ERGONOMIC IMPROVEMENT OF VISIBILITY AT URBAN INTERSECTIONS FOR PREVENTING FREQUENT CROSSING COLLISIONS

Midori Mori and Sadao Horino
Department of Industrial Engineering and Management, Faculty of Engineering
Kanagawa University
3-27-1 Rokkakubashi, Kanagawa-ku, Yokohama 221-8686 JAPAN
Corresponding author’s e-mail: mori@kanagawa-u.ac.jp

Abstract: In Japan, quarter-million crossing collisions at intersections accounted for one-fourth of the total accidents in 2005 and more than half of them occurred at uncontrolled intersections in urban areas. Our studies revealed that risks of crossing collisions were due to poor visual environment at intersections. The present study aims to clarify the visual environment at urban intersections and to discuss risks and countermeasures for safety in crossing collisions in terms of direct visibility, as well as of indirect visibility assisted by traffic convex mirror. Field study revealed that 80% of the right/left-ward visible ranges at 27 routes at 19 intersections with lower priority were insufficient to confirm the safety; meanwhile 60% of 23 mirrors compensating poor quality of direct visibility did not function for the safety. Therefore, the improvement of direct/indirect visibility at intersection should be given the highest priority and the feasibility of low-cost/low-technology oriented countermeasures was practically proved.

1. INTRODUCTION

Quarter-million crossing collisions at intersections, the second most frequent pattern among traffic accidents following rear-end collisions, accounted for one-fourth of the total accidents in Japan, 2005 and doubled in last 20 years. Three-fourths of crossing collisions occurred at urban intersections, more than half of them occurred at uncontrolled intersections.

Considerable number of investigations and measures for prevention of traffic accident have been conducted from traffic/road management authority point of view which focused mainly driver’s carelessness as for causes of accident, consequently emphasized safety enforcement and education rather than engineering redesign and/or control of traffic environment (ITARDA, 2003). However, ergonomic study on preventing crossing collisions should focus on what really happened and why accidents frequently occurred at uncontrolled intersections.

Previous studies done by authors revealed that risks of crossing collisions depended on the quality of visual environment of intersections, including indirect visibility provided by traffic convex mirror at an intersection. Our ultra-wide-angle photograph analysis revealed that most of right/left-ward visible ranges at 10 intersections were insufficient to confirm the safety, and the quality of the direct visibility was closely associated with the frequency of crossing collisions. In addition, more than half of 23 traffic convex mirrors (“mirror(s)” ) installed at urban 10 intersections in Yokohama had marked shortcomings as a device for ensuring the safety in crossing and preventing collisions, and ergonomic guidelines for installing mirror were proposed (Mori et al., 2006; Horino et al., 2006).

In response to our proposal based on these results, the road management authority in Yokohama improved visibility of these mirrors by repair works in June 2006 by applying “three ergonomics requirements” suggested by us. The present study, therefore, aims to clarify the visual environment at urban intersections before and after the improvement and to discuss dangers and countermeasures for the safety in crossing collisions focusing direct/indirect visibility assisted by mirror.

2. METHOD

2.1 Overview of the Field

The Road Traffic Law in Japan requires drivers to drive on the left side of the road and drivers with the lower priority to stop momentarily at a legal stop line while crossing uncontrolled intersections.

A field study was carried out to measure and assess the direct visibility from drivers’ viewpoint while crossing along 27 routes of lower priority at 19 intersections, as well as the indirect visibility provided by 23
circular convex mirrors mounted on 15 poles at 10 intersections (coded as “a” through “l”) (Figure 1). Traffic environment, traffic volume, and structural settings resembled each other among these intersections located in Tsurumi Ward, a south-east urban community area in Yokohama.

Figure 1. Overview of the Field: Tsurumi Area in Yokohama, Japan

2.2 Assessment of Visual Environment at Intersections

2.2.1 Ultra-wide-angle Photograph Analysis

An ultra-wide-angle photographs of the front field of vision at 180 degrees were obtained at 19 intersections. The composite photograph was composed of 7 pictures taken by a digital camera, making use of the picture processing software (Figure 2).

