Safety Evaluation of Converting On-Street Parking from Parallel to Angle

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To increase the supply of parking in the central business district of Lincoln, Nebraska, the city converted parking on several streets from parallel to angle. The conversions were made on streets that had enough room to permit the removal of a traffic lane to provide the additional street width needed for angle parking without increasing traffic congestion. The safety effects of converting on-street parking from parallel to angle were evaluated and the cost-effectiveness of the parking conversion was determined. The conversion resulted in a significant increase in the number of parking-related accidents; the number of parking-related accidents per million vehicle miles also increased significantly. But when the increase in accident exposure caused by the increase in parking activity was considered, there was no significant increase in the parking-related accident rate, nor was there a significant change in the severity of the parking-related accidents. The on-street conversion was cost-effective because the increase in accident costs resulting from the conversion was lower than the cost of providing additional off-street spaces.

To increase the supply of parking in the central business district of Lincoln, Nebraska, the city converted parking on several streets from parallel to angle. The conversions were made on streets that had enough room to permit the removal of a traffic lane to provide the additional street width needed for angle parking. Although the removal of traffic lanes did not increase congestion, the city was concerned about a possible increase in accidents.

The objective of this study was to evaluate the safety effects and cost-effectiveness of converting on-street parking from parallel to angle. The rates and severity of parking-related accidents before and after the conversion were compared to determine the safety effects. In addition, an economic analysis was conducted to determine the cost-effectiveness of the conversion.

PREVIOUS RESEARCH

Several studies (*1*) have compared the accident experience of angle and parallel parking. The studies have reported accident rates for parallel parking to be from 19 to 71 percent lower than those for angle parking. Many of the studies were before-and-after studies involving changes from angle to parallel parking. However, none of them were before-and-after studies of changes from parallel to angle parking, and none of the studies accounted for the change in accident exposure associated with the change in parking configuration. For example, when angle parking is changed to parallel parking, accident exposure is reduced because fewer parking spaces remain after the conversion. Therefore, the reductions in accidents that have been associated with changes from angle to parallel parking may have been caused by changes in accident exposure rather than by differences in the types of parking maneuvers associated with the parking configurations.

Humphreys et al. (*2*) found parking utilization to be a primary factor affecting accident rates. Increased parking utilization resulted in significantly higher accident rates regardless of the type of parking. Type of parking was found to have no effect on accident rates when parking utilization, abutting land use, and street classification were taken into account. Thus, these findings brought into question the conclusion of many studies that parallel parking is safer than angle parking.

PARKING CONVERSION

Since September 1987 27 block faces in downtown Lincoln have been converted from parallel to angle parking. The typical parallel parking space was 22 ft long and 8 ft wide. The minimum width of the adjacent traffic lane was 12 ft. This traffic lane was removed to provide the additional space needed for angle parking.

The typical angle parking space that replaced the parallel parking is 9 ft wide and has a 15-ft stall line extending from the curb. The parking angle is 55 degrees, which is the angle used in Lincoln as a balance between number of spaces and ease of parking. The minimum width of the adjacent traffic lane is 15 ft.

STUDY SITES

Of the 27 block faces, 15 were not included in the study because the parking on them had been converted less than a year ago, and 1 other was excluded because traffic-volume data were not available. Eleven converted block faces were thus evaluated. In addition, to account for any overall change in the parking-related accidents in the central business district during the study period, eight block faces on which the parallel parking had not been converted were used as comparison sites. Thus, 19 block faces were included in the study.

