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A Computer Simulation Analysis for the Development of Pedestrian Overpasses on King Fahad Road in Riyadh, Saudi Arabia

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Abstract. King Fahad Road, a limited access cross-town expressway running north and south within the city of Riyadh, has a problem with numerous pedestrian crossings on the roadway surface. The problem appears to be particularly acute on the portion of roadway north of Khurais Road. This is a section of roadway severely lacking in facilities to provide for pedestrian crossings. This section of the highway had originally been designed as a typical 80-meter street. Pedestrian overpasses, however, were not adequately provided nor were consideration taken of previous traffic and pedestrian movement patterns. In fact, and because King Fahad Road is designed as an express way, several previously-existing street intersections at grade are now blocked, resulting in inconveniences to pedestrian and vehicular traffic.

While the function of the roadway has changed from a major arterial street to a limited access expressway, the needs of pedestrians, in particular, have not changed. Many people in this portion of the highway cross in order to assume commercial activities and in the opposite direction in the afternoon. This results in a significant number of pedestrian crossings taking place continuously.

This paper relied on the empirical evidence gathered and the methodology utilized in gathering the data in the study area and at the time described. Data was collected using direct observational techniques in the study area, with the author and three hired junior planners serving as data collectors. The analysis is based on a computer program to simulate the optimum development of pedestrian overpasses locations based on the field-collected data. It confirms the shortage in pedestrian overpasses.

1. Introduction

King Fahad Road, an expressway running north and south through the central portion of Riyadh, links the northern and southern ring roads. While the section of the expressway south of Khurais Road has been better-planned, with pedestrian bridges being provided and the expressway being lower than the normal street level in densely populated areas, the section of the expressway north of Khurais Road was converted into a limited access expressway after the original construction. This section of the highway had originally been designed as a typical 80-meter street. Facilities such as pedestrian overpasses were not adequately provided, nor were the highway recessed below the normal street level, nor were consideration taken of previous traffic and pedestrian movement patterns. In fact, and because King Fahad Road is designed as an express way, several previously-existing street intersections at grade are now blocked, resulting in inconveniences to pedestrian and vehicular traffic.

While the function of the roadway has changed from a major arterial street to a limited access expressway, the needs of pedestrians, in particular, have not changed. From field observations, many people were found crossing King Fahad Road as a result of commercial activities. This results in a significant number of pedestrian crossings taking place continuously.

Due to the high traffic volume and high speeds (100-120 km/h speed limits), which characterize vehicular traffic on King Fahad Road, pedestrian safety and pedestrian time to cross are prime considerations involved in the need to improve facilities for pedestrians. Moreover, due to the extreme length of roadway confronted with such pedestrian crossing problems, there is also the problem of determining the number of pedestrian bridges to employ, and consequently, their optimal deployment. In addition, it must also be considered how pedestrians will make use of such facilities, once they are properly and sufficiently provided. This consideration is well-stated by Firth [1].

> "The provision of designated crossing facilities for pedestrians is probably the most popular environmental countermeasure aimed at pedestrian safety. Footbridges, subways, pelican, and zebra crossings are all regarded as safe places for pedestrians to cross the road, but to be of value they must be used by the pedestrian and used effectively."

Mackie and Older [2] used empirical evidence to demonstrate that the risk of an accident to a pedestrian is the lowest on a designated crossing facility, but crossing within 50 yards of such a facility greatly increased the risk. Thus, the problem becomes one of attempting to determine the appropriate number and locational deployment of pedestrian bridges such that pedestrians will willingly utilize such facilities without being coerced into doing so through design features employed primarily as a means to discourage or prevent pedestrian unlawful crossings. Although intended for the safety of both drivers and pedestrians, such features can be aesthetically unpleasant, such as high fences or walls on the median strip or on the outside of traffic lanes.

A review of the literature reveals many articles dealing with pedestrian disobedience at signalized intersections, or mid-block crossings; however, research is scant pertaining to behavior in the presence of pedestrian overpasses. The Florida Pedestrian Planning and Design Guidelines indicate that grade-separated mid-block crossings can reduce pedestrian travel time and help to maintain the continuity of a neighborhood by providing a connection over major arterials or freeways [3]. However, depending on their design, grade-separated crossings often have significant drawbacks. Some grade-separated crossings are very steep and are difficult for people with mobility impairments to negotiate. They are often not considered pedestrian friendly because users are frequently forced to travel out of their way to use the structures. In the end, the effectiveness of a grade-separated crossing depends on whether or not pedestrians perceive that it is easier to use than a street crossing [3].

