An Unconventional Design for Bus U-Turns at Signalized Intersections

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Abstract

This paper addresses an unconventional design for accommodating bus U-turns at signalized intersections based on a case study in Miami, Florida. Field data were collected at the study site, including traffic volumes, traffic conflicts, pedestrian/bicyclist activities, signal phase sequence, headway of buses, and radii of bus U-turns. A detailed operational analysis was performed at the signalized intersection using Synchro. The results of the operational analysis indicate that implementation of the unconventional bus U-turn design at the signalized intersection will not cause major operational problems when the total entering volume is less than 4,000 vehicles per hour. To address the safety concerns at the study intersection, both crash analysis and conflict analysis were conducted. A review of accident data for the subject intersection indicates that accidents related to the bus U-turn occur infrequently. The eight-hour conflicts analysis showed that very few conflicts were caused by bus U-turn movements.

Introduction

Many studies about the operational and safety effects of U-turns at unsignalized and signalized intersections have been conducted. Past research results show that there is no evidence to prove that U-turns at medians or signalized intersections present major safety or operational problems (Potts et al. 2004, Carter et al. 2005, Zhou et al. 2002). However, few studies have been found to deal with heavy vehicle U-turns. There is typically inadequate geometry for a bus to make a U-turn from the exclusive left-turn lane at most signalized intersections. This paper addresses an unconventional design for accommodating a bus U-turn at a signalized intersection based on a case study in Miami, Florida.

Background

Miami-Dade Transit (MDT) was requested by the City of Sunny Isles Beach to evaluate the safety of buses on Routes E and S that make a U-turn at the intersection of Collins Avenue (SR A1A) and Galahad Dade Boulevard (193rd Street). Presently, both of these routes require northbound buses to make U-turns at the subject intersection, then return southward along Collins Avenue before continuing on to the Aventura Mall.

Purpose

The purpose of this analysis is to provide policy makers with an objective assessment of the traffic operations and safety of the current routing at the subject intersection. In addition, this study indicates under what traffic conditions the unconventional design for bus U-turn may cause traffic congestion and safety problems.

Existing Conditions

A site review was conducted to assess the existing operational and design characteristics of the intersection on December 14 and 15, 2004. The study intersection is located at Collins Avenue (SR A1A) and Galahad Dade Boulevard (193rd Street). The major roadway direction is north-south bound on SR A1A, which is a four-lane, divided arterial with a speed limit of 35 mph. The minor roadway direction is east-west bound on 193rd Street. The east side of the intersection is the entrance to a residential condominium, Ocean One. The west side of 193rd Street is a private two-lane street that provides access to OceanView. An unconventional U-turn lane for bus was installed before the residential condominium was built in 2001. Figure 1 shows the intersection layout at the subject intersection.

Figure. 1 Intersection Layout at the Subject Intersection

At the intersection, the northbound buses that will be making the U-turn are channelized and separated to the right of the adjacent through-traffic by a striped separator of approximately six feet. The traffic signals for the bus U-turn and the northbound left-turns are optically programmed signal heads, which restrict the visibility of these indications in adjacent lanes. This helps to keep northbound through-traffic on Collins from being confused by the conflicting indication for the bus U-turn.

Data Collection

Field data were collected on December 14 and 15, 2004. A video camera was used to record traffic operations at the intersection from the top of Marco Polo Ramada Plaza Beach Resort, located approximately 1,000 feet south of the intersection. A total of eight hours of videotape was recorded, including two AM peak hours, two PM peak hours, two noon hours, and two non-peak hours.

Traffic data were obtained from the videotapes. While reviewing the videotapes, researchers tracked each vehicle movement at the intersection, especially the bus U-turn movements. The following information was recorded:

- eight-hour turning movement counts
- traffic conflicts
- pedestrian/bicyclist activities
- signal phase sequences
- headways of buses
- radii of bus U-turns

Crash data for the subject intersection were provided by the Florida Department of Transportation, District 6 Traffic Operations Office. The crash data were pulled for three years, from 2001 to 2003. The system timing data for the subject intersection were obtained from Miami-Dade County.

