vide the motorist with more-complete information about the nature of the hazard and an appropriate safe approach speed. This could be accomplished with the use of special-message advance-warning signs coupled with speed advisory plates.

Finally, the results of the study indicate that driver-education activities (such as Operation-Lifesaver) should offer an important contribution to the safety problem at grade crossings by making motorists more aware of hazards at grade crossings and how to respond to them. This includes an understanding of the function and operation of the various types of warning devices.

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Pedestrian Cross Flows in Corridors

C. J. KHISTY

An investigation into the nature of pedestrian cross flows in corridors at right angles to one another is described. This study was undertaken by using time-lapse photography to determine the effect of a minor pedestrian flow crossing a major pedestrian flow. Such cross flows of pedestrians are common in major activity centers and in special event transportation systems, such as universities, bus stations, art galleries, museums, and places of entertainment. The results of this study were compared with those obtained from theoretical gap and collision analysis. The comparisons were found to match closely. A design criterion for facilities where cross flows of pedestrians occur is developed based on the data gathered from the films and the theoretical analysis.

This paper describes a study undertaken at Washington State University to examine the characteristics of pedestrian cross flows in corridors, passageways, and hallways and to determine the effect of one pedestrian flow crossing another. Statistical analysis was used to explain these characteristics and to establish a design criterion for facilities where such cross flows of pedestrians occur. Flow characteristics of pedestrians in single channels have been studied and documented by several researchers (1-4). However, investigations into the nature and characteristics of pedestrian cross flows is very limited (5).

Pedestrian crossing movements in this study were observed by using time-lapse photography. Speed-density-flow relations were established from data derived from films. Pedestrian conflicts at cross flows were also observed and analyzed from films. Subsequently, a theoretical gap analysis was used to verify the experimental work. A design criterion based on this investigation is suggested for pedestrian facilities.

PEDESTRIAN CROSS FLOWS

Cross flows of pedestrians are ubiquitous. Corridors, passages, and hallways in schools, booking offices, cinema theaters, art galleries, museums, and places of entertainment are instances where such cross flows are commonly observed. Where pedestrian densities are low, cross flows of pedestrians seldom create problems; but when the pedestrian densities in one or both streams are heavy, the probability of conflicts is high.

Corridors, for instance, dominate the space configuration in buildings. When two corridors cross one another, their users have to use a common area, similar to an uncontrolled highway intersection. Corridors in school and college buildings serve to circulate their users when class schedules require movement of students and faculty on an hourly basis. Conflicts of two pedestrian streams at the junction of two corridors are all too common in such situations. When corridor widths are narrow and the pedestrian concentrations are high in both streams, pedestrian walking speeds, particularly in the minor flow, come to a standstill and queues build up. In the major flow there is evidence of extremely restricted walking speeds, shuffling, and frequent conflicts. One of the reasons for this condition is that corridor widths are usually determined by building codes rather than with respect to pedestrian traffic demand. Even those guidelines and design criteria currently used for corridor design do not take cognizance of cross-flow con-

Figure 1. Location map.

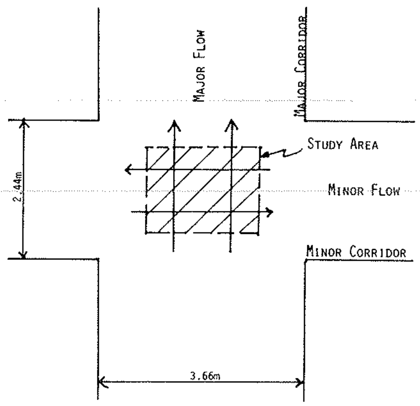


Figure 2. Density and speed relation of major flow.

