

Evaluating the Pedestrian Environment in Abu Dhabi

Authors

Abdulla Salem Al-Kathairi, Chief of Roads Section
Rasin K. Mufti, PhD, Chief of Study and Design
Atef M. Garib, PhD, Chief of Design (Traffic)

Abu Dhabi Municipality, P.O. Box 263, Abu Dhabi, United Arab Emirates
Tel: 971-2-677-9223 Fax: 971-2-6794518

Ibrahim El Sanhoury, PhD, Transportation Engineer, ibrahims@abudhabitrip.co.ae
Bradlee F. Williams, Transportation Director, brad.williams@parsons.com

DeLeuw, Cather International Limited, P.O. 46736, Abu Dhabi, United Arab Emirates
Tel: 971-2-665-2512 Fax: 971-2-665-7592

Submitted 30 July, 2001

Word Count 6,172

ABSTRACT

This paper evaluates the pedestrian environment in Abu Dhabi. The evaluation, conducted in conjunction with the Abu Dhabi Master Transportation Plan, focuses on two parts. The first addresses the overall adequacy of the walkway environment. The second deals with the various pedestrian crossing facilities used in the city. The walkway environment is generally adequate, but locations exist in which walking is difficult, dangerous, or not feasible. Several urban design aspects that enhance the walking environment are discussed. The performance of uncontrolled, controlled, and grade-separated mid-block pedestrian crossings, is evaluated, as well as pedestrian crossings at roundabouts and signalized intersections. Both marked and unmarked pedestrian crossings function effectively as unmarked crossings, due to the lack of regulations forcing drivers to yield to pedestrians in marked crossings. Their performance is enhanced by the presence of medians, which are not always well maintained. At signalized intersections, pedestrians can find generally adequate crossing opportunities, but pedestrian green time is too short at some locations. The only mid-block pedestrian signalized crossing in Abu Dhabi has potential for more wide-spread application on arterials, provided additional safety measures are implemented. The commonly found three-lane roundabouts are hazardous locations for pedestrian crossings due to the high speeds they allow. The growing number of grade-separated pedestrian crossings enhance pedestrian safety, albeit at high cost. Summary conclusions and recommendations, and preliminary goals, objectives, and a short-term action plan are discussed. The need for better pedestrian accident data, and the potential use of GIS in pedestrian planning are emphasized.

INTRODUCTION

The Abu Dhabi Municipality is updating its Master Transportation Plan. The previous plan, which has been implemented over the last twenty years, was designed for the year 2000. The update will tailor the now well-established transportation system to meet existing and future transportation needs of Abu Dhabi through the year 2020. The Master Transportation Plan recognizes the need to integrate the various transportation modes, including private cars, taxis, and buses, with those of pedestrians and other non-motorized modes. In an integrated transportation system, walking plays an important role. Based on a recent household travel survey, over 25 percent of work trips are made on foot in Abu Dhabi's central business district, with its high-density mixed-use development.

Abu Dhabi is the capital of the United Arab Emirates, a country established in 1971 as a federation of seven Gulf coast states. Over the past 25 years, population in the city and surrounding region has grown rapidly, reaching a current population of nearly 600,000. The city continues to grow at a rapid pace, growing by 18 percent between 1995 and 2000. If this growth rate continues at this rate, the population in downtown will increase from 218,000 to 418,000 by the year 2020. This growth is creating intense competition for space, particularly within downtown.

Pedestrian facilities constitute an important element of Abu Dhabi's transportation system. Substantial resources have been devoted to pedestrian facilities in the past, and the welfare of pedestrians continues to rank high on the city's list of priorities for the future. A multi-year program for construction of numerous grade-separated crossings was approved six years ago.

Abu Dhabi has been designed according to the "superblock" concept in which very large blocks, known as sectors, contain a mix of residential and commercial land uses. The sectors are separated by large arterial streets, and have pedestrian areas, parking, and collector streets inside.

The data collection reported in this paper was based primarily on observational evaluation derived from field trips. In addition, video footage of intersection vehicle and pedestrian movement, Abu Dhabi's GIS database, and signal phasing plans from the TCC (Traffic Control Center), were consulted.

This paper addresses the evaluation of the pedestrian environment in detail. The walking environment both along arterials and within the sectors is evaluated in terms of safety, continuity and convenience. Special attention is given to the various types of pedestrian crossing facilities currently used. The performance of uncontrolled, controlled, and grade-separated mid-block pedestrian crossings, as well as pedestrian crossings at roundabouts and signalized intersections, is evaluated.

