Rain-Related Impacts on Selected Transportation Activities and Utility Services in the Chicago Area

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ABSTRACT

An intensive meteorological study of summer precipitation in the Chicago area during 1976–78 furnished detailed data needed to perform a study of the impacts of rain on selected transportation-related activities and on certain utility services. Degree of effect on these activities was studied on a rain day versus non-rain day basis and further on a land use basis to help infer changes in impacts due to urban-influenced increases in rain occurrences, rainfall amounts and storm activity. Added rain resulted in over 100% more vehicle accidents, particularly in the urban area, but the accident severity associated with rain was greater in the rural areas. Rainfall decreased ridership of mass transit systems by 3–5% and apparently this was disproportionately due to midday discretionary riders such as shoppers. Little relationship of rain to pleasure boat emergencies was found but more rain decreased usage of pleasure boats. The number of delays in flight departures from O'Hare Airport was highly related to rain, increasing from only 0.3% of all flights delayed on non-rain days to 18.2% delayed on heavy (≥1.3 cm) rain days. The percentage of the total electrical power outage time which was due to storms varied greatly by power district, ranging from 33% to over 80%. In general, downtown Chicago experienced less time without power due to storms, than did suburban areas. Telephone service was unaffected by rain conditions in Chicago but usage was increased. The results of these selected impacts indicate that an urban-related increase in summer rainfall will lead to certain undesirable impacts on those traveling, particularly by auto or air.

1. Introduction

As part of a project to study the influence of Chicago on precipitation and storminess (Changnon *et al.*, 1979a), a series of investigations were made of the impacts of these conditions on certain Chicago-area activities and support functions (Changnon *et al.*, 1979b). Isolation of the impacts due solely to urban-changed weather is very difficult (Changnon *et al.*, 1977). We instead explored the easier to define relationships between particular weather types (those types which are modified by large urban areas, such as rain and thunderstorms) and certain types of human activities without trying to isolate the effects of the *modified* component of each weather type.

The study sought to answer such questions as, "What happens on a rainy day in an urban area? Do car accidents increase? If so, by how much? Does ridership on the mass transit system increase or decrease and by what percent? How much money does the transit system lose or gain? If a person plans to depart from the major airport on a rain day, what are his chances of a delayed flight compared to his chances on a non-rain day?" Auto accidents, mass transit ridership, boating emergencies, flight departure delays at O'Hare Airport, power interruptions and interruptions in telephone service were selected for study. The relationships between rainfall and most of these phenomena are generally known or suspected in a qualitative sense, but there is relatively little literature on quantitative relationships. Thus, one goal of this study was to begin to provide quantitative data.

This quantitative investigation was accomplished by comparing the selected activities and functions on rain, heavy rain and thunderstorm days with the same activities on non-rain days. Further classification of these comparisons by rural, suburban and urban parts of the metropolitan area allowed inferences to be made about differences in the impact of rain on these activities in areas of varying land use.

The results of these analyses were then used to qualitatively assess the influence of the modified component of the weather. We assumed that an increase in a weather type (such as more heavy rain events or heavier rain rates) would result in an increase in the frequency or the severity of impacts on those activities which were found to be influenced by that weather type. For example, if more automobile accidents occurred on rainy days than on dry days, it could be assumed that an increase in the number of rainy days would result in an increase

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in accidents, although the increase might not be linear.

a. Study area

The Chicago metropolitan area, including parts of northwestern Indiana downwind from Chicago, was selected for study primarily because of the availability of extensive rainfall data for the area. A network of 320 recording raingages was in operation from the spring of 1976 until the fall of 1978 as part of the Chicago Area Program (Changnon and Semonin, 1978). Typical gage density was 1 gage per 23 km^2.

Activities occurring throughout the Chicago–Northwest Indiana region were studied even though some of the area probably does not experience urban-modified weather. Since the purpose was to examine the effects of particular types of weather, with no effort being made to isolate the effects of modified weather, it was not necessary to restrict the study to areas of weather modification. Also, a broader geographical area enabled the examination of weather effects on all types of land use areas (densely populated urban zones, suburban communities and rural areas). Since many weather effects vary with land use, such findings are important when planning land use changes in areas of modified weather. The exact study areas used varied for different impacted activities, depending on data availability.