Seven photos were taken continuously from drivers’ eye point, vertically at 1.2m height from the ground level and horizontally at 3 different points; at 2.1m behind the front end of a test passenger car while stopping at a legal stop line (P1); at 2.1m behind the boundary line between an intersection and the crossing road (P2); and where direct right-left visibility became perfect (P3).

2.2.2 Assessment of the Direct Visibility

The visual environment at intersection was assessed by the following criteria (Figure 2): (1) items obstructing the visual environment; (2) items enhancing the visual environment; (3) the right/left-ward visible range \(D_1\): the value measured] measured at P1 and P2: the visible distance from drivers’ eye point between c-d (Right)/a-b (Left); and (4) the minimum right/left-ward visible range for safety confirmation \(D_0\): the value calculated] at P1 and P2: the minimum visible distance from drivers’ eye point between c-d/a-b necessary for confirming the safety of crossing road.

(1) Obstructing items and (2) enhancing items were analyzed by making use of the ultra-wide-angle composite photograph. (3) Right/left-ward visible range \(D_1\) were actually measured at intersections and (4) The value of \(D_0\) were calculated as the travel distance of an approaching car with higher priority while a car with lower priority stopping at P1 or P2 went across an intersection, on the basis of Equation (1),(2). The direct visibility was assessed whether a driver with lower priority could look over the distance \(D_1 > D_0\) or not \(D_1 < D_0\), and indicated in 2-grade scale; “+: Good”, namely effective to confirm the safety \(D_1 > D_0\) and “-: Poor”, so dangerous to be improved \(D_1 < D_0\).

2.2.3 Assessment of the Indirect Visibility Provided by Mirrors

Photograph of each mirror was taken by a digital camera from drivers’ viewpoint at a legal stop line, entering from lower priority direction. The indirect visibility of mirror was assessed using the following 3 criteria and indicated by a 3-point scale: (1) position of road lane, (2) blind area, (3) road surface markings (Figure 2). Combining 3 criteria, it was assessed in 2-grade scale as follows; “G: Good”, namely effective to confirm the safety and “P: Poor”, so dangerous to be improved (Mori et al., 2007).
In addition, the distance between four spots on road-side reflecting on a mirror edge and the boundary line were actually measured as for the right/left-ward indirect visible range from drivers’ eye point at P1.

2.2.4 Assessment of the Continuity of the Direct Visibility and the Indirect Visibility

The amount of blind areas in right/left-ward visible range was measured as an index of the continuity of direct/indirect visibility, because complementary relationship between direct/indirect visibilities was essential to ensuring safety.

2.3 Frequency and Pattern of Collisions at Intersections

The frequency and pattern of crossing collisions resulting in injury or fatalities at 10 intersections from April 1998 to November 2006 were investigated through cooperation of a local police authority.

3. RESULTS AND DISCUSSION

3.1 Assessment of Visual Environment at Intersections

3.1.1 Right/left-ward visible range and obstructing/enhancing items for visibility at stop line (P1)

The right-ward visible distance \(D_1\) at P1 varied between 1.7 m and 55.0 m (median: 7.0 m; IQR: 4.1-11.5 m), while the left-ward visible distance varied between 0.9 m and 77.2 m (median: 6.8 m; IQR: 5.2-11.9 m) (Figure 2). A driver with lower priority could look over the minimum right/left-ward visible distance for safety confirmation \(D_0\) (41.7-57.8 m) \(D_1 > D_0\) at only 3/54 routes (6%).

![Figure 2. Direct/Indirect Visibility Not Improved even after the Repair Work (No.1B, 2006)](image)

Various obstructing items located along the street included buildings, private/public facilities and trees. The top 3 items were walls, telegraph poles, and fences (39-19%, respectively among all 54 routes). Meanwhile, only 3 items such as corner cut-offs, open spaces, and sidewalks were identified as enhancing items (42/54 routes).
3.1.2 Right/left-ward visible range and obstructing/enhancing items for visibility at boundary line (P2)

$D_1$ at P2 varied as follows; [Right] 9.6-291.4 m (median: 28.4 m; IQR: 16.7-42.9 m), [Left] 7.6-326.0m (median: 30.1 m; IQR: 3.9-52.7 m). A driver with lower priority could look over $D_0$ (33.3-47.8 m) [$D_1 > D_0$] at 10/54 routes (19%). Various obstructing items were identified at 53/54 routes and 3 enhancing items were identified at 50/54 routes.