A significant study pertaining to pedestrian perceptions of crossing facilities was conducted in Scotland [4]. Surveys were conducted at 10 different crossing types at 30 sites, including three pedestrian overpasses (14% of the survey). In all, 890 interviews were undertaken. When asked the reason why they had chosen to use the crossing facility, 39% of interviewees cited convenience, 39% cited that it was on their route and 36% cited safety as a factor. The main reasons cited for not using the provided facility were that traffic was light or that it would take too long. Many more men gave this response than women.

At one overpass site, all pedestrians used the overpass, as it was the main route across a busy road leading to the center of town. At the second site, some people opted to walk to a round-about rather than cross with no crossing, but due to the road layout, most people used the bridge. At the third site, more people used a new pelican crossing under the bridge. About 65% of people interviewed at the overpasses rated the position of the crossing as important or very important in deciding to use it.

There were some pedestrian overpass-related studies such as the PEDROUTE way [5], bi-directional pedestrian flow characteristics [6], pedestrian route choices between escalator and stairway [7] and pedestrian travel time functions calibration and validation [8]. To extend the previous research on pedestrian behavior, the PEDROUTE is adapted to simulate pedestrian flow and validated with real data.

Early in 1985, the Transport and Traffic Survey Division of the Hong Kong recognized the need to study pedestrian movement characteristics. A comprehensive study of the pedestrian flow characteristics in Hong Kong was conducted [9] as well as research on pedestrian speed/flow relationships for walking facilities in Hong Kong [10].

Research on the analysis of factors affecting the choice of route of pedestrians [11] and pedestrian movements in Bangkok [12] concluded that pedestrian discomfort, frustration and concern for safety increase as the level of congestion increases, and high demand with limited capacity for pedestrian facilities result in a tremendous concentration of people. Therefore, it is particularly important to study pedestrian movements, especially during peak hour periods. The design of a pedestrian overpass is necessary for maximum realization of its capacity and safety of pedestrians. Predicting pedestrian flows and delays in congested areas requires a sophisticated pedestrian simulation/assignment model. The advancement of modeling, together with the research on pedestrian behavior, indeed contribute to the development of pedestrian simulation models.

II. The Study Area

A reasonably lengthy (approximately 1.7 km in length) section of King Fahad Road was chosen as an area in which closer study of pedestrian and vehicular movement would take place. This strip was located between Tahlia Street as the northern boundary, and the end of the commercial development approaching Khurais Road, as the southern boundary. Fences and other coercive devices exist south of the southern boundary, which restricts, but does not entirely prevent, pedestrian crossings (Fig. 1).

Fig. 1. The City of Arriyadh (Source: Generated by the author based on Riyadh Municipality General City Map).

This section of King Fahad Road was chosen because it met specific criteria of interest. These criteria include the following:

1. Informal observation had revealed that this section of highway was one in which the number of pedestrian crossings was the greatest due to commercial activates on both sides, thus rendering any research findings of greater interest to decision-makers.
2. This section of the highway was "contained" by these boundaries (viz., pedestrians proceeding to a destination north of Tahlia St., should use the already-existing Tahlia St., overpass, as presently available, and pedestrians proceeding to a destination south of the study area should be small in number due to the absence of commercial development south of the study area).
3. It was not intuitively obvious how many pedestrian bridges may be required for this area and where their optimal placement should be, thus leading to interesting results of greater interest.

Through informal observation it was noticed that the frequency of pedestrian crossings was particularly high during the early morning hours of the day when commercial activity was beginning (i.e., 8:00 – 10:00 a.m.), and the prime evening hours (4:00 – 6:00 p.m.). Moreover, due to the relatively high traffic densities characteristic during these periods, it was thought that the time taken for pedestrians to cross could be very long. Thus, it appeared through such informal observation that the need for pedestrian bridges was most critical during these periods on weekday. It was concluded that the times of interest for the study of the area described should be from 8:00 – 10:00 a.m. and from 4:00– 6:00 p.m. on a normal weekday.

