Effect of Crossing Pedestrians on Traffic Flow in Urban Streets

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Abstract: This paper investigates the effects of crossing pedestrians on traffic flow at intersections. By integrating pedestrian flow and vehicle flow into simulation models in PARAMICS, the research firstly validates the current traffic situation in consideration of pedestrian flow at an urban street in Nagaoka city. The research secondly investigates the effect of crossing pedestrians under various situations of traffic and pedestrian demands. The sensitivity analysis shows that the effect of crossing pedestrians on the network performance is significantly high, especially in scenarios of high pedestrian flow and high traffic volume. The effects reduce the mean system speed greatly, by up to 60% compared with the scenario of having no considerations of pedestrian flow. The paper’s results strongly emphasize the influence of crossing pedestrians on urban streets. It should be considered carefully when simulating or analyzing any traffic network to have a comprehensive recognition on the network performance.

Keywords: Pedestrian, crossing, simulation, traffic, PARAMICS

1. INTRODUCTION

There have been many research studies on traffic analysis in urban streets. These research studies focused on interactions among vehicles, interactions between traffic facility and vehicles, etc. However, concerning vehicle-pedestrian interactions, very few research studies are available for a comprehensive investigation into the influence of crossing pedestrians on network performance. Most of these research studies, exept the studies on pedestrian behavior, pedestrian safety, etc. ignore the effects of pedestrians on traffic flow in the analysis due to its complexity (TRB, 2012; Tu, et al., 2013) which causes inaccurate analysis of network performance to some extent. Therefore, in the modern society, where walking, an environmentally friendly mode of transport, is encouraged, an investigation into the influence of pedestrian flow on traffic network becomes more and more important.

Although there have been many research studies about pedestrians (TRB, 2012) integration of pedestrians into simulation model to investigate the interaction between pedestrian flow and traffic flow has received modest attention. Indeed, concerning pedestrian, most of the research studies concentrated on pedestrian behavior or pedestrian safety (Sisiopiku et al., 2003; Yang et al., 2006; Eleonora et al, 2009; Hagita et al, 2011; Zhou et al, 2011). Some research studies focus on capacity analysis under the effects of pedestrian flow (Brilon et al, 2005; Chen et al, 2007). The analyses were conducted for Capacity of Right-Turn Movements at Signalized Intersections (Chen et al., 2008), or for capacity of entire signalized intersection with the presence of pedestrians or bicycles (Cheng et al., 2008; Chen et al., 2008; Mohsin et al., 2009). Some others analyzed the conflicts between Right-Turning Vehicles and Pedestrians or cyclists at an Urban Signalized Intersection (Hagiwara et al., 2010), pedestrian flow analysis (Richard et al., 1997), Pedestrian Impedance of Turning-Movement Saturation Flow Rates (Nagui et al., 1997). Several papers described real applications6) or developed simulation models for the interaction of vehicles and pedestrians to investigate trade-offs between vehicular and pedestrian traffic (Kardi et al., 2006; Muhammad et al., 2007; Pretto et al., 2011; Takashi et al., 2012). However, these studies stopped at analyzing for individual intersections or investigating the impact on pedestrians. Very few research studies clarify comprehensively the effects of crossing pedestrians on traffic flow in traffic networks.

This paper consists of 6 main parts; each part deals with its relevant aspects. This research's overview and literature review are presented in this section, Section1 – Introduction. For the part of literature review, the theoretical background of the research is discussed. The research objectives are presented and elaborated in Section 2. Section 3 describes in detail the data collection used in this paper. The method of integrations of pedestrians and general traffic into simulation models in PARAMICS is illustrated in Section 4. Section 5 presents the simulation result and sensitivity analysis. Finally, the paper ends with several conclusions and recommendations presented in Section 6.

2. PAPER OBJECTIVE

The paper aims at two targets. The first target is the validation of a current traffic network in consideration of crossing pedestrian effects. Based on the validation, the research concludes with the role of pedestrians in the current observed situation by comparing with the simulation scenario that ignores the pedestrian effects. The second target is the sensitivity analysis of pedestrian effects on network performance under various conditions of pedestrian demand and traffic flow. The analysis aims at emphasizing the important role of crossing pedestrians in any traffic network analysis.