Most of the right/left-ward visible distance [$D_1$] showed wide distribution, but was not enough to confirm the safety at either P1 (94%) nor P2 (81%). In addition, the front end of a passenger car should enter 1.4-4.0 m into the intersection from a boundary line at 22/27 routes/intersection, to get perfect direct vision of the crossing road.

The result revealed dangerous situations was common and this apparently caused crossing collisions. Buildings and/or private/public facilities were identified as obstructing direct visibility by creating a blind area at both P1 and P2 except for only one route.

Although the traffic management authority has emphasized whenever crossing an uncontrolled intersection, a driver should stop and confirm safety at the legal stop line to prevent crossing collisions, it was almost impossible to do so at these intersections, because of the poor direct visibility.

3.2 Association between Quality of Visual Environment and Frequency of Collisions at Intersection

The association between the quality of direct/indirect visibility and the frequency of crossing collisions along 27 routes/19 intersections before the repair work (1998-2005) was analyzed.

Visual environment at 27 routes/19 intersections were classified under 6 types (a-f), which were combination of the quality estimation for direct visibility (2 categories) and indirect visibility (3 categories). The quality of direct visibility was estimated as follows: “+: Good” and “- Poor” focusing on the minimum visible distance for safety confirmation, and the indirect visibility was estimated as follows; “+: Good”, “- Poor” and “0: Not applicable (mirror was not installed)” using “three ergonomics requirements” for installing mirrors (Table 1).

<table>
<thead>
<tr>
<th>Category</th>
<th>Visibility</th>
<th>Direct</th>
<th>Indirect</th>
<th>Right-ward</th>
<th>Left-ward</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Accident frequency</td>
<td>Route/ Intersection</td>
<td>Accident rate(%)</td>
<td>Accident frequency</td>
<td>Route/ Intersection</td>
</tr>
<tr>
<td>a</td>
<td>+</td>
<td>2</td>
<td>2</td>
<td>1.0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>b</td>
<td>+</td>
<td>5</td>
<td>4</td>
<td>1.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c</td>
<td>-</td>
<td>17</td>
<td>4</td>
<td>4.3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>d</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>e</td>
<td>-</td>
<td>15</td>
<td>13</td>
<td>1.2</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>f</td>
<td>-</td>
<td>10</td>
<td>4</td>
<td>2.5</td>
<td>23</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>49</td>
<td>27</td>
<td>1.8</td>
<td>52</td>
<td>27</td>
</tr>
</tbody>
</table>

*Direct visibility [direct visible distance from stop line/boundary line (D1)] + : D1>D0, − : D1<D0
Indirect visibility [1. position of road lane, 2. blind area in a mirror image]
+: 1.center, 2.none, − : 1.peripheral, 2. slightly or seriously, 0 : mirror not installed

By comparison in the past 8 years, it revealed that the collision frequency in “Good” direct visibility varied as follows; the indirect visibility was Poor (c. 2.8 cases/route) >was Good (a. 1.3 cases/route) or was Not applicable (b. 1.3 cases/route), whereas the collision frequency in “Poor” direct visibility varied as follows; the indirect visibility was Poor (f. 3.3 cases/route) >was Good (d. 1.0 cases/route). In another word, the collision frequency under good indirect visibility is almost same with it under “good” direct visibility (a. & b. 1.3 cases/route). This implies the indirect visibility is vital to prevention of collisions. Namely, uncontrolled intersections with “Poor” indirect visibility installed of non-ergonomic mirror tends to increase
crossing collisions. They should be installed at intersection for the sake of compensating a shortage of direct visibility of intersection, and confirming safety on a crossing road (Moukhwas, 1987). To realize this demand, the present official guideline (Japan Road Association, 1980) should be revised so as to meet “three ergonomic requirements” (Horino et al., 2006; Mori et al., 2007).