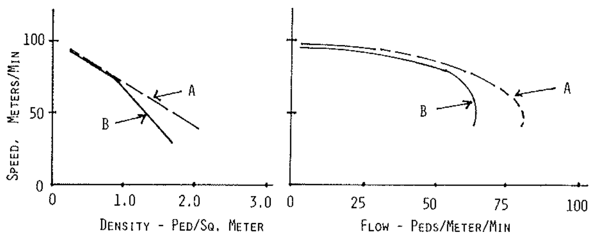
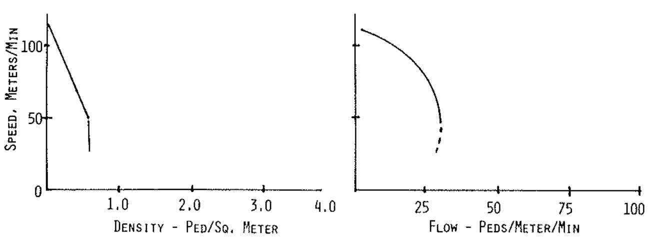


Figure 3. Density and speed relation of minor flow.

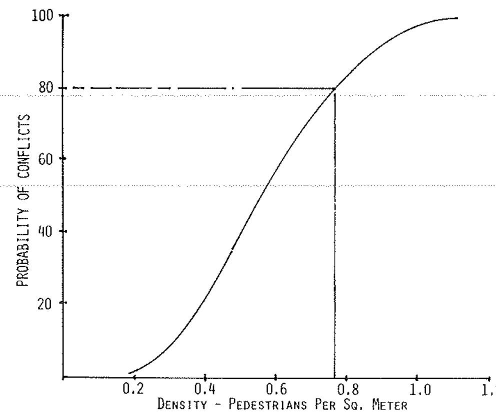


flicts between pedestrians. Generally, two corridors cross one another, where one of the corridors serves the main stream and the other the minor stream. As densities in the main stream rise higher and higher, there is a corresponding increase in conflicts. These conflicts are obviously a function of walking speeds and pedestrian spacing in the main stream. For the purpose of this investigation a conflict is defined as any stopping and shuffling or breaking of the normal walking pace due to a close confrontation with another pedestrian. Such confrontation naturally requires immediate adjustment in speed and direction to avoid collisions (1).

LOCATION AND TECHNIQUE

Although the campus buildings of Washington State University abound with locations where moderate-to-heavy cross flows of pedestrians occur, a location that was suitable to photograph was not easy to find. Basically, a fairly simple location was desired, where two pedestrian flows cross preferably at right angles and where natural boundaries to each flow prevent people from spreading out all over. We desired that each individual flow be predominantly in one direction (in contrast to being two-way). A location that matches these preferences was found

Figure 4. Cross-flow traffic conflicts.



where the pedestrian flow in the corridor crossing had a large variation, and this afforded an opportunity to make observations in a variety of flow conditions. The main corridor is 3.66 m wide and the minor corridor is 2.44 m. The area considered for analysis was 2x1.5 m, and this was clearly marked on the floor of the two intersecting corridors. The number of pedestrians crossing this demarcated area and their speeds was calculated based on this area. This avoided the problem of contending with the edge effect (see Figure 1).

For 3-5 min every hour there is a heavy surge of pedestrians (95 percent students) in the major flow, predominantly in the same direction. A similar flow of somewhat weaker proportion attempts to cross the main flow at about the same time. Time-lapse photography was used in filming this location at a speed of 18 frames/s. Although this speed was not necessary for this study, the equipment available necessitated use of this speed. Filming was done on two different days: Thursday, November 6, and Tuesday, December 2, 1980, during the 12:00 noon and 1:00 p.m breaks. Data were gathered on two rolls of film--super 8, each 15 m long. The analysis of the film was done by using a hand-operated editing machine. All timing measurements were initially made in frames and subsequently converted to real time.

Data

The films yielded two sets of data: first, the flow (q)-density (k)-speed (v) information for the major and minor streams of pedestrians who cross the study area, and second, the number of conflicts observed between pedestrians at different densities.

Flow-Density-Speed (q-k-v) Relations

The q-k-v relations were established for two conditions. In the first case the major flow was observed just before it intersected the minor flow. This is shown as curve A in Figure 2. In the second case, the major flow was observed with the minor flow and the corresponding curve is marked B. Figure 3 shows the q-k-v characteristics for the minor flow crossing the major flow.