3. DATA COLLECTION

3.1 A studied arterial

The study site is a main urban street which lies partly on the Route No. 351 and partly on Route No. 36 leading to Nagaoka Station (Figure 5). From field inspection, this urban street segment has high bus traffic and also a high traffic volume in comparison with other areas in the city. As a gateway to Nagaoka Station, this arterial plays an important role in the traffic network of the city. In the collection of traffic data of this urban street, 10 cameras were placed as shown in Figure 2 to observe the traffic in the period from 7:30 AM to 9:30 AM. Four cameras were set at 4 intersections to record the traffic flow through the main street, the side streets and turning traffic movements. The remaining cameras were used to obtain video footage at bus stops along this route. To get the accuracy of travel time calculation and the time of bus arrival, all cameras were set to start at the same time. In addition, the camera's clocks have been synchronized. The arrangement is illustrated as in Figure 2.

After capturing the traffic situation, the videos were analyzed in the Transportation Laboratory to obtain the data of traffic proportion (Figure 1), traffic volumes, turning proportion, bus interval, car travel time, bus travel time, traffic signals at intersections and offset. There are 13 bus routes in the studied traffic arterial. Based on the data observed, the main street traffic volume on the direction towards the station is around 514 vph, and 365 vph on the opposite direction during the peak hours. The detailed traffic volumes are displayed in the part of comparison between simulated flows and observed flows at the end of the following calibration process.

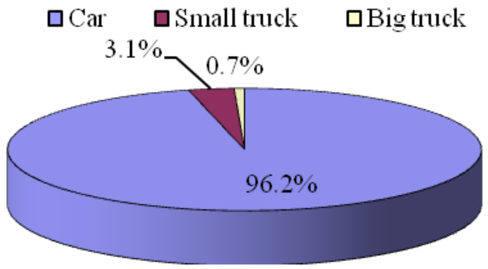

Figure 1. Traffic proportion at the studied site.

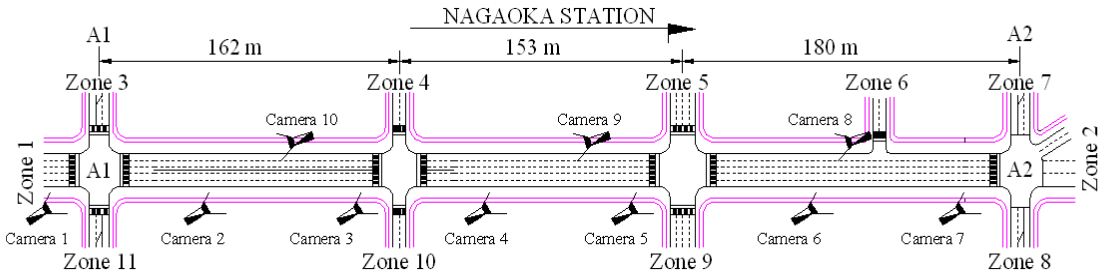

Figure 2. The arrange of record camera to collect data at the studied site.

3.2 Data collection on pedestrian

The research defines pedestrian trip as a trip made by pedestrian to cross one crossing. A video based software (SEV) (Minh, 2007) is used to collect walking speed, pedestrian flow, etc. The dimensions of pedestrian crossings at four intersections along the studied arterial are illustrated in Figure 3 and Table 1

Table 1: Pedestrian crossing and pedestrian trip.

Intersections	1	2	3	4
Hourly pedestrian trip	615	577	853	805
Main street	A=17.3 m		B=4.5 m	
Side street	A= 11.3 m		B=4.5 m	

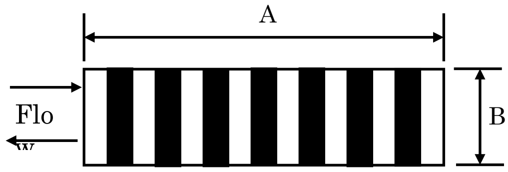

Figure 3. The dimensions of pedestrian crossings.

The pedestrian speed is determined based on the recorded videos and field observation. With Kolmogorov-Smirnov Test (test statistic Z=0.968; Most Extreme difference D=0.059; and P-value=0.306>0.05), the pedestrian speed can considered a normal distribution as shown in Figure 4.