The study and comparison sites are shown in Table 1. All of the sites were on downtown streets that have 25-mph speed

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TABLE 1 STUDY AND COMPARISON SITES

Block Face	Speed Limit	Street Ways	Street Lanes	Spaces Before	Spaces After	Turn-over	% Use	ADT
Study Sites								
1	25	2	2	1	6	4.21	100	2,300
2	25	2	2	4	10	4.18	92	2,200
3	25	2	2	6	12	3.54	92	3,400
4	25	1	3	4	9	8.05	94	3,100
5	25	1	3	6	14	8.05	94	3,100
6	25	1	3	7	16	7.92	94	2,550
7	25	1	3	5	13	3.24	88	5,330
8	25	1	3	5	11	8.05	94	4,100
9	25	1	3	5	10	8.05	94	4,100
10	25	1	3	9	14	5.96	94	5,730
11	25	2	2	8	16	2.97	85	1,000
Comparison Sites								
1	25	1	4	7	7	8.05	92	12,300
2	25	1	4	1	1	8.05	92	12,300
3	25	1	4	8	8	8.05	94	11,600
4	25	1	4	8	8	8.05	94	11,600
5	25	1	4	5	5	7.92	94	15,200
6	25	1	4	4	4	7.92	94	15,200
7	25	1	4	6	6	7.92	94	13,500
8	25	1	4	10	10	7.92	94	13,500

limits. Four of the eleven study sites were on two-lane, two-way streets; the rest were on three-lane, one-way streets. All the comparison sites were on four-lane, one-way streets.

The study sites had 60 parking spaces before the conversion and 131 spaces after the conversion. The comparison sites had 49 spaces. All the spaces were metered with time limits of 1 or 2 hr. The parking turnover on the study-site block faces ranged from 2.97 to 8.05 parkers per 8-hr parking day between 9:00 a.m. and 5:00 p.m. The turnover on all the comparison-site block faces was about 8 parkers per 8-hr parking day. The average parking utilization during the 8-hr parking day was from 85 to 100 percent on the study-site block faces and from 92 to 94 percent on the comparison-site block faces. The parking turnover and utilization on each block face were obtained from a parking study (*3*) conducted in downtown Lincoln in 1985. These data were believed to apply to the study period because the on-street parking revenues per space on the study- and comparison-site block faces have remained nearly constant since 1985.

The study-site average daily traffic (ADT) counts were much lower than those of the comparison sites. The study-site ADTs ranged from 1,000 to 5,730 vehicles per day (vpd). The comparison-site ADTs ranged from 11,600 to 15,200 vpd. The ADTs were computed from traffic counts provided by the city.

ACCIDENT DATA

The accident report files maintained by the city of Lincoln were reviewed to determine the number of parking-related accidents that occurred on each block face. The parking-related accidents included not only parked-vehicle and parking-maneuver accidents but also any accidents determined to have resulted from the presence of on-street parking. For example, also included were collisions in which one vehicle was trying to avoid a vehicle involved neither in parking nor in the collision. And only those accidents that occurred on weekdays between 9:00 a.m. and 5:00 p.m. were included.

The parking-related accidents before and after the conversion were identified for each study site. Because the parking on all block faces was not converted at the same time, the before and after periods had to be determined individually for each study site. A 3-month adjustment period was used. Therefore, the after period for each study site was the time beginning 3 months after the conversion until the end of 1989. The before period for each study site was an equal number of weekdays before the conversion.

The parking-related accidents for the comparison sites were identified for the years 1986–1989, which covered the duration of longest before and after periods of the study sites. However, the study sites had different before and after periods, ranging from 282 to 518 days. Therefore, the numbers of parking-related accidents on the comparison-site block faces before and after the conversion had to be determined separately for each study site.

The numbers of parking-related accidents for the study sites are shown in Table 2. On most of the study-site block faces, the number of parking-related accidents during the 8-hr parking day increased from none before the conversion to one or two after the conversion. Overall, the number of study-site parking-related accidents increased from two to eleven (450 percent) after the conversion from parallel to angle parking. Meanwhile, the total number of comparison-site parking-related accidents also increased between the before and after periods for each study-site block face. On the average, the