III. Methodology

This section of the article is intended to describe the empirical evidence gathered and the methodology utilized in gathering the data in the study area and at the time described. These data were collected using direct observational techniques in the study area, with the author and three hired junior planners serving as data collectors. The data that was collected related to several pertinent issues:

1. The location of unlawful pedestrian crossings within the study area.
2. The number of unlawful pedestrian crossings that are taking place at each location.
3. The time required for pedestrians to cross.
4. The strength of relationship that exists between the pedestrian crossing time and the traffic density for variations in the range of traffic densities observed during peak times.
5. The observed demographic characteristics (i.e., age, gender and nationality) of these pedestrians.

Following a morning practice session in which observational check-list forms were tested and junior planners trained in data collection, a morning (May 19, 2003) was selected in order to collect data in the study area. For this pilot project, seven data collectors, including the author, were deployed in such a manner that they were distributed equidistantly along the study area on the east side of King Fahad Road. These data collectors were charged with the task of determining the location of each pedestrian crossing during the period of interest (i.e., 8:00 – 10:00 a.m. and from 4:00 – 6:00 p.m.) with the light posts along the highway (spaced evenly at approximate 80-meter intervals) serving as reference points for the data collectors. These start near the entrance ramp and end at the front of a vacant lot on the west side of the road. Each of these posts faces another one on the eastside of the road. Additionally, the data collectors were charged with assessing the demographic characteristics of each pedestrian, whether or not the pedestrian was encumbered with a large object (e.g., a bicycle), his crossing direction (i.e., west to east or east to west), and the beginning and ending time for each portion of his crossing (i.e., from the beginning of the time of attempting to cross to the time he reaches the median and from the time the median is reached until he reaches the opposite side of the expressway). One of the data collectors on each side of the highway was also charged with computing the traffic densities (vehicles per minute) in either direction on as many occasions as possible during the two-hour time period. It is noteworthy to point out that this approach is actually required even when using automated traffic counts. Observation was needed in order to better understand the problem; moreover, specific data for a specific location is not easily obtainable, as bureaucracy is still controlling the gathering of data.

IV. Data Collection Results

A summary of the data collected over this two two-hour time periods can be described as follows: 123 pedestrians crossed King Fahad Road during the two two-hour time periods. With regard to the demographic characteristics of the pedestrians, 100% of the pedestrians were adult males; an estimated 95.5% of the pedestrians were non-Saudi; while 1.6% of the pedestrians were encumbered by large objects (bicycles in both instances).

Of the pedestrian crossings, 59.9% of the crossings were from east to west and 40.1% of the crossings were from west to east. Traffic densities varied between 40 and 95 vehicles per minute during the study period. The average pedestrian crossing time, over the course of both directions of traffic, was 144.3 seconds with a standard deviation of 268.0 seconds. The pedestrian crossing locations for the 123 pedestrians observed are summarized in Table 1.

Table 1. Locational distribution of pedestrian crossings on King Fahad Road during period of study

Location (light post numbers)	Number of crossings	Percentages	Cumulative percentage
1 – 2	2	0.01626	0.01626
2 – 3	6	0.04878	0.06504
3 – 4	9	0.07317	0.13821
4 – 5	3	0.02439	0.16260
5 – 6	6	0.04878	0.21138
6 – 7	5	0.04065	0.25203
7 – 8	3	0.02439	0.27642
8 – 9	5	0.04065	0.31707
9 – 10	22	0.17886	0.49593
10 – 11	4	0.03252	0.52845
11 – 12	7	0.05691	0.58536
12 – 13	1	0.00813	0.59349
13 – 14	0	0.00000	0.59349
14 – 15	2	0.01626	0.60975
15 – 16	6	0.04878	0.65853
16 – 17	1	0.00813	0.66666
17 – 18	10	0.08130	0.74796
18 – 19	5	0.04065	0.78861
19 – 20	8	0.06504	0.85365
20 – 21	18	0.14634	1.00000
Total	**123**	**1.00000**	

Relating the time required for each pedestrian crossing with the traffic densities at the time of crossing, by utilizing the data points as noted in collecting each half of the total crossing time, one was able to compute the coefficient of determination for the relationship between these two variables. A large value for the coefficient of determination could have been useful in enabling further predictions on average crossing time for specified vehicle densities characterizing a portion of expressway at a given time during the day.