3.3 Assessment of the Continuity of Direct Visibility/Indirect Visibility at Intersection

3.3.1 Comparative Assessment of the Indirect Visibility of Mirrors

Thirteen mirrors (57%) were repaired by the road management authority in Yokohama(2006). As a result, mirrors assessed as “Good” based on the “three ergonomics requirements” criteria after repair works of 12(52%) increased by 22% compared with 7(30%) before the repair (Mori et al., 2007). However, only 10/23 mirrors (43%) were installed as compensating a shortage of the direct visibility of intersection and confirming the safety of crossing road.

Half mirrors were still improperly installed and had limited effect on preventive safety even after the repair work. However, simulation analysis using CAD system showed that 7/11 poor mirrors could be improved by low-cost/low technology oriented measures. In addition, application of new practical guidelines for mirror installation proposed by us including “three ergonomic requirements” for preventive safety, is a typical low-cost and low technology-oriented simple improvement to prevent crossing collisions.

3.3.2 The Continuity of Direct Visibility and Indirect Visibility at Intersection

The continuity of direct/indirect visibility at intersection, that is to say, the complementary relationship between direct/indirect visibility varied as follows; enough visible distance provided by good direct visibility \((a+b)\) were 20%, or good indirect visibility \((d)\) were 4%, and poor indirect visibility \((c+f)\) were 35%, poor direct/indirect visibility \((e+f)\) were 63% (Figure 3).

It might be noted that drivers were unable to look over enough visible distance at “No. 1 B”, where frequent collisions occurred (R: 5 cases/8 years, L:4 cases/8 years), due to the blind area not improved even after the repair works (Figure 2). This intersection was a typical example posing a structural risk of frequent accidents, because both the direct and the indirect visibility which essentially is supported by mirrors were poor.

Furthermore, mirror is not always necessary for intersections where already satisfying necessary direct visible distance to confirm the safety \((a+c:17\%)\). Intersections where poor mirrors are installed might have more risks of collision to compare with intersections without mirrors, as described above 3.2.
3.4 Feasibility Study of Improvement of Visual Environment at Intersections

Blind areas at uncontrolled intersections not covered by the direct/indirect visibility were found within [right] 3.9-14.0m, [left] 7.6-10.6m from the boundary line. Basically, a visible distance on the crossing road close to intersection is to be ensured by the direct visibility. Therefore, improvement of the direct visibility as well as improvement of the mirror would be effective to prevent collisions.

Case studies were conducted on the effect of the direct visibility improvement by removing or displacing obstructing items such as a telegraph pole and installing corner cut-offs, and the feasibility of these measures through cooperation between the road/traffic management authority and the community was proved.

4. CONCLUSIONS

Field studies using ultra-wide-angle photograph analysis revealed that 80% of the right/left-ward visible range at 27 routes/19 intersections with lower priority was insufficient to confirm the safety; meanwhile 60% of 23 mirrors compensating poor quality of direct visibility did not perform function and more collisions occurred at intersections with poorly functioned mirrors.

The improvement of direct/indirect visibility should be given the highest priority and the feasibility of low-cost and low-technology oriented countermeasures through cooperation between the road/traffic management authority and the community was proved.

Crossing collisions at intersections can be prevented by improving the visual environment; improvement of direct visibility removing obstructing items and/or installing corner cut-offs, as well as improvement of indirect visibility displaying clear information by ergonomically-installed mirrors.

5. ACKNOWLEDGEMENT

Authors present heart-full thanks to Mr. Tatsuomi Oniki and Mr. Yasutaka Shimizu for their eager cooperation with this research project through their graduate thesis.

6. REFERENCES


EQUATIONS

Equation to Get the Safe Visible Distance \([D_0]\) for Right/Left-ward

\[
t = \sqrt{\frac{2(w + x + y)}{\alpha}}
\]  \hspace{1cm} (1)

\[
D_0 = \frac{V}{3.6}t
\]  \hspace{1cm} (2)

- \(t\): passing time through an intersection of vehicle with lower priority [s]

- \(V\): speed limit for vehicle with higher priority [m/s]

- \(\alpha\): acceleration at start, 1.5 [m/s²]

- \(x\): distance between the intersection boundary line and the point of driver’s eye-point projected on the ground level [m]

- \(y\): distance between the eye-point of driver and the rear of a vehicle [m]

- \(w\): the width of road with higher priority [m]