Additionally, the data collection phase involved a meeting with representatives from the City of Sunny Isles Beach to assess their concerns about the bus U-turn at this intersection. The expressed concerns are summarized as follows:

- U-turning of buses across the intersection is an unusual and unexpected maneuver; this could cause confusion for unfamiliar motorists (tourists and visitors).
- U-turning of buses causes congestion at the intersection.
- U-turn maneuvers cause traffic safety concerns.
- U-turning buses create a possible hazard for people standing on the southwest corner of the intersection due to the tracking of the U-turning buses.
- Exhaust fumes from the buses pollute the area of Ocean One.
- Buses waiting in the bus lane block the visibility of bicyclists and pedestrians, especially for northbound traffic turning right (across the bus lane) into the Ocean One condominium entrance.

The City has suggested that Miami-Dade Transit consider relocating the U-turn for routes E and S up to Hallandale Beach Boulevard, approximately 3 miles to the north.

Operational Analysis

The subject intersection currently operates at an acceptable level of service (LOS) based on the eight-hour field observation on a typical weekday. The intersection geometry, traffic volumes, and signal timing data were collected for a detailed analysis. Synchro 6.0 software was used to perform the capacity and LOS analyses for four different time periods: AM peak hours (7:00-9:00 AM), noon peak hours (11:00 AM-1:00 PM), PM peak hours (4:00-6:00 PM), and non-peak hours. Synchro is a complete software package for modeling and optimizing traffic signal timings and implements the methods of the 2000 *Highway Capacity Manual* (HCM), Chapter 16, "Signalized Intersections". It provides an easy-to-use solution for single intersection capacity analysis and timing optimization. Synchro defaults to calculate the percentile delay, which is different from the HCM's average control delay. Synchro's output also provides the average control delay based on the HCM methods.

The HCM's average control delays from Synchro's output are summarized in Table 1. As listed in Table 1, the overall intersection currently operates at LOS "A" during the AM peak hours and noon time, and at LOS "B" during the afternoon and PM peak hours. Bus U-turn volume is approximately 15 buses per hour for both peak and non-peak hours. The bus headway is about four minutes for buses making a U-turn at the intersection. The average control delay of U-turning buses is approximately 53 seconds per vehicle. The LOS of bus U-turns is "D." The through-traffic on SR A1A operates at LOS "A" or "B". The left-turn and right-turn vehicles from the minor road operate at an acceptable LOS "D." The analysis results show that the bus U-turn does not cause major operational problems at the intersection. This is because the overall intersection is currently operating at level of service "A" or "B," and no individual lane group is worse than LOS D.

To determine under what volume conditions adding a bus U-turn will significantly increase the overall delay at the intersection, additional operational analyses were conducted by gradually increasing the traffic volumes at the intersection. All approaches received the same percentage increase, except the bus U-turn volume. Figure 2 shows the impact of increasing the bus volumes and total volumes entering the intersections. Four curves were developed for bus volumes: 0, 10, 20, and 30 buses per hour. According to the *Highway Capacity Manual*, the LOS of the intersection is "E" when the average delay is greater than 55 seconds per vehicle. Figure 2 indicates the intersection operates at LOS "E" when the bus volume and total volume entering the intersection are (30, 4500), (20, 5000), (10, 5375), and (0, 6375).

Table 1. Level of Service (LOS) at the Study Intersection

Intersection SR A1A @ 193rd St.		Northbound			Southbound	Eastbound		Westbound		Total
		LT	TH/RT	U-turn	TH/RT	LT	RT	LT	RT	
PM Peak	Delay (sec./veh)	23.8	5.4	53	13.7	51.4	9.1	43.9	43.9	11.6
	LOS	C	A	D	B	D	A	D	D	B
AM Peak	Delay (sec./veh)	6.3	4.6	52.9	8.9	50.1	7.6	37.6	37.6	8.6
	LOS	A	A	D	A	D	A	D	D	A
Noon Peak	Delay (sec./veh)	7.0	4.0	52.9	8.8	51.1	9	48.1	48.1	8.7
	LOS	A	A	D	A	D	A	D	D	A
Non Peak	Delay (sec./veh)	18.3	5.0	52.9	10.9	51.6	9	41.5	41.5	10
	LOS	B	A	D	B	D	A	D	D	B