The evaluation of the pedestrian infrastructure is followed by a section of summary conclusions and recommendations. Preliminary goals, objectives, and a short-term action plan that will serve as inputs to the policy development task in the next phase of the Master Transportation Plan, are discussed in the last section of this paper.

EVALUATION OF THE PEDESTRIAN ENVIRONMENT IN ABU DHABI

The evaluation of the pedestrian environment in Abu Dhabi begins with an overall assessment of pedestrian safety trends during 1999-2000, followed by a discussion of the walkway environment. Pedestrian crossings facilities are discussed last.

Pedestrian Safety

Summary statistics of pedestrian accidents in Abu Dhabi indicate that there were 469 accidents involving pedestrians in 1999, with 38 fatalities. In 2000, there were 519 accidents with 34 fatalities. These figures indicate an 11 percent increase in pedestrian fatalities as well as total number of casualties. This is a significantly increasing trend, and highlights the need to improve pedestrian safety. A substantial number of accidents involving pedestrians

occurs on major downtown streets. In addition, intercity roads are the scene of fewer accidents but a high proportion of fatalities, due to the higher speeds they allow. Over 40 percent of pedestrian accidents occur on local and collector roads, but due to the lack of the sector location in the database, it is not possible to determine whether these occurred in downtown or residential sectors.

The Walkway Environment

Within Sectors

Downtown Abu Dhabi is characterized by mixed land uses. Within sectors, sidewalks along buildings generally exhibit good overall continuity and width appears adequate (See Exhibit 1). Even along strips of shops and other commercial activities, sufficient width often remains even when various types of street furniture and other obstructions exist.

However, there are situations when a narrow sidewalk, sometimes less than 1.2 meters in width, parked cars, obstructions protruding from shops, and street furniture make walking inconvenient or infeasible. Some shop owners permanently use sidewalk space. These situations may pose difficulty for some pedestrians, including the elderly, people with baby strollers, or young children, especially residents who have no choice in regard to their immediately adjacent walking environment. In addition, vertical clearance is inadequate in some locations, due to low-mounted air-conditioners. This poses a clear risk of injury. In rare cases, a sidewalk is completely missing.

Moreover, there are numerous plaza-like areas between buildings that provide valuable space for residents. These areas are contiguous to the adjacent sidewalks, and provide safe areas used for play and recreation. Because of the high curbs used in Abu Dhabi, these areas are shielded rather well from vehicular traffic, except large sport-utility vehicles, and few infractions occur.

Another urban design feature common to both the CBD area and residential neighborhoods is the space reserved between buildings, small and large. Buildings typically are not built immediately adjacent to each other, and the space between land plots results in narrow alleys between buildings available to pedestrians. These alleys combine with sidewalks to form a large and contiguous network of walkways that make for a highly “permeable” and hence pedestrian-friendly environment, as pedestrians can chart shorter routes to their destinations. In addition, relatively large pieces of curbed and paved land merge with sidewalks to extend this network. These aspects of the urban design positively impact the city’s environment, even in downtown areas, despite high-rise buildings and large arterial roads.

In residential neighborhoods outside the business districts, the positive aspects of this urban design feature are enhanced by the presence of lawns, trees, and other vegetation. Here too, however, one can see various fixtures that result in a break in the continuity of the sidewalk. These include ramps for cars and strollers, steps to buildings that extend into sidewalks, and ill-placed telephone booths.

Crossing the roads and ubiquitous parking lots found within sectors in the downtown area appears reasonably safe. In many locations, speed bumps are in place to reduce vehicle speeds. The design of the parking lots is varied. Some parking lots have only one entry/exit, and are adjoined by a continuous sidewalk. These are the easiest to negotiate. Others are less pedestrian-friendly, and more attention must be paid to vehicles. The ongoing program of constructing underground parking structures provides an opportunity to improve the pedestrian environment. Reducing the number of illegally parked vehicles, especially at street corners, and in the aisles of parking lots, will make the environment more open and easy to survey for pedestrians. In addition, depending on the location, some of the area devoted to surface parking may be re-allocated to pedestrian uses.

As a result of the city’s rapid growth, there is continuous development and re-development of land. Construction sites thus form a persistent theme in the cityscape. However, many contractors pay little attention to

the walkways they displace when they bound their sites. Pedestrian are thus forced in to streets, minor or major, and face a dangerous situation.