Conflict Study

The number of collisions or near collisions were counted when the major and minor streams were crossing at various densities. Figure 4 shows the relation between pedestrian densities and the percentage of collisions that occurred in the study area.

Analysis and Discussion

An examination of curves A and B in Figure 2 indicates no significant change in the major flow pattern because of the minor flow up to a pedestrian density of about 0.8-1.0 pedestrians/m^2. Beyond this density the difference between curves A and B for flow and speed increases progressively. The curves shown in Figure 3 for the minor flow appear to confirm that the minor flow suffers when the density reaches 0.7-0.8 pedestrians/m^2. Notice that speeds for the minor flow are slightly higher than speeds for the major flow when the densities are low. This is probably because pedestrians in the minor flow have to be more aggressive in crossing the major flow.

An important observation made from the films was that the speed and density of the major flow were more or less independent of the minor flow. In fact, the minor flow was heavily dependent on the characteristics of the major flow. Evident, for example, is that pedestrians in the minor flow waited outside the major flow until a large enough gap appeared, and then accelerated their pace to get across. The streams hardly mixed, except for a very small number of pedestrians who turned right or left. Also, the major flow appeared to be homogeneous and continuous as opposed to the minor flow, which was in some cases discontinuous or stationary.

The films also brought out that, when the density in the major flow reached levels beyond about 1.0 pedestrians/m^2, the minor flow reduced drastically and queues built up. In fact, one found high densities building up in both the major and minor streams simultaneously.

Conflict Study

The analysis of pedestrian conflicts shown in Figure 4 connects the density of pedestrians in the study area with the percentage of conflicting pedestrians. In a sense the curve supports that, at density of about 0.8 pedestrians/m^2, the conflicts are 80 percent. A close examination of the films revealed that restricted passage of the minor flow through the main flow could be accomplished at densities even higher than 0.8 pedestrians/m^2 but pedestrians, in such cases, invariably turned themselves sideways to expose the minimum profile position in order to pass.

Gap Analysis

In order to verify the conclusions drawn from the films, an analysis of cross flows by using gap analysis was used. If two pedestrian streams, one major and one minor, cross one another, what is the flow in the main stream that will make it uncomfortable for pedestrians in the minor stream to cross?

The analysis assumed that pedestrians crossing the minor stream constitute a Poisson process, and that the width of the main stream is 1 m. Also assumed was that the speed of pedestrians that cross the main stream is 1.22 m/s. The number of t-second intervals in an hour is 3600/t, whereas in an interval of t seconds, the probability of no pedestrians passing through the area is e^{-vt}, where v is the pedestrian speed. Based on these assumptions, the number of pedestrians who can cross the main stream was tabulated and the results are given in the following table:

Capacity of Pedestrian Cross Flows [(pedestrians/min)/m] Major Flow Width, A	Minor Flow Width, B	Total Capacity (pedestrian/min)
30	30	60
40	28	68
50	25	75
60	22	82
70	19	89
80	17	97

Recognize that these results indicate, in effect, some capacity values of pedestrians in a minor stream to cross a major pedestrian stream based on queuing theory (7). The major and minor cross flows shown in the table match the experimental results fairly closely. When the values of the permissible flows in the major and minor streams shown in the table are added, it appears obvious that this figure could be used for practical design purposes.

Design Criterion

When this study was undertaken, one of the important objectives was to gather sufficient data about the character and nature of two pedestrian cross flows to suggest an acceptable design criterion. Design and performance criteria are the preferred means of control where they can be administered capably.

Based on the discussions and also on the general objectives of providing continuity, convenience, and comfort (1), the following values are suggested:

1. Minimum speed of 60 m/min,
2. Maximum flow of 75 pedestrians/min/m for the total of the two flow rates, and
3. Maximum density of 0.8 pedestrians/m^2.