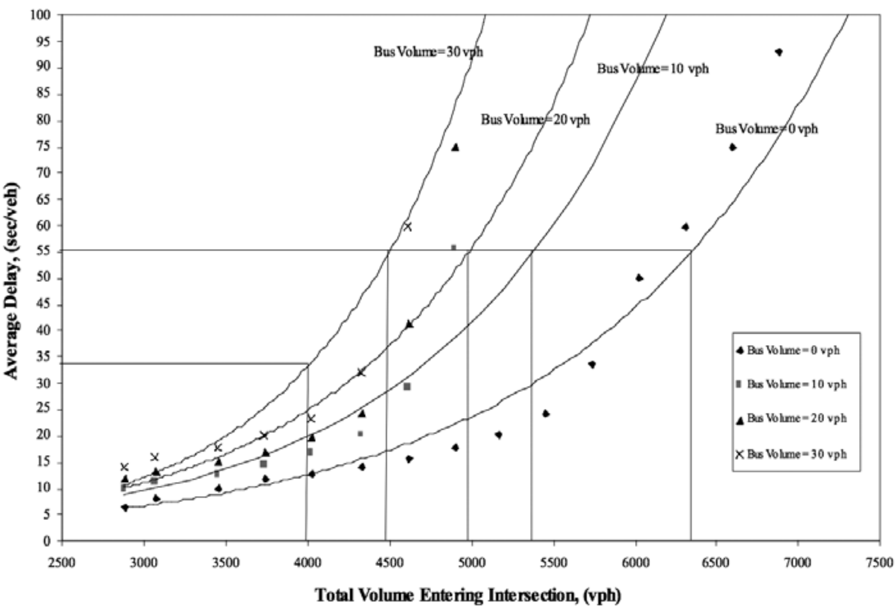

Figure 2. Impact of Bus Volumes on the Intersection Delays

This implies that an increase in bus volume from 0 to 10 buses per hour could reduce capacity by 16 percent, an increase in bus volume from 10 to 20 buses per hour could reduce an additional 7 percent, and an increase in bus volume from 20 to 30 buses per hour would reduce capacity by another 10 percent. Figure 2 also suggests that the intersection always operates at LOS "C" or better when the total volume entering the intersection is less than 4,000 vehicles per hour and bus U-turn volume is no more than 30 buses per hour.

Safety Analysis

Both crash analysis and conflict analysis were conducted to evaluate the safety of the subject intersection. Data collected include three-year crash data and eight-hour videotape for traffic conflicts. Researchers paid special attention to the crashes and conflicts caused by U-turning buses. Both crash frequency and crash rates are used for crash analysis, and the number of conflicts and conflict rates were computed for conflicts analysis. The percentage of crashes and conflicts related to bus U-turns were used to indicate the impacts of bus U-turns on the intersection safety.

Crash Analysis

Crash data at the subject intersection were collected for a three-year period (2001 to 2003). The total number of recorded crashes was approximately 27 in the three-year period, an average of 9 crashes per year. This number is relatively low when compared to the high crash intersection with over 15 crashes per year in the county. Five of the crashes were bus-related. All five were property-damage-only crashes. There were two bus-related accidents in 2001 and 2002, and one accident related to bus U-turns in 2003. The accidents involving the bus were caused mainly by careless driving or the ignoring of the traffic signal by the other drivers.

Figures 3, 4, and 5 illustrate the percentages of each type of crash in the years 2001, 2002, and 2003, respectively. Figure 6 shows the percentage of each type of crash in the three-year period. Approximately 64 percent of the total crashes were rear-end and sideswipe, especially on southbound SR A1A. These two types of crashes are caused by the unexpected left turns from southbound SR A1A and the blockage problem on the right-turn-only lane by the bus stop approximately 200 feet away from the intersection on southbound SR A1A.

It is interesting that the total number of crashes has dropped from 13 in 2001 to 5 in 2003. The corresponding crash rates also were significantly reduced, from 1.32 to 0.50 (accidents per million entering vehicles) from 2001 to 2003. The number of injuries also has dropped from 6 to 1 from 2001 to 2003. This implies that the intersection safety has improved in the last few years. Figures 7 and 8 illustrate the trend of crash frequency and crash rates from 2001 to 2003.