Along Arterials

Major arterials in Abu Dhabi are characterized by the presence of frontage or service roads that provide access to abutting commercial or residential land uses. In this case, sidewalks are reduced in width. Based on a survey of several locations in the CBD, it appears that in the majority of cases, the sidewalk width remains sufficient to maintain pedestrian traffic at good levels of service. At night, congestion may be observed at some popular shopping locations. Continuity of the sidewalks appears adequate in most locations.

Mid-Block Pedestrian Crossings

In principle, the large sectors should satisfy many of the resident's pedestrians needs internally, without the need to cross major roadways on a regular basis. In practice, however, there is a continuous flow of pedestrians across the busy arterials, as well as within the sectors, as people go to offices, shops, parks and mosques in other blocks. In Abu Dhabi, the length between signalized intersections can reach one kilometer. In downtown there are approximately 20 segments of major streets where the distance between signals exceeds 500 meters.

The distances between junctions are too long to prohibit crossing the street at-grade, between the signalized intersections. In addition, certain land use distributions (e.g. a parking garage located across the street from a shopping mall) encourage mid-block crossings. In the following sections, detailed evaluations of mid-block crossings (see Exhibit 2) are provided.

Uncontrolled Mid-Block Crossings

Major arterials in Abu Dhabi have medians, usually landscaped, that separate opposing vehicular traffic flows. These medians are usually about 5 meters in width, except near the intersections, when the width reduces to approximately 1.2 meters to allow for left-turn lanes. Medians reduce the effective street width to be crossed, and allow dealing with one direction of vehicular traffic flow at a time. Speed limits on these roads are usually 60 kph, and people are allowed to travel up to 20 kph above posted speed limits without penalty. As a result speeds much higher than the posted speed limit are often observed.

The medians of marked crossings are not always paved, and in some cases, not on level with the curb. As a result, pedestrians have to wait behind and step over the curb; some pedestrians stand on the narrow curb to improve their view of oncoming vehicles. These factors reduce both the safety and convenience of these crossings. The location of the crossings relative to intersections appears inappropriate in some cases, creating situations in which it is difficult to cross safely.

Wrought-iron fences are often used to regulate mid-block median crossings by pedestrians in the CBD. Many openings in the fences are provided, creating opportunities for pedestrian crossings. Spacing varies, and is usually in the order of 100-200 meters. In addition, many other informal openings can be found throughout over the city, in locations where no fence exists, and places where the fence was simply broken down by pedestrians.

The Municipality has formalized some of these crossings, both in locations with fences as well as those without, by paving safety islands in the median openings and providing pedestrian pavement markings (zebra striping) and signs warning motorists of the presence of pedestrian crossings.

The high speeds and traffic volumes on Abu Dhabi's arterial streets make them unlikely candidates for zebra-striped at-grade pedestrian crossings according criteria in the United Kingdom and United States (1,2). Laws in these countries and others (3,4,5,6) require vehicles to stop in order to allow pedestrians in marked crosswalks to cross the street.

In contrast, there is currently no legal requirement in Abu Dhabi that obliges vehicles to stop when pedestrians enter a marked crosswalk. Field observations at many downtown locations indicate that the primary function of marked crosswalks in Abu Dhabi is to regulate the locations at which pedestrians cross, rather than elicit yielding or stopping for pedestrians and thus make pedestrian crossing safer. In effect, pedestrians and drivers treat marked crossings in the same way as an unmarked crossing: Pedestrians wait for an appropriate gap without expecting vehicles to yield; and drivers, indeed, do not yield.

Yellow flashing warning lights together with pedestrian crossings traffic signs, based on design criteria established in a 1995 pedestrian study (7), have also been installed at several crossings. The medians of these crossings are generally paved or tiled and in good condition, providing a comfortable and safe waiting area for pedestrians.

Field observations at several crossings of this type consisted of watching the crossings in operation, as well as attempting to get vehicles to yield by entering the crosswalk when traffic was approaching (The latter is not recommended as an observation technique).

These observations suggest that the flashing signals have no discernible impact on moving traffic. Even when vehicles are distant, pedestrians entering the crosswalk, and even those already in the crossing, cannot expect the approaching traffic to stop or even slow down. In other words, these crossings function in effect as the more common marked crossings that do not have warning lights. When traffic flow is heavy, such as when through traffic is discharged from an upstream green phase, speeds are high, no one seems to slow down, and pedestrians have to wait until there is a gap in traffic of adequate length. When traffic is low, pedestrians find little difficulty waiting until a gap is found.