Weather impacts during the summers (June–August) of 1976, 1977 and 1978 were chosen for the analyses. Summer weather impacts were chosen since summer is the season of greatest urban precipitation modification (Landsberg, 1970), and these years were chosen to correspond to the extensive available data (Changnon *et al.*, 1979b).

b. Methodology

A number of analytical methods were employed, depending on the nature and availability of data (Bertness, 1979). Most analyses used the "matched-pair" approach used by Sherretz and Farhar (1978) in a study of traffic accidents in the St. Louis area. This method makes use of matched pairs of days. On one of the matched days some weather phenomena, such as rainfall, has occurred and on the other it has not. Human activities occurring on one of the days are then compared to the same activities on the other day. For instance, Sherretz and Farhar compared the mean number of traffic accidents occurring between 1600 and 2100 (all times CDT) on summer days having rainfall between those hours with the mean number of traffic accidents between 1600 and 2100 on a set of matched days (each occurring exactly one week from one of the rain days and having no rainfall). The difference between the means was then compared using the *t*-test for matched pairs.

The typical analysis in this study employed the following procedure. First, a data set (such as ridership records for the Chicago bus system) was acquired from the appropriate agency. If possible, records were obtained for all three summers, but shorter records were also accepted. Next, the boundaries of the relevant geographical area (for instance, the city limits of Chicago) were identified and particular hours of observation were selected (such as 0500–2100 for mass transit riders). Then network rainfall records for the selected hours and places were searched to identify raindays and non-rain days. A rainday was defined as one on which at least 80% of the raingages within the designated areas received at least 0.25 mm of rainfall during the selected hours. A non-rain day was defined as one on which no more than 20% of the raingages received $\geq$0.25 mm of rainfall.

A list was then prepared of all days meeting the rain-day criteria. Next, the day exactly one week later than each rain day was checked to see if it met the criteria for being a non-rain day. If it did, it was selected for the sample. If it did not (if more than 20% of the gages reported rain), or if it fell on a holiday weekend, it was rejected. In this case, the day one week prior to the rainday was examined. If it was acceptable (and had not been matched to any other rainday) it was included in the sample. If neither of the potential non-rain days were acceptable, both they and the rain day were eliminated from the sample.

Using these lists, mean numbers of auto accidents, mean numbers of injuries per auto accident, mean numbers of bus passengers, and mean numbers of rapid transit passengers were prepared for rain days and for the matched non-rain days. The resulting means were then compared to determine the relative impacts of the rain days on the phenomena being studied. (For example, traffic accidents doubled in some locations on rain days and bus ridership decreased by 3–4%.)

Particular advantages of the matched-pair approach are that it can be employed even when only a year or two of data are available and that the study area can serve as its own control. Many variables having nothing to do with the weather are controlled rather effectively whether or not their existence is known. For example, the daily number of traffic accidents would depend on many factors in addition to the presence or absence of rainfall. These would include such things as general road conditions (numbers of potholes, width of roads, adequacy of signs), traffic volumes, numbers of drinking drivers, etc. Time and budget constraints did not allow an analysis or even identification of all these other factors. However, variations in such factors as potential traffic volumes or numbers of drinking drivers should be minimized by comparing Mondays with Mondays, Saturdays with Saturdays, etc. Further, by comparing days only one week apart, such factors as progressive deterioration or improvement in road surfaces would be minimized. While this technique would not eliminate all errors due to unforeseen factors, it should reduce these errors considerably.

For some analyses, it was not possible and/or appropriate to use the methodology as outlined here and alternate procedures were employed and will be described where appropriate. Finally, some analyses examined the impact of rainfall amount on an activity. Daily rainfall amounts in an area, such as a township or service area of a transit system, were computed by averaging the rainfall amounts received by each gage within the area during the hours of interest.

c. Interpretation of results

The results in the following sections must be interpreted with caution. First, because of relatively short records and selection criteria that eliminated most days from consideration, some conclusions are based on very small samples. Second, since most social data were daily records, while rainstorms occurred during only a few hours of the day, the impact of the rain during the time *when* it was actually falling is no doubt underestimated. (However, this problem would not invalidate conclusions regarding the total impact of rainfall on a day's activities.) Third, the rain/non-rain day approach is meant only to indicate the types and degrees of impacts which may be expected to coincide with rain days. Causation is not necessarily implied. For instance, the tremendous increase found in delayed departures from O'Hare Airport on rain days is also related to the poor visibility and turbulence often associated with summer rain conditions. Finally, no attempt was made to establish the mechanisms by which a weather type affected an activity. Neither the physical processes resulting in an accident or emergency (for example, rain resulting in slick roads and slick roads leading to accidents caused by skidding) nor the behavioral decisions relevant to the emergency (the decision to drive during a rainstorm or the decision not to drive more cautiously than usual) were examined separately in this exploratory study. For these reasons, the results in the following sections cannot be viewed as definitive statements regarding the causative relationships between rainfall and the selected activities, but rather as indications of the presence and approximate degrees of impacts which should be examined in greater depth and sophistication in future studies.