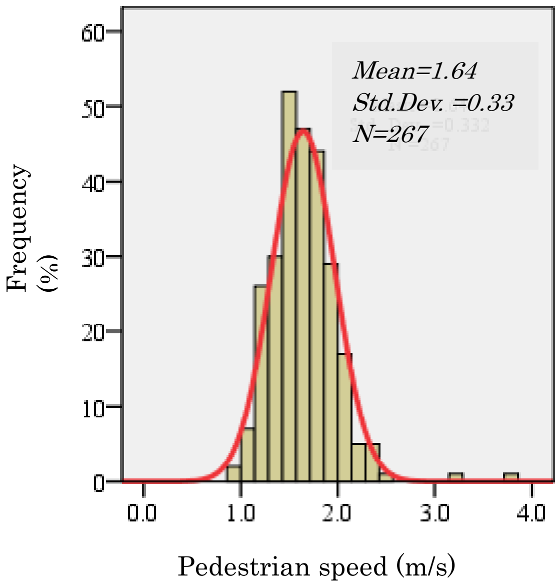

Figure 4. Observed distributed walking speed.

4. SIMULATION IN PARAMICS

4.1 Traffic arterial

All the traffic information, control information and geometric information of the study site are inputs to the PARAMICS Modeler – a microscopic simulation software (Quadstone Limited, 2012). The displays from the map and the interface of PARAMICS are as shown in Figure 5.

4.2 Integration of pedestrians in the network

According to Quadstone Paramics, signalized pedestrian crossings can be modeled using the concepts of agent type, agent space, region, connector, etc. The interaction between pedestrians and vehicles is analyzed through the concepts of shared spaces and vehicle aware space. First of all, the research defines four study areas of pedestrians at four intersections in the studied arterial. The Space types are then defined in the study areas, including pedestrian space, shared aggressive space, vehicle aware space, etc. The demand regions are defined to input the demand of pedestrians at each approach of each intersection. These demand regions may specify a source point for agents to be released onto a network or a destination point for agents to be removed from the network. A snapshot of the interaction between pedestrian flow and traffic flow at an intersection in the studied traffic arterial is shown in Figure 6.

Figure 5. Studied area (above) and nework in Paramics (below).

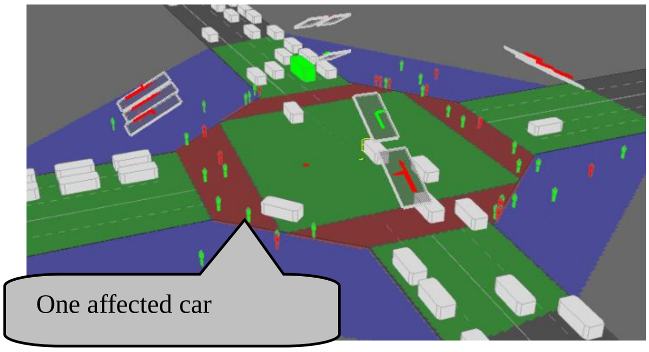

Figure 6. Simulation of pedestrian at an intersection.

5. RESULT AND ANALYSIS

5.1 Validation under consideration pedestrian effect

This part shows that the validation results of the current traffic situation in consideration of pedestrian effects. For traffic flow validation, the observed traffic flows at 32 points in the traffic network during the peak hours were validated. The simulated traffic flows were obtained from PARAMICS by setting a period of 15 minutes to collect data at 32 points during the peak hours. From the simulation results and observation data, the traffic flows in the 4 intervals during the peak hour from 8:00 to 9:00 are plotted around the 45-degree line, as shown in Figure 7. The values of simulated traffic flows and observed traffic flows cluster closely to the 45-degree line. The relative error of traffic flows at all observed points is 15 percent.

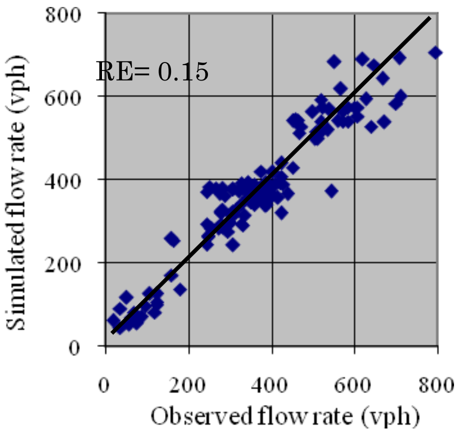

Figure 7. Traffic flow validation.