Controlled Mid-Block Crossings

There is one controlled mid-block crossing in Abu Dhabi. This is a push-button actuated mid-block pedestrian signal, located on Corniche Road. The pedestrian cycle is designed such that there is a minimum of 55 seconds between the end of one walk phase and the beginning of the next. The minimum time it takes to turn green is 15 seconds. Pedestrians often get impatient and cross after pressing the button, but before the pedestrian signal turns green.

One of the two vehicle traffic signals on the left (median) on the eastbound leg is mounted low, and somewhat hard to see for traffic in the left and middle lanes when traffic is heavy. There is also a taller signal at the same location, but it is almost completely obscured by a tree. As a result, cars often screech to a halt after noticing at the last moment that the signal was red. The warning sign in the median that notifies drivers of the signal is almost completely obscured by vegetation.

Grade-Separated Mid-Block Crossings

The Grade-Separated Pedestrian Crossing program forms an important element of the city's transportation infrastructure. Currently, there are eight underpasses and one overpass (See Exhibit 3). The Grade-Separated Pedestrian Crossing program is proceeding with the design and construction of an additional 22 underpasses already approved by the government, primarily in the downtown area. Other underpasses are planned.

Observation of pedestrian movements at the two grade-separated crossings that still allow at-grade crossings indicates that large numbers of pedestrians will continue to take the shortest path across major roadways, even at increased risk to their safety.

Pedestrian Crossings at Intersections

Signalized Intersections

A substantial share of pedestrian crossings of arterials in the CBD occurs at the signalized intersections. Most, but not all of the signalized intersections in the city are equipped with pedestrian signals. An informal inventory of 53 signalized intersections in the northern part of Abu Dhabi Island showed that 37 were equipped with fully functioning traffic signals.

Sixteen intersections had either no pedestrian signal at all, or had pedestrian signals missing, non-operational, or operating in an improper fashion, on one or more legs of the intersection. At some of those locations, recent construction work is seen as the reason for the absence of the signal. Installation of pedestrian signals at those locations seems to be only a matter of time. At others, there appears to be no concrete plan to install and/or repair pedestrian signals. Some of the latter include high-traffic locations.

Some pedestrian signs and signals were aligned incorrectly, probably as a result of a motor vehicle collision. Most signalized intersections have pedestrian signal phases and crosswalks with clearly delineated pedestrian paths. They are designed with median islands and, if applicable, with free right turn islands.

Crossing signalized intersections forms an important element in sector-to-sector pedestrian movements. In downtown Abu Dhabi, the following observations can be made regarding the safety and efficiency of pedestrian movements at signalized intersections.

Crossing the Free-Right Turn Lanes – The majority of signalized intersections in Abu Dhabi have free-right-turn lanes, which improve intersection capacity (These turns are not fully free. Drivers still have to merge and yield to traffic on the dominant movement.) They pose a problem for pedestrians however, since none of these turns is equipped with a pedestrian signal. When vehicular traffic is light, pedestrians need to wait only a short time before crossing. With higher traffic, the delay increases. In some locations, both the observed speed and volume of approaching vehicles are high. At some intersections, there are dual-lane free-right-turns. This results in a larger crossing distance for pedestrians and allows higher speeds for turning vehicles, multiplying the hazard to pedestrians. Many of these turns are equipped with flashing yellow traffic signals that warn the drivers about the potential for pedestrian presence in the roadway.

It is not clear whether the flashing lights are effective in cautioning drivers. They are usually installed quite close to the pedestrian crossing, well into the curve, and sometimes are facing in a direction tangential to the curve at that point. They also appear to be mounted somewhat high. These factors may make them less easily visible, and difficult to notice in time to carry out gentle deceleration. It is also possible that even effectively placed flashing lights will soon be ignored if drivers conclude that it is “only pedestrians” that are the reason for the warning signal. At some intersections, pedestrians wishing to cross the free-right-turn lane from the sidewalk to the triangular waiting island find their view of oncoming vehicles blocked by large advertising signs. At a few locations, the ends of the median island are marked by very smooth tiles, posing a risk for pedestrians to slip and fall into the intersection.

Crossing the Approach and Exit Lanes – An evaluation was performed of the practice of crossing the street at a signalized intersection.