2. Traffic accidents

The impact of any rainfall and of heavy rainfall on the number and severity of summer automobile accidents in the Chicago–Northwest Indiana area was determined using analyses similar to those of Sherretz and Farhar (1978) in their study of St. Louis accidents. Accident data were obtained for Chicago and outlying townships in Cook County for June, July and August of 1976 and 1977 from the Illinois Department of Transportation. Accident data for selected townships in Lake, Porter and La Porte Counties in northwestern Indiana (just east of Chicago) were obtained for the summers of 1977 and 1978 from the Indiana State Police. Rain days and non-rain days were selected for each township using the matched pair procedure based on the observation hours of 1600–2100 CDT.

a. Frequency of accidents

The numbers of accidents occurring on the rain and non-rain days were determined using the matched pair approach and are presented in Tables 1 and 2. On the average, traffic accidents in the townships more than doubled on rain days. Although results for some townships are based on few pairs of days, the magnitude and consistency of the results suggests that rainfall very definitely leads to increased numbers of accidents. Further, the results are similar in magnitude to those for St. Louis.

Although nearly all townships experienced substantial increases in accident numbers on rain days, Tables 1 and 2 reveal large variations among the townships in the magnitudes of the rain day/non-rain day accident ratios. Results for some of the townships were based on small samples suggesting that the variations are partly a function of chance. But it is also possible that the impact of the rainfall varies spatially depending on some unmeasured local factors.

It was believed that traffic volume and/or road type (low or high speed) are prime factors that would modify the impact of the rainfall. An extensive analysis based on traffic volumes or road types could not be pursued in this study, so the population density for each township was computed instead [based on data from the U.S. Bureau of the Census (1967, 1973a,b)] and this was used as an indication of traffic volumes and types of roads. It was assumed that townships with low population densities would have generally lower traffic volumes and higher percentages of high speed country driving than would high density areas. Townships with very high population densities would probably have more traffic congestion, but perhaps a higher percentage of low-speed city-type driving.

The quartile of Cook County township with the highest population densities (including Chicago

TABLE 1. Number of accidents on rain and matched non-rain days in Cook County, Illinois, by township.[a]

Township	Population (km^{-2})	Mean number of accidents on rain days	Mean number of accidents on matched non-rain days	N (number of pairs)	Significance[c]	Ratio of accident numbers on rain days to accident numbers on non-rain days
Least densely populated quartile of townships						
Barrington	81	4.00	1.73	15	S	2.31
Orland	155	1.22	1.00	9		1.22
Lemont	156	1.12	0.00	8	S	—
Palos	377	3.73	1.55	11	S	2.41
Hanover	378	2.40	1.30	10		1.85
Rich	452	3.50	1.50	8		2.33
Palatine	574	4.43	3.29	14		1.35
						Mean ratio: 1.91 (N = 6)
Townships with intermediate population densities						
Schaumburg	627	4.67	2.58	12	S	1.81
Northfield	753	5.40	2.07	15	S	2.61
Bloom	764	4.09	1.82	11		2.25
Bremen	977	5.90	3.00	10	S	1.97
Elk Grove	1064	3.00	1.55	11	S	1.94
Lyons	1079	7.17	3.67	12		1.95
Stickney	1231	2.08	0.58	12	S	3.57
Wheeling	1254	7.75	4.83	12	S	1.60
New Trier	1520	3.24	1.71	17	S	1.90
Thornton	1543	16.83	6.00	6	S	2.81
Leyden	1768	8.38	5.31	13		1.58
Worth	1851	10.00	5.67	12	S	1.76
Calumet	1982	1.60	1.60	10		1.00
						Mean ratio: 2.06 (N = 13)
Most densely populated quartile of townships						
Niles	1997	13.00	5.92	12	S	2.20
Maine	2098	9.75	4.31	16	S	2.26
Proviso[b]	2165	12.92	4.58	12	S	2.82
Norwood Park	2779	1.91	0.64	11		3.00
Evanston	4108	4.94	1.75	16	S	2.82
Berwyn, Oak Park, Cicero	4882	12.50	4.92	12	S	2.54
City of Chicago	5811	43.00	17.12	8	S	2.51
						Mean ratio: 2.59 (N = 7)