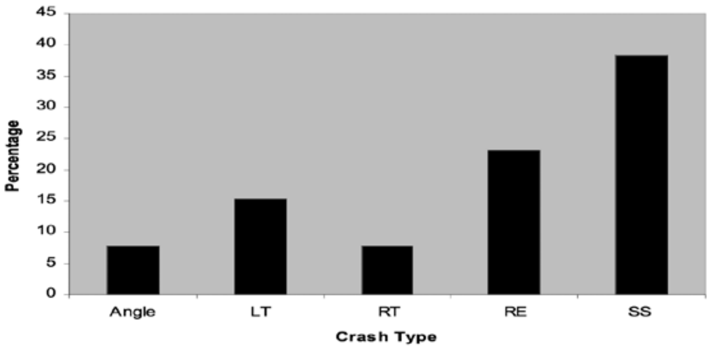

Figure 3. Distribution of Crash Type in 2001

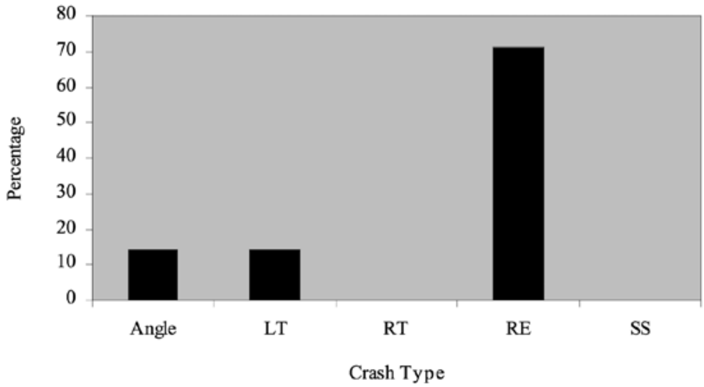

Figure 4. Distribution of Crash Type in 2002

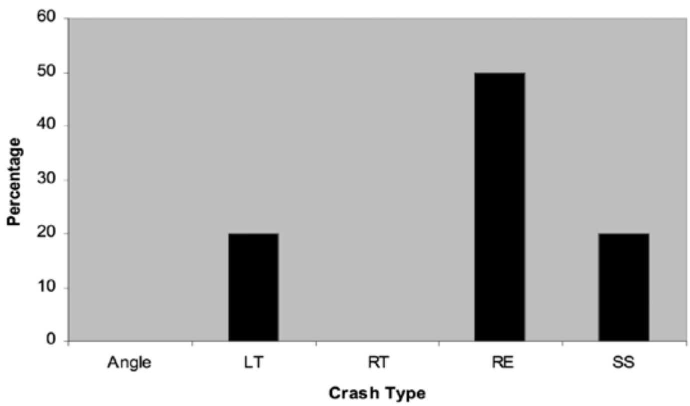

Figure 5. Distribution of Crash Type in 2003

Legend: LT=left turn, RT=right turn, RE=rear end, SS=side swipe

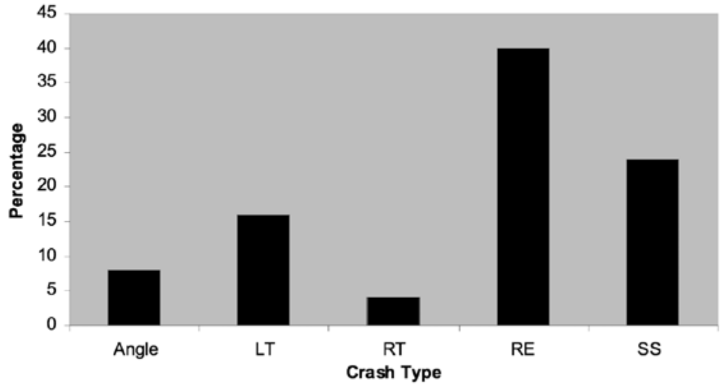

Figure 6. Distribution of Crash Type, 2001 - 2003

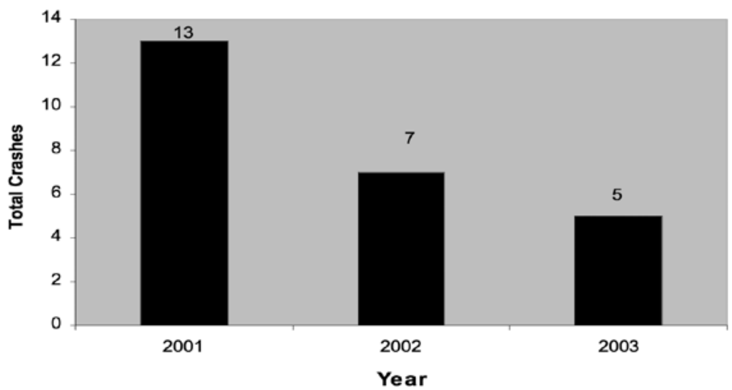

Figure 7. Change of Crash Frequency, 2001 - 2003

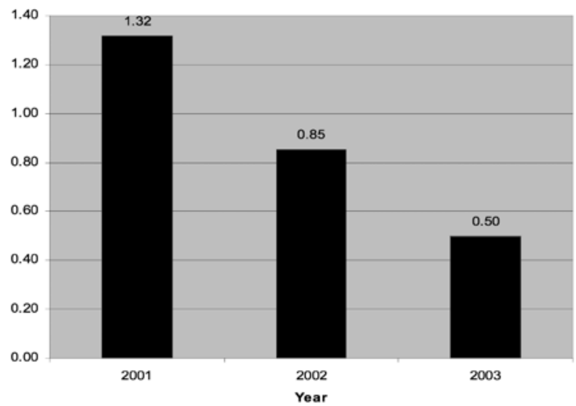

Figure 8. Change of Crash Rates, 2001 – 2003

(accidents per million entering vehicles)

The critical crash rate method was used to determine the safety level of the study intersection. This statistical tool can be used to screen for high-accident locations by utilizing a confidence interval that can be adjusted up or down to accommodate the needs of a particular safety program. If a segment has an actual crash rate higher than the critical rate, the location may have a potential highway safety deficiency and may need additional analysis. To compute the critical crash rate for a site, the following equation was used:

$$F_c = F_\alpha + k(F_\alpha/M)^{1/2} + 1/(2M)$$

Where:

F_c = the critical crash rate

F_α = statewide average crash rate

K = a probability constant. K = 3.291 for a 99.95% confidence level for urban area

M = vehicle exposure, calculated per million entering vehicles (MEV)

The Florida statewide average crash rates for intersections that have the characteristics of being 4-5 lanes, 2-way, divided, raised, and 4-leg are 0.479, 0.473, and 0.445 crashes per million vehicles for the years 2001, 2002, and 2003, respectively. Based on the above equation, the corresponding critical crash rates for the year 2001, 2002, and 2003 are 1.26, 1.32, and 1.19, respectively. The crash rates in the years 2002 and 2003 are less than their critical crash rates. The crash rate in the year 2001 is a slightly higher than its critical crash rate. However, the actual average crash rate for the three-year period is 0.89 at the intersections, which is lower than the critical crash rate of 1.25 during the same period. This implies that the location has no potential safety deficiency.

Conflicts Analysis