However, the coefficient of determination ($\mathbf{r^2}$) was computed to be .077 for the 246 data points collected (two data points for each pedestrian crossing). Thus, the strength of relationship between the variables, vehicle density and pedestrian crossing time, were shown to be very weak through the range of observed densities. A higher coefficient of determination would be expected for a dataset, which includes somewhat lower and somewhat higher traffic densities.

V. Analysis of the Data Using Computer Simulation

The data collected in this study, as described in the previous section, was utilized to calibrate a computer model of the author's own design. The computer simulation model required the location distributional data as input and through the generation of 500 random pedestrian crossings (employing the locational criteria), determined the average crossing time and the standard deviation of crossing time for all possible pedestrian bridge locations (considering from one to three pedestrian bridges to be deployed in the study area). A schematic flow diagram of the computer simulation program is shown in Fig. 2.

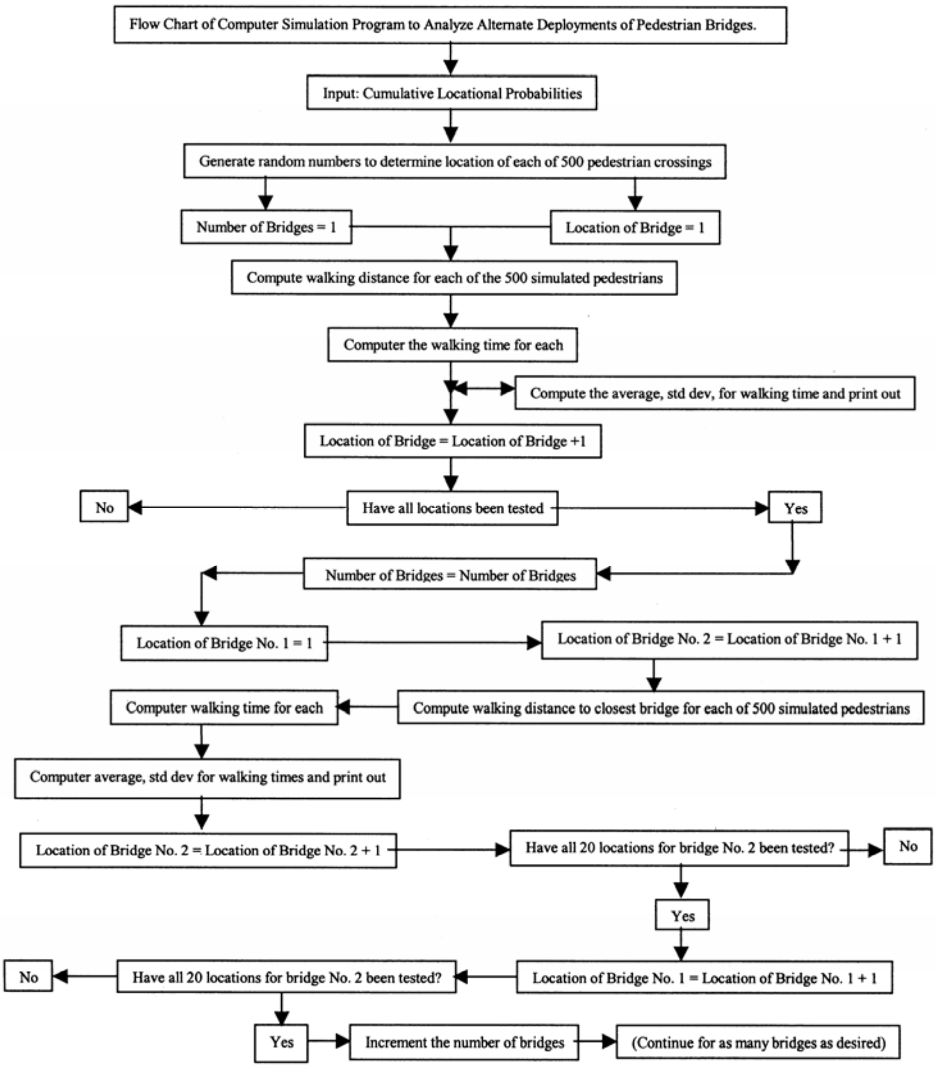

Fig. 2. A schematic diagram of the computer simulaiton model used to evaluate the deployment of pedestrian overpasses locations.