TABLE 2 PARKING-RELATED ACCIDENTS

Study-Site Block Face	Number of Weekdays Before	Number of Weekdays After	Number of Accidents Before	Number of Accidents After	Total Number of Accidents at the Comparison Sites Before	Total Number of Accidents at the Comparison Sites After
1	407	407	0	2	4	8
2	383	383	0	0	4	8
3	374	374	0	1	2	4
4	518	518	0	1	5	9
5	500	500	0	1	5	9
6	518	518	0	1	5	9
7	341	341	0	2	2	5
8	282	282	1	1	5	5
9	337	337	0	0	2	5
10	337	337	1	1	2	5
11	375	375	0	1	3	7
Total	4,372	4,372	2	11	Not Applicable	
Mean	397.5	397.5	.2	1.0	3.5	6.7

total number of comparison-site accidents increased from 3.5 to 6.7 (90 percent). Therefore, the number of study-site accidents expected during the after period if the parking had not been converted would have been two plus 90 percent, or about four parking-related accidents. Thus, the increase in study-site parking-related accidents over the expected increase was from four to eleven (175 percent). According to the Poisson distribution test, all three of these increases are statistically significant at the 5 percent level of significance.

Prevailing traffic conditions and the level of parking activity did not change during the study period. However, mild weather during the winter months of 1987 resulted in an unusually low number of accidents in 1987, which was during the before period of the study sites. The numbers of parking-related accidents during the 8-hr parking day on the comparison-site block faces from 1986 through 1989 are shown in Table 3. There was only one accident in 1987 compared with an average of 3.5 accidents per year. But, as shown in Table 3, this was also the case on 11 other block faces in downtown Lincoln that were not included in the study. The parking on these block faces was angle parking throughout the study period. In 1987 there were only 6 accidents on these block faces compared with an average of 10.5 accidents per year. Thus, the low number of parking-related accidents in 1987 was not limited to the comparison sites but was the general case in downtown Lincoln. The large increase in accidents on the comparison-site block faces was therefore attributed to the mild winter weather in 1987.

ACCIDENT RATES

The accident rate commonly used in comparisons of parallel and angle parking has been expressed in terms of accidents per million vehicle miles (*1*). However, as mentioned previously, this rate does not account for the change in accident exposure caused by the difference in the parking activity between parallel and angle spaces. Parking activity is a function of the turnover and utilization of the parking. In addition to the common accident rate, therefore, an accident rate was computed in terms of accidents per million space-hours per 1,000 parkers per million vehicle miles as follows:

$$AR = N/(T * P * H) \quad (1)$$

where

AR = accident rate (accidents/10^6 space-hr/10^3 parkers/10^6 vehicle-mi),
N = number of parking-related accidents,
T = vehicle miles of travel (millions),
P = number of parkers (thousands), and
H = number of space-hours of parking used (millions).

TABLE 3 ANNUAL PARKING-RELATED ACCIDENTS

Block Faces	1986	1987	1988	1989
Comparison Sites	5	1	3	5
Others not included in the study	10	6	14	12

The vehicle miles of travel, the number of parkers, and the number of space-hours used in Equation 1 were computed as follows:

$$T = (0.48 * ADT * D * L)/10^6 \quad (2)$$

$$P = (TO * S * D)/10^3 \quad (3)$$

$$H = (8 * U * S * D)/10^6 \quad (4)$$

where

ADT = average daily traffic (vpd),
D = number of parking days,
L = length of block face (miles),
TO = turnover rate (parkers per space per parking day),
S = number of parking spaces, and
U = percentage of space-hours used.

In calculating the rates for each study site, the space-hours of parking, number of parkers, and vehicle miles of travel were computed for the 8-hr parking day for the number of weekdays shown in Table 2. The number of spaces, turnover rate, percentage of space-hours used, and ADT shown in Table 1 were used to compute these values for each site. About 48 percent of the ADT at the study sites occurred during the 8-hr parking day.