The purpose of the conflicts analysis is to identify the potential conflicts between buses and other vehicles or pedestrians/bicyclists. Traffic conflicts are interactions between two or more drivers where one or both drivers take an evasive maneuver to avoid a collision (Robertson et al. 1994, Parker and Zegeer 1988, Parker and Zegeer 1988a). In this study, traffic conflicts at the intersection were used as an additional measure to quantify the safety effects of bus U-turns at the intersection. These conflict types are:

- slow vehicle, same direction conflict (C1)
- lane change conflict (C2)
- bus U-turn conflict (C3)
- angle conflict (C4)
- pedestrian and vehicle conflict (C5)

Based on this definition of traffic conflict, an occurrence was considered as a conflict when a vehicle applied brakes, swerved, or noticeably decelerated to avoid a collision. Data were extracted by tracking each vehicle movement from videotapes for an eight-hour period.

As shown in Table 2, a total of 48 conflicts were recorded by videotape. Most of the conflicts were of type C1 (16 rear-end conflicts), and type C2 (17 lane change conflicts). This is due to the fact that there is a bus stop on the outside lane of southbound SR A1A that becomes a right-turn-only lane providing access to the Lehman Causeway.

Table 2. Summary of Traffic Conflicts Observed in the Field

Conflict Type	Number of Conflicts Observed	Conflict Rates (conflicts/hour)	Conflict Rates (Conflicts per thousand Vehicles)
1	16	2.0	0.9
2	17	2.1	0.9
3	2	0.3	0.1
4	10	1.3	0.6
5	3	0.4	0.2
Total	48	6.0	2.7

The signal phase sequence at this intersection has the bus U-turn, followed by the northbound protected-left-turn (with concurrent through-traffic), followed by the northbound and southbound through-green, then the east-west movements. Due to the heavy use of the bus stop mentioned above, passenger loading and unloading time is typically greater than the time allotted for the northbound protected-left-turn phase. Thus, the southbound through-vehicles are released prior to the bus leaving the stop. This results in brief periods of congestion where vehicles have to slow down or make a quick lane change to avoid the stopped bus. This is how most of the observed rear-end and sideswipe conflicts occurred.