Signal operation – Four-leg intersections with free-right-turn lanes form the most common type of signalized intersections in Abu Dhabi. Pedestrian signals at these intersections operate in a unified manner. There is a single

green phase for pedestrians crossing any particular leg that begins with (or starts about one second before) the start of the green phase for the vehicular traffic coming from the next leg clockwise to the one in question (called the corresponding leg). This is the only phase during which pedestrians can cross both parts of the leg without experiencing any conflict with vehicular traffic. At any other time during the traffic signal cycle, the pedestrian signal is red.

The duration of the pedestrian green phase is a function of the length of the vehicle green phase for the corresponding leg. For intersections with a given cycle length, the phasing may vary depending on several factors. A typical four-leg signalized intersection with a 140-second cycle-length, has approximately 21 seconds of pedestrian green, and 9 seconds of flashing green when the corresponding leg is a major leg of the intersection. After the pedestrian signal turns red, another 10 seconds transpire before the corresponding leg's vehicle green phase ends, and it is no longer safe to walk. Thus, in the current manner of operation, the pedestrian signal causes no reduction in the vehicle capacity of the intersection. For a minor leg of the intersection, the green phase for pedestrians is approximately 16 seconds, and flashing green extends for another 7 seconds, followed by another 10 seconds of green for the corresponding vehicle phase. In the 2000 Edition of the Manual of Uniform Traffic Control Devices (8), the use of flashing walking person (flashing green, symbolizing WALK) is no longer permissible. The intended meaning of flashing red is that "a pedestrian shall not enter the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a steady WALK (i.e. steady green) signal indication shall proceed out of the traveled way". It appears that this is the intended meaning of flashing green in Abu Dhabi.

In a study carried out in Abu Dhabi in February 2001, the lowest average walking speed measured was 1.33 meters per second, the mean speed was 1.43 m/sec, and the highest was 1.53 m/sec. Assuming a pedestrian speed of 1.33 m/sec, the time to cross both the approach and exit lanes for a typical geometrical configuration with four approach lanes (which includes a left-turn lane) and three exit lanes is:

$$\begin{aligned} & (\text{number of lanes} * \text{lane width} + \text{median island width} + 2 * \text{free-right-turn island offset}) / \text{pedestrian speed} \\ &= (7 * 3.65 + 1.5 + 2 * 1.0) / 1.33 \\ &= 21.9 \text{ seconds.} \end{aligned}$$

This is less than the 23 seconds of green-plus-flashing-green (for the shorter pedestrian phase). Thus, at a signalized intersections characterized by the above phasing, intersection geometry, and pedestrian walking speeds, there is adequate time for pedestrians to clear, provided they start almost immediately after the beginning of the green phase. Some studies have estimated the mean start-up time (the time from the start of the WALK signal to the moment the pedestrian steps off the curb and starts to cross) to range from 2.5 sec for older pedestrians to 1.9 sec for younger ones (9). Later starts will result in completing the crossing when the pedestrian signal has turned red, with a possibility that the green phase of the next vehicle stream has begun (which will result in vehicle-pedestrian conflict).

Many signalized intersections operate with a cycle length of 120 seconds, and some intersections with a 140-second cycle operate on a 120-second cycle during off-peak traffic periods. The shorter signal phases for vehicle traffic result in a corresponding decrease in pedestrian green times. For the minor legs, total green times (including flashing) as low as 12 seconds have been measured (Steady green was measured at only 4 seconds, and the vehicle phase of the corresponding leg itself lasted only 16 seconds). At these locations, the pedestrian signal provides insufficient time for crossing the leg in question, even if the entire vehicle phase is considered utilizable, and if one assumed all pedestrians depart immediately at the start of the pedestrian green.

Moreover, some intersections with 140-sec cycles have legs with as many as six approach lanes (four through lanes and two left-turn lanes), and four exit lanes as well as a wide median, adding substantially to the distance needed to cross. Depending on phasing, the pedestrian signal may not provide adequate crossing time for pedestrians.

This discussion describes the basic features common to all four-leg intersections with free-right-turn lanes. Three-leg intersections with free-right-turn lanes operate in a similar manner, and can be analyzed by making appropriate adjustments.

Intersections not equipped with free-right turns differ in their operating characteristics. There are only a few intersections in the city that do not have free-right turns. At such intersections, pedestrian who cross must watch out for conflicting right-turn traffic from the corresponding leg. The solution to this problem is to create an explicit pedestrian phase that takes some time away from the vehicle phases.