In addition to the before and after accident rates, adjusted-after accident rates were also calculated for each study site. The adjusted-after accident rates were the after accident rates reduced to account for the increase in parking-related accidents on the comparison-site block faces as follows:

$$R_i' = R_i(B/A) \quad (5)$$

where

R_i' = adjusted-after accident rate for study site i,
R_i = after accident rate for study site i,
B = number of parking-related accidents on the comparison-site block faces during the before period for study site i, and
A = number of parking-related accidents on the comparison-site block faces during the after period for study site i.

The parking-related accident rates computed for each study site are shown in Table 4. Mean parking-related accident rates are also shown. The mean accident rate, based on vehicle miles of travel, increased from 4.6 to 33.6 accidents per million vehicle miles after the conversion. When the increase in the number of parking-related accidents on the comparison sites was considered, the rate still increased to 17.5 accidents per million vehicle miles. But when the effect of the level of parking activity was also considered, the parking-related accident rate increased only from 28.1 to 36.0 accidents per million space-hours per 1,000 parkers per million vehicle miles.

The one-tail paired t-test was used to determine whether the after and adjusted-after mean parking-related accident rates were significantly higher than the before mean parking-related accident rates. The comparison of the before with the after mean parking-related accident rate is shown in Table 5, and the comparison of the before with the adjusted-after mean

TABLE 4 PARKING-RELATED ACCIDENT RATES AT STUDY SITES

Block Face	Accidents/ Million Vehicle Miles			Accidents/ Million Space Hours/ 1,000 Parkers/ Million Vehicle Miles		
	Before	After	Adjusted After	Before	After	Adjusted After
1	0	78.3	39.1	0	389.7	194.9
2	0	0	0	0	0	0
3	0	28.8	14.4	0	54.9	27.5
4	0	22.8	12.7	0	17.3	9.6
5	0	23.6	13.1	0	8.0	4.4
6	0	22.7	15.4	0	6.8	3.8
7	0	40.3	16.1	0	89.9	36.0
8	31.7	31.7	31.7	263.3	54.4	54.4
9	0	0	0	0	0	0
10	19.0	19.0	7.6	46.0	19.0	7.6
11	0	97.7	41.9	0	134.4	56.7
Mean	4.6	33.6	17.5	28.1	70.4	36.0

TABLE 5 COMPARISON OF BEFORE AND AFTER PARKING-RELATED ACCIDENT RATES AT STUDY SITES

Parking-Related Accident Rate	Mean Diff.	Stand. Dev.	Sample Size	t-value	Level of Significance[a]
Accidents/ Million Vehicle Miles	29.0	32.7	11	2.94	< 0.01
Accidents/ Million Space Hours/ 1,000 Parkers/ Million Vehicle Miles	42.3	143.6	11	0.98	> 0.20

[a] One-tail, paired t test.

parking-related accident rate is shown in Table 6. In both cases, the after and the adjusted-after mean rates in terms of accidents per million vehicle miles were significantly higher than the corresponding before mean accident rate at the 5 percent level of significance. But the after and adjusted-after mean accident rates in terms of accidents per million space-hours per 1,000 parkers per million vehicle miles were not significantly higher than the corresponding before mean accident rate at the 5 percent level of significance.

Thus, the conversion from parallel to angle parking resulted in a significantly higher mean parking-related accident rate when the measure of accident exposure was vehicle miles of travel. However, when the measure of accident exposure included the level of parking activity, there was no significant difference in the mean parking-related accident rates.

ACCIDENT SEVERITY

From 1986 through 1989, 13 percent of the parking-related accidents on streets in downtown Lincoln were nonfatal injury accidents, and the rest were property-damage-only accidents. Of the 11 parking-related accidents that occurred at the study sites after the parking had been changed from parallel to angle parking, 2 (18 percent) of them were nonfatal injury accidents, and the other 9 (82 percent) were property-damage-only accidents. There was no statistically significant difference between the percentages of nonfatal injury accidents for the parallel and angle parking according to the binomial distribution test of proportions conducted at the 5 percent level of

