end, lane-change, and crossing conflicts. Depending on simulated angle of collision, post processing of data was done to filter conflict between vehicles and pedestrians. After quantifying the conflicts presently occurring in the intersection, different alternatives for its improvement was analyzed. The measures of safety improvement were analyzed by applying modifications to previously calibrated and validated VISSIM model. The methodology of the study is presented in Figure 2.

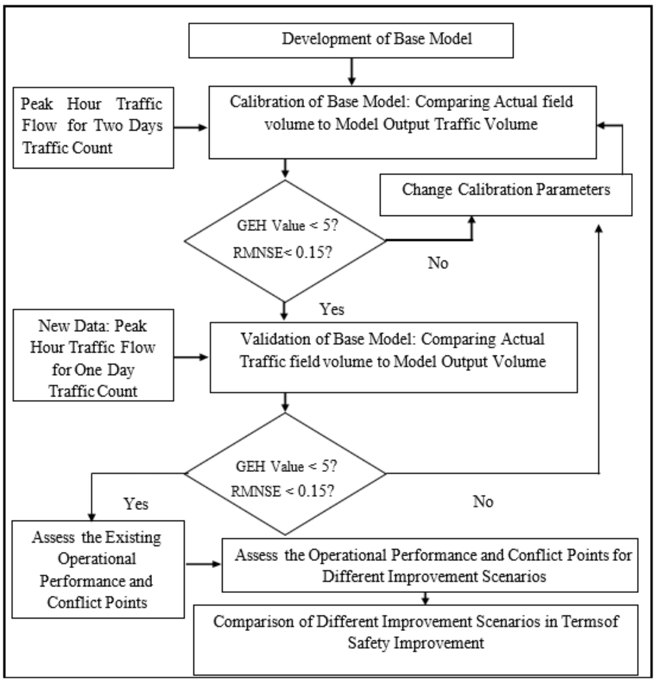

Figure 2 Methodology Flowchart

5. Data Analysis and Results

7.1 Hourly Traffic Volume

A three-day traffic count was conducted to identify the peak hour at the intersection. The peak hour was determined to be from 9:00 AM to 10:00 AM, during which an average of 3,758 vehicles passed through the intersection over the three days. Additionally, 318 pedestrians crossed the intersection during the same period. Figure 3 shows the hourly traffic flow in the intersection. On Day 1, 3,713 vehicles were recorded during the peak hour, followed by 4,005 vehicles on Day 2 and 3,555 vehicles on Day 3. The directional traffic volume is presented in table 1.

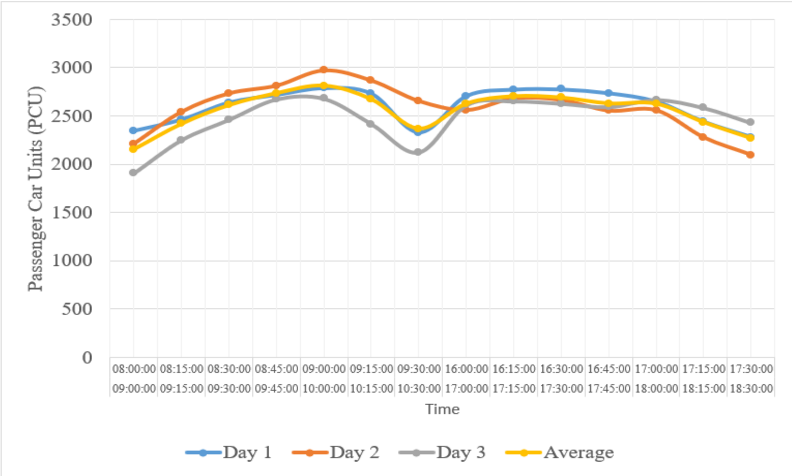

Figure 3 Hourly traffic volume

Table 1 Directional Volume

	Sanothimi (East Leg)		Jadibuti (South Leg)		Kadaghari (North Leg)		Total
Day	Jadibuti (South Leg)	Kadaghari (North Leg)	Sanothimi (East Leg)	Kadaghari (North Leg)	Sanothimi (East Leg)	Jadibuti (South Leg)	
Day 1	830	463	404	648	238	1130	3713
Day 2	721	465	395	623	286	1515	4005
Day 3	638	406	334	627	254	1296	3555

7.2 Speed Distribution

Vehicle speeds were measured using a radar gun, while pedestrian speeds were determined through a videographic survey. Fifty samples of each vehicle type and pedestrians were analyzed to calculate the average, minimum, and maximum speeds [20]. A spot speed survey of vehicles was also conducted, revealing that the 50th percentile speed was 22.6 km/h, and the 85th percentile speed was 30.5 km/h. Refer figure 4 for speed distribution of vehicles.