Regarding vehicle travel time validation, the travel time is measured on the road segment A1A2 (as in Figure 2) for vehicles traveling from intersection 1 to intersection 4 from recorded video tapes and from the PARAMICS modeler. Vehicles were classified into 2 groups, bus and non-bus. The comparisons for every interval during the peak hours are shown in Figure 8.

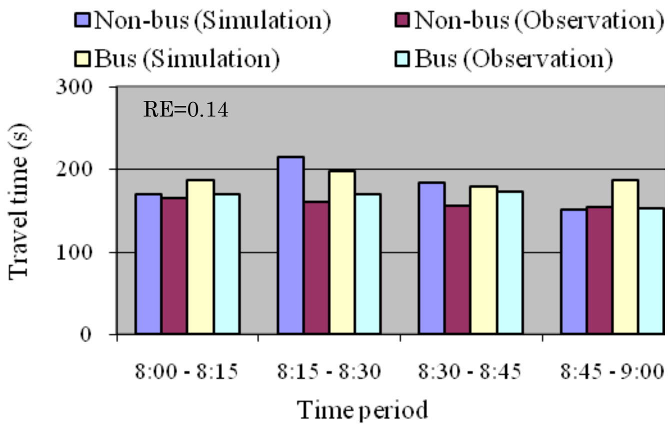

Figure 8. Vehicle travel time validation.

The travel times of bus and other vehicles for each direction on the main street in the observation case and simulation case are approximately the same. The average relative error of travel times of bus and non-bus is 14% as shown in Figure 8. As for pedestrian flow, the research compared the pedestrian flows at each signal cycle of the studied intersections. The data of simulated pedestrian flow are derived from the simulation in Paramisc. The values of simulated pedestrian flows and observed pedestrian flows (person per minute) distributes closely along the 45-degree line with low relative errors as shown in Figure 9.

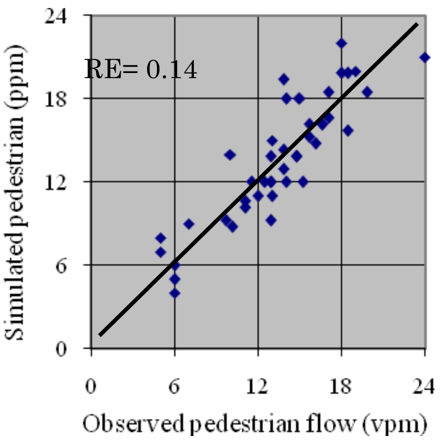

Figure 9. Pedestrian flow validation.

5.2 Effect of pedestrian

As shown in Table 1, the average number of pedestrian trips per intersection at the current study site is 712. By comparing with the scenario that pedestrian flow is not studied like in many previous studies, the research would like to show the effect of crossing pedestrians in urban streets. The effect is studied in terms of four indicators in this research. They are the number of stop times in the network, total turn delays at the signalized intersections, the trip time travel reductions from zones to zones, and the mean system speed. Although there are relationships among those indicators, the research would like to show the magnitude of the effect on each of them. When analyzing each indicator term with Paramics, the effect is studied in each 15 minute interval of the peak hours. As shown in Figure 10, during the simulated peak hours, the number of stop times increases from 4.3% to 9.3%, with average figure of 5.8%. Meanwhile, the increases of turn delay and the trip travel time from zones to zones are from 2.7% to 4.8% and from 2.1% to 4%, respectively. The mean system speed (MSS), which is defined as the ratio of vehicle-distance traveled to vehicle hour traveled (Equation 1), decreases by around 2.6%. The details are shown in Figure 10.

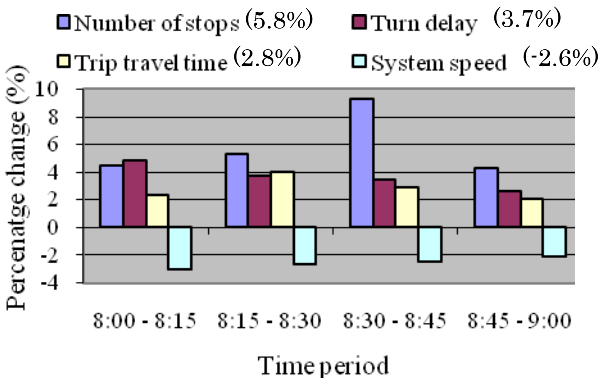

Figure 10. The effects of pedestrian at the current situation.