TABLE 6 COMPARISON OF BEFORE AND ADJUSTED-AFTER PARKING-RELATED ACCIDENT RATES AT STUDY SITES

Parking-Related Accident Rate	Mean Diff.	Stand. Dev.	Sample Size	t-value	Level of Significance[a]
Accidents/ Million Vehicle Miles	12.9	16.2	11	2.63	0.01
Accidents/ Million Space Hours/ 1,000 Parkers/Million Vehicle Miles	7.9	93.8	11	0.28	>0.20

[a] One-tail, paired t test.

significance. Thus, no significant change in accident severity occurred as a result of the parking conversion.

ECONOMIC ANALYSIS

The conversion of on-street parking from parallel to angle parking provided an average of 6.5 more parking spaces per block face at a nominal cost. The conversion was accompanied by about a 280 percent increase in the number of parking-related accidents per million vehicle miles with no significant increase in accident severity. For the conversion to be cost-effective, the increase in accident costs resulting from it must be less than the cost of providing the additional spaces off-street. The additional accident cost per year is

$$\mathrm{AAC} = (C_a * \mathrm{IAR} * D * P * \mathrm{ADT} * \mathrm{BFL})/(10^8 * S) \qquad (6)$$

where

AAC = additional accident cost (dollars per year per space),
C_a = average parking-related accident cost (dollars per accident),
IAR = increase in number of parking-related accidents per million vehicle miles,
D = number of parking days per year,
P = percentage of ADT during parking day,
BFL = average block-face length (miles), and
S = average number of additional spaces per block face.

The accident cost figures currently used by the city of Lincoln (*4*) are $13,600 per fatal or nonfatal injury accident and $1,700 per property-damage accident. Because of the random occurrence of fatal accidents in the city of Lincoln, the same accident cost is used for fatal and nonfatal injury accidents to avoid overemphasizing locations where a fatal accident occurs. The accident cost used for fatal or nonfatal injury accidents is the weighted average cost, which was derived using the National Safety Council costs and the numbers of fatal and nonfatal injury accidents that occurred in Lincoln during 1989. On the basis of these accident costs and the severity of parking-related accidents observed in downtown Lincoln, the average parking-related accident cost is about $3,250.

The adjusted average increase in the number of parking-related accidents per million vehicle miles shown in Table 6 was 12.9, and the average number of additional spaces per block face was 6.5. The number of parking days per year in downtown Lincoln is 307, and 48 percent of the ADT is during the 8-hr parking day. The average block-face length in downtown Lincoln is about 300 ft.

Substituting these values into Equation 6, the annual additional accident cost resulting from the parking conversion in downtown Lincoln is

$$AAC = 0.054 * ADT \quad (7)$$

The present worth of the annual additional accident cost is

$$PAC = 0.054 * ADT * PWF \quad (8)$$

where PAC is the present worth of additional accidents (dollars per space) and PWF is the present worth factor of a uniform series.

The recent cost of developing off-street parking facilities in downtown Lincoln, including land acquisition, demolition, and construction, is about $10,400 per space. Therefore, for the parking conversion to be cost-effective, the present worth of the additional accident costs per space would have to be less than $10,400.

The ADT at which the additional accident cost of the conversion would be equal to the cost of providing the additional spaces off-street can be found by setting Equation 8 equal to the average cost per space of off-street parking and solving for ADT as follows:

$$ADT_{BE} = (18.5 * C_s)/PWF \quad (9)$$

where ADT_{BE} is the break-even ADT (vpd) and C_s is the average cost of off-street parking (dollars per space).

Using a 10 percent interest rate and a 30-year service life, the break-even ADT in downtown Lincoln would be 20,400 vpd. This indicates that the conversion would be cost-effective on streets with ADTs below 20,400 vpd. It would not be cost-effective on higher-volume streets, where lower-cost off-street parking can be provided, or where an increase in traffic congestion may occur. As shown in Table 1, the ADTs were well below 20,400 vpd on the block faces where the conversions were made in downtown Lincoln. Therefore, it is readily apparent that converting on-street parking from parallel to angle in downtown Lincoln was cost-effective.