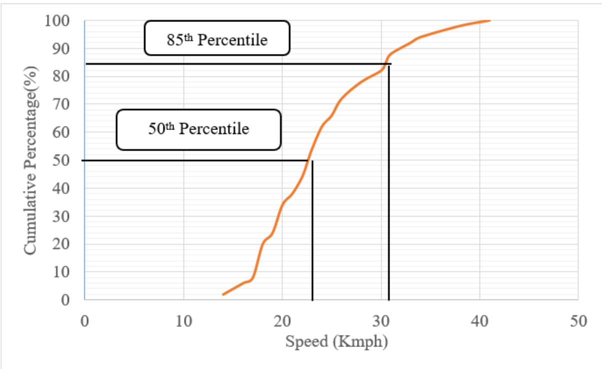

Figure 4 Speed Distribution of Vehicles

7.3 Calibration of Model

Calibration was performed for traffic volume, average speed, and queue length using data from two days. The model was calibrated by evaluating Geoffery E. Havers (GEH) statistics and Root Mean Squared Normalized Error (RMNSE) values. A trial-and-error approach was employed to achieve the desired calibration. Refer table 2 for calibration of volume, table 3 for calibration of speed and table 4 for calibration of queue length.

Table 2 Calibration of Volume

SN	From	To	Simulated Volume	Actual Volume in Field	GEH Statistics
1	Sanothimi (East Leg)	Jadibuti (South Leg)	785	776	0.32
2	Sanothimi (East Leg)	Kadaghari (North Leg)	478	464	0.64
3	Jadibuti (South Leg)	Sanothimi (East Leg)	379	400	0.83
4	Jadibuti (South Leg)	Kadaghari (North Leg)	622	636	0.55
5	Kadaghari (North Leg)	Sanothimi (East Leg)	255	262	0.43
6	Kadaghari (North Leg)	Jadibuti (South Leg)	1256	1323	1.86

Table 3 Calibration of Speed

SN	Category	Average Speed in Field (Kmph)	Average Speed in model (Kmph)	RMNSE
1	Two-Wheeler (Motor Cycle)	27.64	27.44	0.03
2	Pedestrian	4.18	4.18	0
3	Four-Wheeler Light (Jeep, Car)	24.02	23.26	0.11
4	Four-Wheeler Heavy (Truck, Bus)	20.68	20.18	0.1

Table 4 Calibration of Queue Length

SN	Leg of Intersection	Queue length in VISSIM model	Actual queue length in Field	RMNSE
1	Sanothimi (East Leg) Leg	15.28	15	0.07
2	Kadaghari (North Leg) Leg	12.36	12	0.1
3	Jadibuti (South Leg) Leg	16.32	16	0.08

7.4 Validation of model

Once the model was sufficiently calibrated, validation was conducted using Day 3 traffic data (third-day volume). The GEH statistics and RMNSE values were calculated for Day 3 traffic by following a process similar to the calibration method. Refer table 5 for validation of volume, table 6 for validation of speed and table 7 for validation of queue length.

Table 5 Validation of Volume

SN	Movement	Volume in VISSIM model	Actual Volume in Field	GEH Statistics
1	Sanothimi (East Leg) to Jadibuti (South Leg)	617	638	0.83
2	Sanothimi (East Leg) to Kadaghari (North Leg)	412	406	0.28
3	Jadibuti (South Leg) to Sanothimi (East Leg)	314	334	1.1
4	Jadibuti (South Leg) to Kadaghari (North Leg)	600	627	1.08
5	Kadaghari (North Leg) to Sanothimi (East Leg)	245	254	0.56
6	Kadaghari (North Leg) to Jadibuti (South Leg)	1229	1296	1.88

Table 6 Validation of Speed

SN	Category	Average Speed in Field (Kmph)	Average Speed in VISSIM (Kmph)	RMNSE
1	Two-Wheeler (Motor Cycle)	27.64	27.44	0.03
2	Pedestrian	4.18	4.18	0
3	Four-Wheeler Light (Jeep, Car)	24.02	23.26	0.11
4	Four-Wheeler Heavy (Truck, Bus)	20.68	20.18	0.1