A total of 10 angle conflicts (type C4) were recorded. A few vehicles (average 2-4 vehicles per hour) were observed attempting to make a left turn from southbound

SR A1A into Ocean One, which caused angle conflicts with northbound through-vehicles because it is a prohibited movement. Some conflicts also were observed between left-turning vehicles from Ocean One and right-turning vehicles from OceanView. A total of two conflicts caused by bus U-turns were observed in eight hours.

Two types of conflict rates were calculated. The first one is the ratio between conflicts and the number of hours of observation. The number of conflicts per hour shows the conflicts that might be found during different hours of the day. The second one corresponds to the ratio between conflicts and traffic volumes. This rate is defined as the number of conflicts per thousand involved vehicles by maneuver type. As shown in Table 2, there were, on average, 6 conflicts in an hour and approximately 2.7 conflicts per thousand vehicles involved at the intersection.

Overall, it was found that the results of the conflict study are very consistent with the crash analysis. Based on the limited number of conflicts and crashes caused by bus U-turns, there is no indication that U-turning buses are a major safety concern at the subject intersection.

Observations and Conclusions

To overcome geometric constraints, an unconventional design was implemented to accommodate the U-turn of the buses at the intersection. Based on our observations at the intersection, Florida DOT and Dade County Traffic Engineers have done an outstanding job in accommodating this unusual situation in the best manner possible. With the use of optically-programmed traffic signals, the confusion to the motorists should be minimal. To unsuspecting motorists, there should not be any conflicting information displayed—they simply see standard traffic signal indications. When it is the bus's turn to go, the motorists see a red signal and should be expected to understand and abide by it.

The results of operational analysis show that the subject intersection currently operates at LOS "A" during AM peak hours and LOS "B" in PM peak hours. The average delay for the overall intersection is approximately 9-12 seconds per vehicle. Signal timing and the phase sequence are proper for accommodating the special bus U-turn movements and appear to do so as effectively and efficiently as can be expected. The more-detailed operational analysis indicates that implementation of the unconventional bus U-turn design at the signalized intersection will not cause major operational problems when the total entering volumes is less than 4,000 vehicles per hour at the studied location.

The eight-hour conflicts analysis showed that very few conflicts were caused by bus U-turn movements. A review of accident data for the subject intersection indicates that accidents related to the bus U-turn occur infrequently. There are, on average, 1.7 crashes related to the bus U-turns per year. The accidents involving the bus were caused primarily by careless driving or the ignoring of the traffic signal by other drivers. Crash analysis also indicated that intersection safety has improved significantly over the three-year period. Based on these limited accident frequencies and number of conflicts, there is no indication that the bus U-turn at the subject intersection constitutes a major safety concern.

Of significance is the fact that approximately 64 percent of total crashes are rear-end and sideswipe collisions. These two types of crashes are caused by unexpected left turns from southbound SR A1A and the blockage problem of the right-turn-only lane by the bus stop approximately 200 feet south of the intersection.

It was observed that most buses did not stop behind the stop bar on the bus-U-turn-only lane. The bus lane's stop line is set back from the stop bar for northbound through-traffic on A1A to provide adequate sight distance for vehicles that are turning right into Ocean One. On some occasions, the buses initially stopped in the proper location, but continued to creep up over the stop bar and, on one occasion, completely over the crosswalk.

Some buses were observed making much larger U-turns than the U-turn pavement markings in the intersection. As indicated by the City, the bus is close to the curb as it completes its U-turn. Figure 9 shows the damaged curb from vehicles making the U-turn maneuver. However, as U-turning speeds are typically very low, the potential for serious crashes is also relatively low.

Relocating the U-turn to Hallandale Beach Boulevard, as suggested by the City, would add approximately 10 minutes to the bus routes. This would require the addition of another bus to the route to maintain the current bus headways. Additionally, this represents an unwanted increase in travel time to the existing bus patrons. It is doubtful that extending these routes would help to serve any additional transit customers, in that the areas to the north are currently served by other Miami-Dade Transit and Broward County Transit routes.

Figure 9. Possible Damage on the Curb from Bus U-Turns

Acknowledgments

This study was funded by Miami-Dade Transit. The safety data provided by the FDOT District 6 Safety Office are greatly appreciated. The author wishes to thank Ms. Jing Liu for her help with editing. The author also wishes to acknowledge the insights of his former colleague Mr. Larry Hagen and the assistance of former graduate research assistant Mr. Harkanwal Singh.

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