[a] Only accidents occurring on the selected days in June, July and August of 1976 and 1977 between 1600 and 2100 CDT are included.
[b] Includes River Forest and Riverside townships.
[c] S indicates significance at 0.05 level using matched pair t-test.

and nearby suburbs) and the quartile with the lowest population densities (townships in northwestern and southwestern Cook County) were identified and grouped, as shown in Table 1. Accident ratios for each of these groups were averaged (unweighted). The seven most densely populated townships had an average rain day/non-rain day accident ratio of 2.59, while six of the least densely populated townships had an average ratio of 1.91 (one township did not have enough accidents to compute a ratio). If it can be assumed that areas with high population densities also have higher traffic volumes, more congestion, etc., these results suggest that rainfall has a greater impact on numbers of traffic accidents in areas of high traffic volumes.[1] Of course, this conclusion should not be accepted without further research based on longer periods of record, actual road and traffic volume data, and perhaps in-depth analyses of townships with abnormally high or low ratios for their population groups.

Results for the Indiana data were somewhat

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[1] The mean accident ratios for the two groups of townships are significantly different at the 0.01 level using a one-tailed t-test.

TABLE 2. Numbers of accidents on rain and matched non-rain days in parts of Lake, Porter, and La Porte counties in northwestern Indiana.[a]

County–Township	Population (km^{-2})	Mean number of accidents on rain days	Mean number of accidents on matched non-rain days	N (number of pairs)	Significance[d]	Ratio of accident numbers on rain days to accident numbers on non-rain days
Lake–North	1,493	13.31	6.54	13	S	2.04
Lake–Calumet	1,342	10.54	6.38	13	S	1.65
Lake–Hobart	595	2.10	1.40	10		1.50
Porter[b]	129	1.60	.60	10	S	2.67
La Porte–Michigan	856	2.50	1.79	14		1.40
La Porte[c]	103	1.55	1.27	11		1.21

[a] Only accidents occurring on the selected days in June, July and August of 1977 and 1978 between 1600 and 2100 CDT are included.
[b] Includes Portage, Westchester, Pine, Liberty, and Jackson townships.
[c] Includes Cool Spring, New Durham, Springfield, Center, and Scipio townships.
[d] S indicates significance at 0.05 level using matched pair t-test.

inconclusive since there were no townships with population densities corresponding to those in Cook County's most densely populated quartile of townships. However, the results were not inconsistent with those for Cook County, since five of the six Indiana townships had relatively low accident ratios, as might be expected in areas of low and intermediate population density (see Table 2).

b. Accident severity

Sherretz and Farhar (1978) found no consistent relationship between rainfall and accident severity, which was defined as the number of injuries per accident. The Chicago study employed the same definition of accident severity and, as in the St. Louis study, some areas showed increases in accident severity on rain days and some showed decreases (Table 3). It was again believed that the impact of rainfall on accident severity was partly a function of traffic volume or type of road.

The average accident severity ratio for townships in the most densely populated quartile was 1.03. The average severity ratio for the least densely populated townships (excluding one) was 1.69. This suggests that rainfall has little effect on accident severity in areas of relatively high volume, low-speed, city-type driving, but that in more rural areas with perhaps more high-speed driving there were ~70% more injuries per accident on rain days than on non-rain days.[2] However, the large variations within each of the three categories of townships and the occurrence of several very low ratios in townships having between 600 and 1100 people km^{-2} suggest a complex situation. A much more detailed study is needed before a firm conclusion can be reached as to urban versus rural differences in accident severity.

Results on accidents from Indiana are generally inconclusive, but moderately consistent with those from Chicago. Three townships with low population densities had accident severity ratios of 1.48, 1.50 and 2.45 whereas three townships with intermediate population densities had ratios of 1.71, 1.29 and 1.36. The high ratios were expected in the areas of low population density, but the ratios for the townships with intermediate population density were somewhat higher than those for the townships of comparable density in Cook County. The differences may reflect chance due to the small sample size, or they may reflect such factors as differing road conditions or law enforcement policies.