Table 7 Validation of Queue Length

SN	Leg of Intersection	Queue length in VISSIM model	Actual queue length in Field	RMNSE
1	Sanothimi (East Leg) Leg	15.21	15	0.05
2	Kadaghari (North Leg) Leg	13.14	13	0.04
3	Jadibuti (South Leg) Leg	15.42	15	0.1

7.5 Present scenario of conflicts

The trajectory file (.trj) generated by the VISSIM model was exported and analyzed using the Surrogate Safety Assessment Model (SSAM). SSAM detects conflicts based on surrogate safety measures such as Post Encroachment Time (PET) and Time to Collision (TTC). The default maximum TTC value of 1.5 seconds and the default maximum PET value of 5 seconds were used. SSAM identifies three types of conflicts: crossing conflicts, rear-end conflicts, and lane-change conflicts. During the vehicular peak hour, a total of 3,341 conflicts were observed, including 1,469 crossing conflicts, 1,518 rear-end conflicts, and 339 lane-change conflicts. Table 8 shows present scenario of conflicts in the intersection.

Table 8 Present Scenario of Conflicts

SN	Type of Conflict	Total Conflicts	Crossing Conflicts	Rear end Conflicts	Lane Change Conflicts
1	Vehicle-Vehicle Conflict	2805.00 (83.95%)	948.00	1518.00	339.00
a	Motorbike-Motorbike	1296.00	394.00	728.00	174.00
b	Motorbike-Car/Jeep Conflict	799.00	289.00	423.00	87.00
c	Motorbike-Bus	244.00	74.00	139.00	31.00
d	Motorbike-Truck/HGV	97.00	34.00	57.00	6.00
e	Car/Jeep-Car/Jeep	206.00	90.00	98.00	18.00
f	Car/Jeep-Bus	100.00	40.00	45.00	15.00
g	Car/Jeep-Truck	37.00	16.00	16.00	5.00
h	Bus-Bus	10.00	6.00	3.00	1.00
i	Bus-Truck	10.00	4.00	4.00	2.00
j	Truck-Truck	6.00	1.00	5.00	0.00
2	Pedestrian-Vehicle Conflict	536.00 (16.05%)	521.00	0.00	0.00
a	Pedestrian-Motorbike	228.00	228.00	0.00	0.00
b	Pedestrian-Car/Jeep	200.00	200.00	0.00	0.00
c	Pedestrian-Bus	27.00	27.00	0.00	0.00
d	Pedestrian-Truck	66.00	66.00	0.00	0.00
	Total	3341.00	1469.00	1518.00	339.00

The rear end and crossing conflicts were higher in number than lane change conflicts and the significant contributor for lane change conflicts were motorbikes which shows lack of lane discipline in motorbike riders.

Presently 83.95% conflicts occur between vehicles and 16.05% conflicts occur between vehicles and pedestrians. Refer figure 5 for the types of conflicts based on angle of collision. The conflicts between motorcycle-motorcycle is highest among all conflicts. The conflicts were mainly observed at the pedestrian crossings and in middle of the intersection where vehicular exchanges take place. Refer figure 6 for heatmap of conflicts at present.