CONCLUSION

The conversion from parallel to angle parking in downtown Lincoln resulted in a significant increase in the number of parking-related accidents on the converted block faces. In addition, the number of parking-related accidents per million vehicle miles of travel on the block faces also increased significantly. But when the increase in accident exposure due to the increase in the number of spaces was accounted for, there was no significant increase in the parking-related accident rate on the block faces. There was no significant change in the severity of parking-related accidents as a result of the conversion, either.

Although these findings may suggest that there is no difference in the safety effects of parallel and angle parking, this is not so. Instead, the findings indicate that the difference between the safety of the two types of parking is primarily a result of differences in levels of parking activity rather than in the nature of the parking maneuvers associated with them. Therefore, where the supply of parking spaces is sufficient, the conversion of on-street parking from parallel to angle should *not* be considered, because the number of accidents will increase as a result of more parking activity because of more parking spaces. In the same way that no parking is safer than parallel parking, parallel parking is safer than angle parking, because it reduces accident exposure.

The conversion more than doubled the number of parking spaces on the block faces. However, the cost of the additional parking-related accidents caused by the conversion was less than the cost of providing an equivalent number of additional parking spaces off-street in a parking garage or parking lot. Therefore, the conversion was cost-effective. However, it must be remembered that the conversion was made on streets that had enough room to allow the removal of traffic lanes to provide the additional street width needed by the 55-degree angle parking without increasing traffic congestion. Consequently, additional traffic operations and delay costs were not included in the analysis.

The primary conclusion of this study was that converting on-street parking from parallel to angle may be a cost-effective way of increasing the supply of parking in downtown areas, if the streets are wide enough to provide for angle parking without increasing traffic congestion, as was the case in downtown Lincoln. But, even if the streets are wide enough, on-street parking should not be converted from parallel to angle unless the additional parking-related accident cost is compared with the cost of developing alternative off-street parking spaces. In some cases, the development of off-street parking may be so inexpensive that the cost of alternative off-street spaces would be lower than the cost of the additional parking-related accidents that would occur as a result of the conversion. In other cases, the traffic volumes may be so high that the additional parking-related accident cost would exceed the cost of developing alternative off-street parking spaces. In these cases, converting on-street parking would not be cost-effective. The solution of Equation 9 for various off-street parking costs, as illustrated in Figure 1, could provide a guideline for determining the cost-effectiveness of converting on-

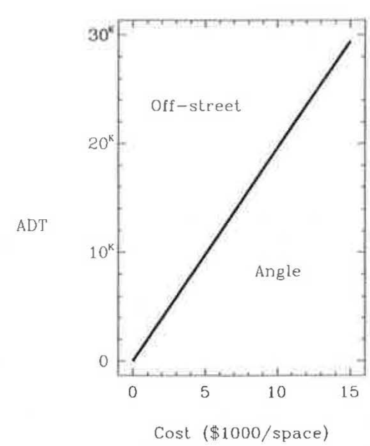

FIGURE 1 Cost-effective guideline.

street parking. Points below the line indicate that the conversion to angle parking would be cost-effective, and points above the line indicate that converting spaces would not be cost-effective when compared with providing the additional spaces off-street.

It should be noted that the findings of this study were based on a limited amount of accident data. Larger sample sizes over a wider range of ADTs are needed to validate the findings. The city of Lincoln has concluded that the conversion of on-street parking from parallel to angle was cost-effective for the ADT levels studied, but it is continuing to study the safety effects of ADTs greater than 6,000 vpd. More research is needed before definitive guidelines for converting on-street parking from parallel to angle can be established. Additional research should be conducted to examine effects of factors such as traffic volumes, speeds, street widths, parking angle, and parking activity on the cost-effectiveness of the conversion.

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