Pedestrian Behavior – Observation confirms that most pedestrians do not adhere to the crossing dictated by the pedestrian signal. Rather, they appear to treat the incoming and outgoing part of the leg they are crossing as separate items, crossing each when they perceive no or manageable conflicts with vehicular traffic. This, in effect, reduces average delay for them, but increases the possibility of accidents. It also impacts vehicular traffic flow. This obviously can give rise to situations in which oncoming vehicles and pedestrians have to maneuver out of each other's way, sometimes leading to dangerous situations.

There are at least three factors contributing to this phenomenon. One is the lack of discipline shown by pedestrians, even when they are aware of regulations. Crossing the intersection at times other than the green phase saves time.

Another factor is the fact that only one pedestrian signal per direction is provided in most cases, mounted on the far opposite side. As a result, pedestrians may fail to recognize that this signal is meant for crossing *the entire leg* in one sweep. At some locations, the signal may actually be hidden from view by the traffic signal pole in the median.

Finally, at some intersections, pedestrian signal timing is not adequate for crossing safely in one phase. At these locations, pedestrians may wait in the median, and complete their crossing in the next green phase. This would extend the time required to cross a single street to what is likely more than most pedestrians are wishing to accept. For this reason, it is far more common for pedestrians to cross when they perceive crossing opportunities.

There are several additional remarks to be made regarding signalized crossings. One is that, as a result of pedestrian behavior, those intersections without pedestrian signals function largely in a manner similar to those with signals. Nevertheless, the lack of pedestrian signals at some intersections is likely to make crossing quite difficult for those pedestrians who are particularly cautious in regard to their safety. Another is that the median islands serve as pedestrian waiting areas, and may be too small for this purpose, especially given the number of pedestrians who go half way across the approach lanes and then wait for the signal to cross the exiting lanes (which are "safe" for only one of the four phases). Finally, given the lack of detailed accident data, it is difficult to assess objectively the degree to which the pedestrians' lack of adherence to the pedestrian signal, the absence of pedestrian signals at some intersections, and the inadequate length of the pedestrian signal phase at some intersections, constitute a safety problem.

Pedestrian Crossings at Roundabouts

At roundabouts, pedestrian crossings are marked with stripes, and curb ramps are provided. Crossing the incoming lanes of a roundabout is somewhat safer than crossing the exiting lanes, since only one traffic stream needs to be monitored. When crossing the exiting lanes of a roundabout, however, the fact that vehicles approach from two directions (from within the roundabout and from the upstream approach), makes crossing more hazardous.

In some countries, small roundabouts have been found effective in reducing vehicle speeds, as well mitigate accidents (5,6). The safety benefits of roundabouts documented in these countries are due to the smallness of the roundabouts, which forces vehicles to slow down. Most of Abu Dhabi 's roundabouts are two or three lanes wide, and are unlikely to experience the safety benefits of the smaller roundabouts.

Observations at three-lane roundabouts, which are quite common, showed that vehicle speeds on the approach lanes to the roundabout are commonly above 80 kph. About 100-200 m from the roundabout, drivers brake, and vehicle speeds at the pedestrian crossing on the approach lanes just before the roundabout are approximately 50 kph. Within the roundabout, assuming no stopping was necessary, speeds are in the 40-50 kph range. When exiting the roundabout, vehicles accelerate, and observed speeds at the pedestrian crossing on the exiting lanes are frequently in the 50-60 kph range.

The high vehicle speeds observed on the roads leading to roundabouts, as well as those within the roundabouts, of the three-lane configuration, accentuate the crossing hazard. It is difficult to cross three lanes of traffic when the approaching traffic travels at high speed *and* is not easily visible.

These large roundabouts are gradually being phased out in Abu Dhabi, although it is likely that several will remain for many years to come. When traffic volumes at a roundabout reach levels that result in large delays, the roundabout is either modified to operate as a signalized roundabout, or the roundabout is removed and replaced by a normal signalized intersection. In both cases, pedestrian crossings then operate basically as signalized intersections.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The discussion in the previous section is summarized in the following points, with appropriate recommendations added:

1. In light of increasing competition for land, appropriate regulation should be developed in Abu Dhabi to protect sidewalks and other areas devoted to pedestrian and other non-vehicle uses from encroachment.
2. Enforcement of parking restrictions within sectors helps to improve the pedestrian environment by making the sectors easier to navigate, and should be implemented immediately in Abu Dhabi. Reclaiming surface land for non-vehicle uses when constructing underground parking should be considered when feasible.
3. Regulation that forces building site developers to preserve a minimum of pedestrian walkways to maintain safe passage for pedestrians, especially along major roads, should be developed in Abu Dhabi.
4. Regulation should be developed in Abu Dhabi that controls the deployment of street furniture as well as how and where to modify sidewalks, in addition to specifying minimum vertical clearance. Locations in which sidewalks are discontinuous or of inadequate width should be identified and mitigation measures proposed. A procedure to receive and process concerns of residents regarding specific features of the pedestrian environment should be developed.
5. Overall, pedestrian signals, signs, and crossings in Abu Dhabi are not maintained as well as they should be. A program of systematic monitoring and maintenance should be developed.
6. Due to its importance in locating trouble spots as well as evaluating alternative pedestrian crossings and other safety improvements, the collection and analysis of appropriately detailed data on accidents involving pedestrians should be started in Abu Dhabi as soon as possible.
7. Designated mid-block crossings, both marked and unmarked, form the bulk of mid-block pedestrian crossings in Abu Dhabi. The presence of a usually wide median boosts the safety of these crossings. However, sight problems may occur, and the physical condition of the median strip is in need of rehabilitation or paving in numerous locations. The location of some of these crossings should be examined to determine whether they are at a conflict point with side streets and relocated if necessary.
8. Except for the better-maintained median waiting areas, the mid-block crossings that are supported by flashing lights are not effective in providing pedestrians in Abu Dhabi with a safer crossing environment than ordinary designated mid-block crossings.

9. Pedestrian-actuated mid-block signals should be further explored as a potential alternative to the more expensive grade-separated pedestrian crossings in Abu Dhabi. Driver respect for the signal and safer crossing conditions for pedestrians should be promoted through awareness campaigns, and through the use of photo enforcement of speed limits as well as red-light violation detection at the crossing.

10. Overall, the grade-separated pedestrian crossings in Abu Dhabi have contributed to making pedestrian crossings safe in several locations where large volumes or other special conditions exist. They reflect the city's commitment to enhancing pedestrian safety, while preserving a high level of service. However, all median openings must be closed in the vicinity of grade-separated pedestrian crossings in order to harness fully the safety advantages of these facilities.

11. At intersections in Abu Dhabi, the free-right-turn lanes pose what appears as a largely manageable problem to pedestrians. In locations of high pedestrian volumes and/or high vehicular traffic, and at intersections where the free-right turn consists of two lanes, the use of alternative cautioning devices for vehicles, (such as little bumps or "cat eyes"), as well as more stringent measures, (such as a separate phase for pedestrians, possibly push-button controlled), should be considered. Advertising signs that block the view of pedestrians wishing to cross the turn lanes must be removed or relocated, and the texture of the material used to pave the islands should be roughened, and the slopes flattened, to provide a safe surface for walking.

12. Overall, the standard four-leg intersection in Abu Dhabi with free right turns appears to provide pedestrians with adequate crossing opportunities. Due to the free-right-turn lanes, a complete pedestrian phase that allows crossing both parts of a leg of an intersection is possible. While there is the possibility of conflict when crossing the right-turn lanes, it is, in most cases, only one lane of traffic that must be crossed, reducing the severity of the problem. However, some signalized intersections do not have functioning pedestrian signals, and at others, the pedestrian phases are too short to allow crossing the intersections in one cycle, or have two free-right-turn lanes. Enhancements to be considered include enforcement of the pedestrian signal, increased pedestrian signal phases, and grade-separated pedestrian crossings. The impacts on pedestrian safety as well as vehicle traffic capacity of the intersection must be taken into account when deciding on the specific measure to be taken.

13. At the few intersections in Abu Dhabi not equipped with free-right-turn lanes, pedestrian signal phasing should be modified to provide safe pedestrian crossing conditions.

14. The decision of how to enhance operations at signalized intersections in Abu Dhabi needs to be based on several criteria. One relates to the evaluation of safety, which is conditional on detailed accident data. If pedestrian crossing behavior is causing accidents, enforcement of walking only during the green phase may be considered. Should the inadequate phase length observed at some signals cause safety problems, extending the pedestrian phase must be considered. There are alternative ways of accomplishing this, including an all-red pedestrian phase at which pedestrians are allowed to cross all four legs, and vehicular traffic comes to a complete standstill. Other solutions include lengthening the phase for a particular pedestrian phase by extending the phase of the corresponding leg. In any case, the reduction in vehicle traffic capacity can be calculated as a function of the change in the vehicle green phases. At a certain point, the only way to safely provide adequate pedestrian capacity without excessively hampering vehicular traffic may be to construct a grade-separated crossing at the intersection.