This suggestion compares well with that recommended by Weston and Marshall (5).

SUMMARY AND CONCLUSION

The investigation described in this paper determines the characteristics of pedestrian cross flows in corridors. The data and analysis from this study were compared with results derived from a theoretical gap analysis. A design criterion suggested is to limit the maximum density in such cross flows to 0.8 pedestrians/m^2.

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Portable Intersection to Accelerate Travel Training of Mentally Handicapped Children

LOUIS J. PIGNATARO AND JOSE ULERIO

This paper describes the design and construction of a portable intersection system to facilitate the travel training of severely and moderately mentally handicapped children. It also describes the procedures used to evaluate the effectiveness of the portable intersection as a teaching tool. The test results showed a statistically significant improvement in test scores with the intersection trainer, both relative to pretraining scores and posttraining scores of a control group trained in the conventional way.

Most of us cross an intersection several times a day without thinking about it, but for thousands of mentally handicapped children this is a hazardous and sometimes impossible task to accomplish. Many handicapped children have learned to board a bus or train and reach their destination but cannot travel independently because of an inability to cross streets safely with consistency. Flashing DON'T WALK signs, traffic lights, street noise, and moving vehicles often confuse mentally handicapped children and create a potentially hazardous condition not only for the child but also for the motorist.

The New York City Board of Education's travel training program teaches handicapped students to travel independently on the public transportation system. The program is designed to provide individualized instruction in transportation skills to handicapped students. Included in this instructional program are the following skills:

1. Safe crossing of streets,
2. Identification and boarding of the correct bus or subway,
3. Exiting of bus or subway at the correct stop,
4. Obtaining assistance when necessary (i.e., lost situations), and
5. Appropriate behavior.

Travel Training is a citywide program that offers instructional services to handicapped students who attend special classes in schools throughout the city. Handicapped students who receive these services are taken out of their classrooms by specially trained travel trainers and return to their classrooms after completing the instructional program. Frequently these students have had little or no experience or specific instruction in travel or travel-related skills prior to entering the program. Therefore, the Travel Training staff uses considerable instructional time in teaching basic prerequisite travel skills, such as street crossing. Over a 10-year period, 85 percent of the handicapped students who participated in the Travel Training program have successfully achieved independent travel. As a result of the program's success, the New York State Education Department validated the program in 1976 and granted funds for the program to assist school districts throughout the state to replicate the program. The inability to cross streets safely with consistency is a major factor in the failure of those students who are not successful in travel training. The specialized nature of the program does not provide sufficient time for any of these students to acquire these basic skills. The present method of teaching street-crossing skills in the classrooms allows for little exposure to an actual intersection for safety reasons, especially when the students are young children or severely handicapped.

A method of exposing the child to a real intersection had to be developed if a child was to behave in a rational manner when approaching an intersection. He or she would have to know that when the signal changed to green he or she had the chance to cross the street. He or she would have to know that when he or she approached an intersection that did not contain a traffic signal, he or she would have to look in both directions before crossing when no cars were coming. The best way to accomplish this type of training was to build an intersection that could be placed inside a classroom where the training could be done by the teacher or an instructor. The intersection had to be relatively easy to assemble and disassemble, compact, and, most importantly, portable.

The Transportation Training and Research Center at the Polytechnic Institute of New York undertook the effort of designing and constructing a portable intersection to facilitate the travel training of severely and moderately mentally handicapped students.

The project's aim was to design, build, and test a small portable intersection that could be assembled and taken apart with relative ease and that could be stored within a relatively small area.

The project was divided into three phases:

Phase 1: Development of preliminary construction plans and construction of prototype model,
Phase 2: Construction of portable intersection, and
Phase 3: Testing and evaluation of the portable intersection.

The intersection system is made up of fiberglass modules that simulate sidewalks, traffic signals, and pedestrian crosswalks; traffic signs; a miniature car and bicycle; barricades to simulate construction areas; a tape recording of traffic noise at an intersection; and a video recording for training instructors and students on how to set up the