After completing a run of the model, the output from the model indicated that the optimal location for a single pedestrian bridge was between the 10^{th} and 11^{th} light posts (i.e. slightly south of Telateen Street), leading to an average pedestrian crossing time of 464.2 second with a standard deviation of 291.7 seconds. This compares very unfavorably with the observed average actual pedestrian crossing time of 144.3 seconds with a standard deviation of 268.0 seconds.

The model showed that if two bridges were to be deployed, the optimal locations would be between the 8th and 9th light posts and between the 19th and 20th light posts (i.e., slightly north of Telateen Street and close to the south end of the study area). The model further showed that such a two-bridge deployment would result in an average pedestrian crossing time of 223.0 seconds with a standards deviation of 144.1 seconds.

The model further showed that if three bridges were to be deployed, the optimal locations would be between the 3rd and 4th light posts, the 9th and 10th light posts, and between the 19th and 20th light posts. It was further shown that such a three-bridge deployment would lead to an average pedestrian crossing time of 142.1 seconds, with a standard deviation of 99.4 seconds. Of course, all other deployments of one, two or three bridges are sub-optimal, leading to greater average pedestrian crossing times. (See Table 2 for a summary of optimal pedestrian bridge deployments and their associated expected average crossing times, and standard deviations of crossing times).

Table 2. Optimal pedestrian bridge locations with associated crossings times as computed be the computer simulation model

Number of bridges	Location (s) (between light post numbers)	Average crossing time (secs)	Standard deviation of crossing time (secs)
1	10 – 11	464.2	291.7
2	8 – 9, 19 – 20	223.0	144.1
3	3 – 4, 9 – 10, 19 – 20	142.1	99.4
0	---	144.3 (measured)	268.0 (measured)

The question now must be addressed concerning the extent to which pedestrians are willing to take extra time in order to avoid a relatively unsafe crossing in favor of safe bridge overpass crossing. A number of articles in the academic literature have addressed the issue of how much extra time pedestrians are willing to spend in using a safe route as opposed to crossing at a less safe location.

Wade, *et al.* [13] reviewed a number of sources [14-16] and arrived at the following conclusion:

> "The amount of additional time pedestrians are prepared to occupy in using a safe route has received comment. Apparently, 100 percent usage of a bridge is likely to be observed when the bridge journey typically takes no more than three quarters of the time for the ground-level crossing."

The issue now arises concerning the application of this heuristic to the problem at hand: the proper number of pedestrian bridges to be allocated to the study area, since the issue of the recommended deployment of bridges has been determined by the computer simulation model for allocations of from one to the three bridges.

The data, as summarized in Table 2, indicates that the typical pedestrian crossing the King Fahad Road during the peak time period studied faces an average crossing time of a moderate 144.3 seconds with an excessively high standard deviation of 268.0 seconds. This indicates that the pedestrian is confronted with a huge variation in the quantity of time he may spend in crossing; the crossing may be short or it may be very lengthy (e.g., approximately 16% of the crossings take more than 412 seconds). Moreover, the length of time required to cross appears to have little relationship to the traffic density over those densities observed during peak time. If pedestrian bridges were to exist, the pedestrian would have to weigh in his mind the certainty of a known crossing time versus the wide variation in an unknown (and risky) crossing time.

Employing the criteria mentioned above would indicate that the typical pedestrian would be willing to face a crossing time of 252.5 seconds on a pedestrian bridge during peak times rather than risk the unsafe crossing at grade level. If only one bridge is optimally deployed, employing the data provided in Table 2 indicates that an estimated 75.4% of pedestrians may prefer to cross at street level during peak times rather than utilize the single pedestrian bridge. Similarly, for two pedestrian bridges optimally deployed, 40.1% of pedestrians may demonstrate the same preference and for three pedestrian bridges optimally deployed, 13.7% may prefer. Additionally, during times at which traffic densities are lower, we can expect to observe greater preferences to not using pedestrian bridges after deployment unless coercive devices are employed.