While the conclusion that rainfall has the specific effects suggested here on accident severity in different types of communities involves some questionable assumptions, it is reasonable to expect that the impacts of more rainfall on traffic conditions in different land use areas in a metropolitan region may lead to different influences on accident severity.

c. Impact of heavy rainfall on accident numbers and accident severity

Rain days in the Cook County and northwestern Indiana townships were divided into those receiving 0.2–12.7 mm, 12.8–25.4 mm, 25.5–50.8 mm and ≥50.9 mm of rainfall. The mean numbers of accidents occurring during periods associated with each of these rainfall amounts are given in Table 4. There is some tendency toward an increase in accident numbers with higher rainfall, but results are not conclusive. Also, a number of statistical problems reduces their validity. (For instance, the data were not standardized to eliminate the influence of varying township sizes.) However, they do agree with results from St. Louis. Basically, no discernible

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[2] The mean severity ratios for the two groups of townships are significantly different at the 0.05 level using a one-tailed t-test.

TABLE 3. Accident severity on rain and non-rain days in Cook County, Illinois, by township.[a]

Township	Number of injuries per accidents on rain days	N_1 Number of accidents on rain days	Number of injuries per accident on matched non-rain days	N_2 Number of accidents on non-rain days	Ratio of injuries per accident on rain days to injuries per accident on non-rain days
Least densely populated quartile of townships					
Barrington	0.550	60	0.346	26	1.59
Orland	0.727	11	0.444	9	1.64
Lemont	1.444	9	—	0	—
Palos	0.439	41	0.353	17	1.24
Hanover	1.375	24	0.538	13	2.56
Rich	0.393	28	0.667	12	0.59
Palatine	0.710	62	0.283	46	2.51
					Mean ratio: 1.69 ($N = 6$)
Townships with intermediate population densities					
Schaumburg	0.286	56	0.677	31	0.42
Northfield	0.444	81	0.612	31	0.72
Bloom	0.467	45	0.700	20	0.67
Bremen	0.441	59	0.467	30	0.94
Elk Grove	0.485	33	0.529	17	0.92
Lyons	0.523	86	0.432	44	1.21
Stickney	0.640	25	0.143	7	4.48
Wheeling	0.376	93	0.328	58	1.15
New Trier	0.255	55	0.310	29	0.82
Thornton	0.564	101	0.472	36	1.19
Leyden	0.266	109	0.348	69	0.76
Worth	0.308	120	0.324	68	0.95
Calumet	0.812	16	0.562	16	1.44
					Mean ratio: 1.21 ($N = 13$)
Most densely populated quartile of townships					
Niles	0.321	156	0.296	71	1.08
Maine	0.333	156	0.290	69	1.15
Proviso[b]	0.477	155	0.382	55	1.25
Norwood Park	0.476	21	0.714	7	0.67
Evanston	0.342	79	0.536	28	0.64
Berwyn, Oak Park, Cicero	0.473	150	0.322	59	1.47
City of Chicago	0.378	344	0.394	137	0.96
					Mean ratio: 1.03 ($N = 7$)

[a] Only accidents occurring on the selected days in June, July and August of 1976 and 1977 between 1600 and 2100 CDT are included.

[b] Includes River Forest and Riverside townships.

relationship was found between different amounts of rainfall and accident severity.

d. Summary

The results of the traffic accident analysis for the Chicago area and northwestern Indiana suggest strongly that rain days resulted in greatly increased accident numbers, and that accident numbers were increased more by rainfall in densely populated urban areas than in more rural areas. Accident severity increased greatly on rain days in rural areas but was approximately constant in dense urban areas. The effects of heavy rainfall on accident numbers and severity were not clearly established. Heavier rainfall was probably accompanied by increased numbers of accidents, but the amount of rainfall apparently had little influence on accident severity. It is reasonable to hypothesize that urban-produced increases in rainfall frequency would result in increased numbers of traffic accidents and, in rural areas, increased severity of accidents.

3. Mass transit ridership

Summer rainfall can be expected to have a variety of impacts on urban travel behavior. It might result in the substitution of mass transit for walking

TABLE 4. Effect of rainfall amounts on accident numbers.

Rainfall amount (mm)	Cook County, Illinois		Parts of Lake, Porter, and La Porte Counties in Indiana[b]	
	Number of periods	Mean number of accidents per period[a]	Number of periods	Mean number of accidents per period[c]
0	315	3.20	71	3.20
≥0.2 mm	315	6.90	71	5.62
0.2–12.7	240	6.14	62	5.74
12.8–25.4	51	9.88	7	4.29
25.5–50.8	16	7.69	1	10.00
≥50.9 mm	8	9.12	1	3.00

[a] 1600–2100 CDT on selected days in June, July and August of 1976 and 1977.

[b] See Table 2 for list of townships.