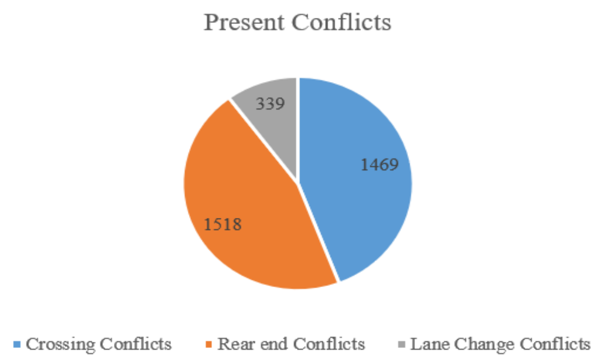

Figure 5 Present Conflicts based on angle of collision

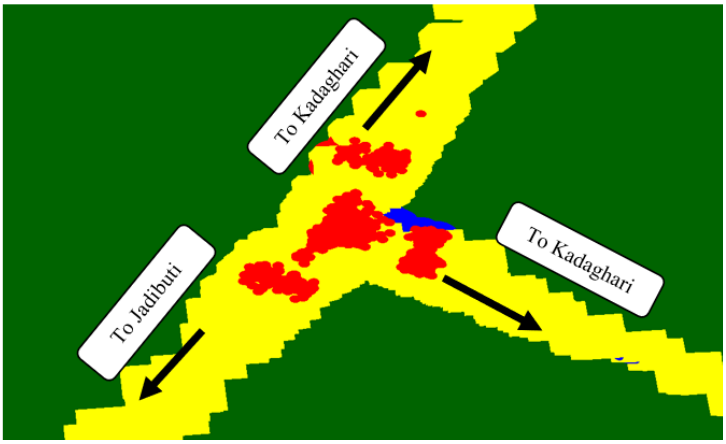

Figure 6 Heatmap of conflicts at present

7.6 Measures of Safety Improvement

After quantification of conflicts in the intersection, various alternatives for improvement was made. The alternatives were applied to the copies of calibrated and validated model with corresponding effects in VISSIM. Different alternatives had varying effect on the improvement of safety. Some alternatives were more efficient than other. It was seen that the pedestrian bridge has significant impact on reduction of conflicts by 41.72% which is the highest among the alternatives when the alternatives are compared by total number of conflicts. Refer table 9 for comparison of safety improvement alternatives.

Table 9 Comparison of safety improvement alternatives

SN	Alternatives	Total Conflicts	Percentage Improvement (%)	Crossing Conflicts	Rear-end Conflicts	Lane Change Conflicts
1	Present Condition	3341	0.00	1469	1518	339
2	Shifting of Pedestrian Crossing: By 15m	2872	14.04	1306	1207	262
3	Shifting of Pedestrian Crossing: By 30m	2673	19.99	1235	1180	258
4	Pedestrian Bridge: At Jadibuti (South Leg) Leg	2588	22.54	1182	1154	252
5	Pedestrian Bridge: At Kadaghari (North Leg) Leg	2543	23.89	1138	1158	251
6	Pedestrian Bridge: At Sanothimi (East Leg) Leg	2563	23.29	1156	1156	251

SN	Alternatives	Total Conflicts	Percentage Improvement (%)	Crossing Conflicts	Rear-end Conflicts	Lane Change Conflicts
7	Pedestrian Bridge: At All Legs	1947	41.72	691	1065	191
8	Speed Enforcement: 25 Kmph	3029	9.34	1521	1277	231
9	Speed Enforcement: 30 Kmph	2685	19.63	1392	1048	245

The alternative of shifting pedestrian crossing by 15m and 30m reduced the number of conflicts by 14.04% and 19.99% respectively. The pedestrian bridges at individual legs reduce conflicts by almost similar amount but the most effective means to reduce the conflicts was observed when pedestrian bridge at all legs were provided i.e. the conflicts reduces by 41.72%. Finally, the speed enforcement of 25 Kmph and 30 Kmph reduced the conflicts by 9.34% and 19.63% respectively. The effectiveness of each alternatives was analyzed in terms of interaction objects i.e vehicle- vehicle or vehicle-pedestrian conflicts. The alternative including pedestrian bridge was effective in reducing vehicle-pedestrian conflicts. The alternatives of speed enforcement were effective in reducing vehicle-vehicle conflicts but caused increment in vehicle-pedestrian conflicts. The alternative of shifting pedestrian crossing was effective in reducing both type of conflicts.

6. Conclusion

The study focused on assessment of vehicle and pedestrian safety at unsignalized intersection at Old Sinamangal by using simulation software VISSIM and SSAM. The intersection has 3341 number of conflicts in the peak hour in which the intersection accommodates 3759 vehicles. The conflicts were highest where motorcycle is involved in both vehicular conflicts and vehicle-pedestrian conflicts since motorcycle compose significant volume among different vehicle classes The alternative related to regulation of speeds were observed to be more effective in reducing vehicle-vehicle conflict but increased vehicle-pedestrian conflicts, and the alternative related to grade separation between vehicles and pedestrians i.e. pedestrian bridge was more effective in reducing vehicle-pedestrian conflict. Furthermore, the alternative of shifting pedestrian crossing reduced both vehicle-vehicle and vehicle pedestrian conflicts. Hence it can be derived that the shifting of pedestrian crossing is better choice among three since it requires minimal investment with great benefits. The study doesn’t consider severity of conflicts since it is quantitative rather than qualitative thus qualitative analysis could also be included in further studies. Signalization of the intersection and its corresponding conflict analysis could also be done.

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