15. Overall, roundabouts connecting three-lane arterials (which represent a commonly found configuration in Abu Dhabi) are hazardous locations for pedestrian crossings, due to the high speeds they allow for vehicles entering and exiting from the roundabout. Solutions must be developed to ensure pedestrians can cross safely at these facilities.

16. A more rational, quantitative method should be developed to combine accident and design aspects into a summary index for various neighborhoods to allow a systematic assessment. The Abu Dhabi Municipality's GIS can be used for this purpose (See Exhibit 4). The GIS is quite detailed, and includes street furniture such as light poles, as well trees and green areas, in addition to all paved and curbed land. The updated GIS allows for a more systematic analysis of the pedestrian environment. The width and area of walkways and sidewalks can be measured effectively, street furniture such as telephone booths or benches not currently included can be added, and

comparisons between the year 1995 and year 2000 can be made in regard to various features. For example, the area of paved and curbed land can be compared to assess whether urban space devoted to pedestrian uses has declined, and by how much. Use of the GIS will also facilitate preparation of a detailed pedestrian improvement plan for individual areas or sectors.

FORMULATING GOALS AND OBJECTIVES

The goal of pedestrian planning in the context of Abu Dhabi's Master Transportation Plan can be stated as "The formal inclusion of pedestrian considerations in the urban transportation planning process in order to further enhance and develop a safe and attractive pedestrian environment that recognizes the varied benefits of walking, while recognizing and addressing to the greatest degree possible the concerns of competing vehicular traffic and other interests". Objectives that support this goal include:

- Development of urban policies that provide for the inclusion of a pedestrian review as an essential element of urban development decisions;
- Building a database of pedestrian facilities and pedestrian accidents;
- Increasing the awareness of pedestrian concerns among planning and engineering professionals; and
- Promotion of a pedestrian "safety culture" fostered through educational and enforcement measures.

In the next phase of the Master Transportation Plan, the goals and objectives, along with recommendations itemized in this paper, will be addressed, expanded, and opened to discussion with a broad set of stakeholders.

REFERENCES

1. Davies, D. G. *Research, Development, and Implementation of Pedestrian Safety Facilities in the United Kingdom*. Report FHWA-RD-99-089. FHWA, U.S. Department of Transportation, December, 1999.
2. UNC *Proposed Recommendations for Installing Marked Crosswalks*, University of North Carolina Highway Research Center, July 2000.
3. FHWA *Pedestrian Facilities Safety And Mobility Guide, Draft Final Report*, Federal Highway Administration, US Department of Transportation, Office of Research and Development, August 2000.
4. Hummel, T. *Dutch Pedestrian Safety Research Review*. Report FHWA-RD-99-092. FHWA, U.S. Department of Transportation, December, 1999.
5. Ekman, L., and C. Hyden. *Pedestrian Safety in Sweden*. Report FHWA-RD-99-091. FHWA, U.S. Department of Transportation, December, 1999.
6. Cairney, P. *Pedestrian Safety in Australia*. Report FHWA-RD-99-093. FHWA, U.S. Department of Transportation, December, 1999.
7. DCIL, *Report on Pedestrian Crossings At Selected Locations in Abu Dhabi*, DeLeuw, Cather International Limited, Abu Dhabi Municipality and Town Planning Department Roads Section, 1995
8. FHWA *Manual of Uniform Traffic Control Devices*, FHWA-SA-89-006 US Department of Transportation, Federal Highway Administration, 1989.
9. Zegeer, C. V., J. R. Stewart, and H. Huang. *Safety Effects of Marked vs Unmarked Crosswalks at Uncontrolled Locations: Analysis of Pedestrian Crashes in 30 Cities*. Submitted to the Transportation Research Board, November, 2000.
10. Leaf, W. A., and D. F. Preusser. *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*. Report DOT HS 809 021, U.S. Department of Transportation, October , 1999.

LIST OF TABLES AND FIGURES

Figures

FIGURE 1 Examples of sector pedestrian facilities

FIGURE 2 Examples of mid-block pedestrian crossings

FIGURE 3 Examples of grade-separated and signalized pedestrian crossings

FIGURE 4 GIS Plot of downtown Sector



FIGURE 1 Examples of sector pedestrian facilities



FIGURE 2 Examples of mid-block pedestrian crossings



FIGURE 3 Examples of grade-separated and signalized pedestrian crossings



FIGURE 4 GIS Plot of downtown Sector