As presented in a simulation guideline3), the mean system speed (MSS) is expressed as follows:

$$MSS = \frac{VDT}{VHT} \tag{1}$$

Where,

MSS: mean system speed (km/h)
VDT: vehicle distance traveled (km)
VHT: vehicle hour traveled (hours)

In summary, the effect of crossing pedestrians at the observed situation is generally moderate. It is due to the low pedestrian demands as well as low traffic flows. The number of stop times is affected the most with the figure up to 9.3% at the third interval of the simulation time. The turn delays are also affected by crossing pedestrians at the intersections. The maximum increase number is around 4.8% during the peak hours. Moreover, crossing pedestrians cause the reduction in mean system speed. The maximum reduction can be up to 3%. This affects the overall performance of the traffic network.

6. SENSITIVITY ANALYSIS

The research would like to conduct a sensitivity analysis of the pedestrian effects under various conditions of pedestrian demand and traffic flow. Like the previous part with the current observed scenario, the percentage change is defined as follows:

$$P = \frac{V_i}{V_0} \cdot 100\% \qquad (2)$$

Where,

P : Percentage changes (%)
Vi : The indicator value in the simulated scenario i
V0 : The indicator value in the simulated scenario without consideration of pedestrian flow

To conduct the sensitivity analysis, the research firstly investigates the effect of pedestrians with various pedestrian demand based on the current traffic flow. The effect becomes significant since the average number of pedestrian trips at each intersection is more than 2100.

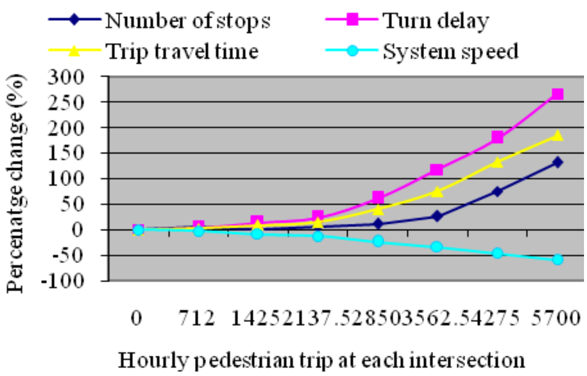

Figure 11 . The pedestrian demand based effect.

As shown in Figure 11, the turn delay at the studied intersections in the traffic network increases significantly when the number of pedestrian trips at each intersection is more than

2100. The figure is from 25% to 260% for the scenarios of great number of pedestrian trips. The impedance of pedestrian causes the increase of the number of stop times in the traffic network. The number of stop times becomes considerable when the number of pedestrian trips is more than 2800. The maximum increased value is around 132% when compared with the scenario of having no consideration of pedestrian effects. In terms of trip travel time from zone to zone in the traffic network, the pedestrian flows increase the trip travel time by 185%. In addition, the result shows that, the vehicle distance traveled is almost unchanged in this arterial. However, these effects reduce increase the vehicle hour traveled significantly. This causes a significant reduction of system speed. As shown in Figure 11, with low pedestrian flow (less than 1400 pedestrian trips per intersection), the system speed is reduced insignificantly, by less than 8%. However, this figure increases sharply when the pedestrian flow increases. The figure can be up to 60% in the cases of high pedestrian demand. It can be said that, the effect of crossing pedestrians is significant, especially in cases of high pedestrian demand. The more the pedestrian trips are, the more significant the effects are. The effects are strongly related to the network performance. Therefore, the effects of pedestrian flow should be considered in any traffic analysis task.

Secondly, the research investigates the effect of pedestrians in consideration of not only pedestrian demand but also the traffic flow variation. For the traffic flow variation, it is obvious that the turning vehicles are affected significantly by crossing pedestrians. For the sake of simplicity, this research uses the average demand released by zones as indicators to compare for this small traffic network. The sensitivity analysis of pedestrian effects based on various values of traffic flow and pedestrian demand is as shown in Figure 12. The details are as follows:

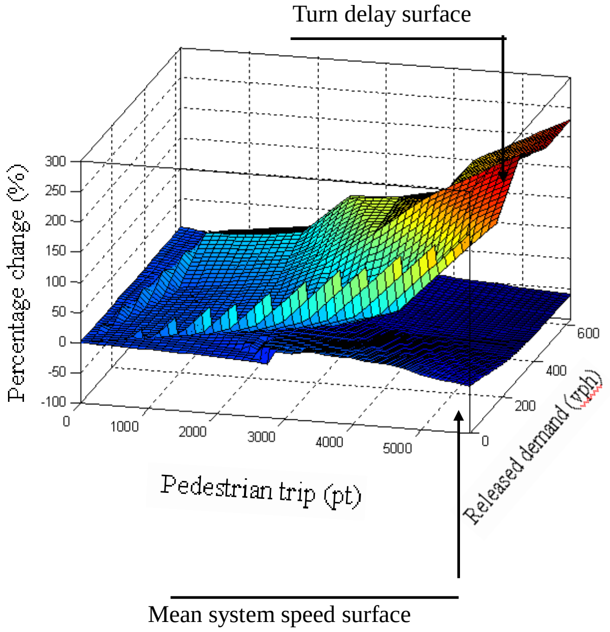

Figure 12 : Sensitivity analysis of pedestrian effects

Based on the above figure, the percentage change is significantly affected by both the traffic flow and pedestrian demand. The slope of the turn delay surface is much higher than that of the mean system speed surface. It improves the high rate of change in terms of turn delay compared with that in terms of system speed. This is reasonable because of the direct relationship between turn delay and crossing pedestrians. The interfere impact indirectly other vehicles in the network following the shockwave mechanism. When the traffic flow increases, the negative effects of pedestrian also increase significantly. That leads to the reduction in system speed as well as the increase of turn delay as shown in Figure 12. However, when the average released demand at each zone is higher than 450 vehicles per hour, the effect reduces slightly. This is reasonable because the network becomes congested at this demand. General traffic cannot travel more because of congestion. The interaction between pedestrian and general traffic is trivial compared with the current congested situation. This interaction is overwhelmed by the interaction among vehicles in the traffic stream.

7. CONCLUSION

The paper aims at two targets. Firstly, the research validates the current traffic network in consideration of crossing pedestrian effects, which have been almost ignored in most of the previous studies. Based on the validation, the role of pedestrians at the current observed situation is verified to be generally moderate due to the low demand of crossing pedestrians. The number of stop times is impacted the most with the figure up to 9.3% at the third interval of simulation time when compared with the scenario of having no considerations of pedestrian effects. The interaction between turning vehicles and pedestrians is generally small, with the highest value of turn delay increase of 4.8% during the peak hours. This causes a slight reduction in mean system speed with the maximum figure of around 3%. Secondly, the research conducts a sensitivity analysis of pedestrian effects in various situations of pedestrian demand and traffic flow. The analysis shows the significant role of crossing pedestrians in the scenarios of high traffic volume and pedestrian demand. It is reasonable because the interaction between vehicle and pedestrian increases in these scenario due to the high demands. The turn delay in the traffic network can increase by up to 260% compared with the base scenario of having no consideration of pedestrian flow. The impedance of pedestrian causes a significant decrease of system speed by up to 60%. The figures prove that the important role of crossing pedestrians in any traffic network analysis. It is especially significant at studied sites where there is high number of crossing pedestrians.

The research has some weak points needed to be improved. The vehicle-pedestrian interaction affects not only the traffic network performance but also the pedestrian behavior as well as pedestrian safety. Although there have been many research studies on pedestrian behavior and pedestrian safety as mentioned in the introduction part, these studies did not analyze comprehensively the real complicated behavior of pedestrians when crossing at intersections in urban streets. Therefore, it should be a target of further studies. In addition, the traffic proportion, turning proportion, etc. are important factors that were not studied much in this in this research. A more comprehensive study should be carried out to deal with these factors.

In modern cities of Japan, because the number of crossing pedestrians increases day by day due to the improvement of public transport system, environmentally friendly campaigns, etc., the consideration of pedestrian effects when analyzing traffic situation should be specially concerned. Especially for the case of Nagaoka city, the number of crossing pedestrians on the road No.365 from Oteohashi bridge to Nagaoka station has increased recently. The reason is that this area has Nagaoka station as a terminal where transport modes are transfered; Aore Plaza was opened; or a lot of shopping centers are located around here. The increasing number of pedestrians causes negative impacts on traffic flow as well as emerges many problems concerning pedestrian safety. Special treatments to pedestrians such as the deployments of scramble crossings, special policies to pedestrian, etc. should be applied to encourage walkability and take form an environmentally friendly transport system.

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