VI. Conclusions and Recommendations

The data collected showed that the frequent occurrence of pedestrian crossings is a significant problem on the segment of King Fahad Road that was studied. Indeed, limited access highways should be designed in such a manner to completely segregate pedestrian from vehicular traffic. With regard to the study area, and the results of the runs of the computer simulation model, it is evident that a comprehensive solution is required in order to alleviate this serious problem of an inappropriate pedestrian-vehicle mixture on an expressway. An effective comprehensive solution will include the following elements:

1. In order to meet the needs of pedestrians, three pedestrian's bridges should be recommended for construction in the study area. This will lead to an overall improvement in pedestrian crossings times during peak pedestrian and vehicular traffic time periods. Such an allocation will result in little desire on the part of pedestrians to cross without making use of the pedestrian bridges. Construction of overpasses is indeed substantial, but the cost of accidents could be equal or greater.
2. These pedestrian bridges should be deployed at the following locations:
   a) Near the front of the King Faisal Foundation Building (linking the commercial strip on the west side of King Fahad Road with the commercial and cultural development of the King Faisal Center).

b) At Telateen Street, connecting the western portion of the street with the eastern portion.

c) Near the south end of the study area, connecting the commercial development on either side of the expressway.

3. Coercive measures must be employed to a limited extent in order to ensure pedestrian compliance with bridge utilization, particularly during non-peak times when the desire to cross the expressway without utilizing the bridges will increase as a timesaving device. Such coercive devices should attempt to maintain the present aesthetic quality of the area while also providing for increased pedestrian and vehicular safety. Barriers erected on the center median could aid in attaining this objective, if such barriers are properly designed. At the present time, the median strip is insufficient to guard against vehicles accidentally crossing the median strip and proceeding “head-on” into on-coming traffic on the opposite side of the median. Thus, such barriers could provide for increased vehicular safety, while at the same time acting as an impediment to pedestrian movement on the expressway surface.
4. Proper design of pedestrian bridges, integrated with the aesthetically pleasing nature of the urban design of the area, could potentially improve the overall attractiveness of the area for shoppers and other pedestrian activities. Attractive design features could encourage pedestrian bridge utilization, thus limiting the desire on the part of pedestrians to cross an urban expressway at street level.

The results of the analysis demonstrated that a computer simulation model could prove useful to enhance traditional heuristic methods in determining an appropriate deployment of pedestrian bridges, at least in situations where the expressway has already been constructed and large numbers of pedestrian are already crossing the expressway in the face of on-coming traffic. Specifically, heuristic approaches and analysis using computer simulation models can prove useful in Riyadh to ascertain an appropriate pedestrian bridge deployment pattern in order to facilitate safe pedestrian crossings over King Fahad Road.

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ليل ا اكاة الكمبيوترية لتطوير جسور ا شاة ا علقة على طريق ا لك فهد الرياض – ا ملكة العربية السعودية

م ـ زيد بن مشهور التركاوي

كلية العمارة والتخطيط، قسم التخطيط العمرا ، جامعة ا لك سعود

(قدم للنشر في ١٤٢٦/١/٢١هـ، وقبل للنشر في ١٤٢٦/٥/١هـ)

ملخص البحث. يعتبر طريق الملك فهد طريقاً سريعاً محدود الوصولية ويخترق مدينة الرياض من شمالها لجنوبها، ولا يخلو الطريق من مشاكل تتعلق بحركة المشاة، وأبرز هذه المشاكل تكمن في الجزء الشمالي من تقاطع طريق الملك فهد مع طريق خريص الذي يخلو من توفير معابر آمنة وتجهيزات كافية للمشاة على طريق تم تصميمه أساساً بعرض ٨٠ مترا. وفي الحقيقة، وكون أن الطريق سريعاً، فإنه تم إلغاء تقاطعات سابقة أدت إلى إزعاجات للمشاة وربكة للحركة المرورية، وبينما تغيرت وظيفة الطريق من كونه شرياني إلى طريق سريع محدود الوصولية، أصبحت حاجة المشاة أكبر، حيث إن الكثير من الناس يحتاجون لعبوره باستمرار.

واستند هذا البحث على بيانات ميدانية وعلى منهجية علمية تم جمعها من موقع الدراسة بمساعدة مخططين ناشئين تم تدريبهم مسبقاً لذلك، وكذلك تم تحليل المعلومات الميدانية من خلال برنامج محاكاة كمبيوترية خاص لتحديد أكثر المواقع كفاءة لجسور المشاة المعلقة في استقطاب أكبر عدد ممكن من الناس عند حاجتهم لعبور الطريق، كما أكد البحث العجز في عدد جسور المشاة المتاحة.