[c] 1600–2100 CDT on selected days in June, July and August of 1977 and 1978.

or for use of a private car if parking problems are perceived. It might result in the substitution of one form of public transportation for another, or in a shift from public transportation into a private car or taxi. Actual ridership on any one rain day probably reflects many types of decisions. Further, net ridership figures probably mask many changes in travel behavior. For example, some people who normally walk to work might ride the bus on a rainy day while others who normally ride the bus might take a taxi or the subway on a rainy day. The resulting change in bus ridership would be smaller than the number of people whose transportation habits were changed by the rainfall.

Analyses were designed to determine the overall impact of rainfall on bus and rapid transit ridership in the Chicago area and to try to determine who, if any general type of traveler (for instance shoppers), is affected by rainfall. It must be remembered, of course, that rain-day impacts included the impacts of other weather conditions accompanying rainfall, such as dark skies and wind, as well as the rainfall itself.

a. Daily ridership frequency

Daily bus ridership figures were obtained from the Chicago Transit Authority (CTA, serving the actual city of Chicago), the North Suburban Mass Transit District (NORTRAN, a public bus system serving north and northwest suburban communities), and the Gary (Indiana) Public Transportation Corporation. Rapid transit ridership records were also obtained from the CTA. Somewhat different portions of the summers of 1976, 1977 and 1978 were analyzed for each system, depending on data characteristics and availability (Bertness, 1979).

Ridership on each of these systems was analyzed using the matched pairs approach. Rain and non-rain days were selected separately for each system using raingages within the area served by the given system. It was assumed that most passengers traveled between 0500 and 2100 CDT. Hence, only rainfall between these times was considered.

Table 5 reflects the impact of rainfall on mean weekday ridership on the three systems. Rainfall caused a small but unmistakable decrease (3–5%) on each of the three bus systems. The impact on CTA rapid transit (electric trains) ridership (a 2.1% decrease) was significant but smaller than the corresponding loss in bus ridership on the CTA. The smaller decrease may be a function of types of ridership such that commuters from the suburbs had fewer transportation alternatives than did bus passengers within the city. Other possibilities are that higher proportions of bus passengers were making discretionary trips and could therefore cancel or postpone them, or that some bus passengers switched to rapid transit.

b. Who was affected

The original study (Bertness, 1979) attempted to determine who changed their travel behavior on

TABLE 5. Impact of rainfall on weekday mass transit ridership in the Chicago area for rainfall occurring any time between 0500 and 2100 CDT.

Transit system	Mean number of passengers on rain days	Mean number of passengers on matched non-rain days	*N* (number of pairs)	Significance[e]	Percent loss of passengers on rain days
CTA bus[a]	1,525,490	1,576,555	18	S	3.2%
NORTRAN bus[b]	15,174	15,925	21	S	4.7%
Gary bus[c]	9,239	9,688	18	—	4.6%
CTA Rapid Transit[d]	378,998	387,253	18	S	2.1%

[a] Chicago Transit Authority records from selected days during July and August of 1976, 1977, and 1978.

[b] North Suburban Mass Transit District records from selected days during July and August of 1976, 1977, and 1978.

[c] Gary Public Transportation Corporation records from selected days during June, July, and August of 1977 and 1978.

[d] Same days as CTA bus but electric trains.

[e] S indicates significant at 0.05 level using matched pair *t*-test.

rainy days. Did shoppers and other passengers making discretionary trips stay home? Did those traveling to work find alternate transportation? This part of the analysis faced many obstacles. No information was readily available on trip purposes or reasons for trip cancellations. Further, ridership figures were on a daily rather than hourly basis making the identification of rush hour travelers, afternoon travelers, etc., impossible.

Several techniques were employed to overcome these limitations. One of these examined the impact of rain at a specific time of day, such as morning rush hour, on total daily ridership on the CTA. Not unexpectedly, the results indicated that midday rain, presumably influencing shoppers and other discretionary passengers, had a larger impact on the day's ridership than did early morning rain, when most travelers were probably headed for work. Rain in the later afternoon and evening had little impact on ridership, passengers having already committed themselves to the day's activities with little choice but to go home, regardless of rain. The losses in ridership, however, were based on very small samples and are not reported here. [They are available (see Bertness, 1979).] It will be necessary to obtain information on travel behavior from questionnaires or interviews and/or obtain hourly ridership figures to properly answer this question.

c. Summary

Rainfall apparently decreases ridership slightly on urban mass transit, although *who* does not ride and *why* they do not ride is still largely unknown. There is some indication that those who ride on a discretionary basis, such as shoppers, are more likely to stay home (or find alternate transportation) on rain days than are people commuting to work. The impact seems to be somewhat higher for bus transportation than for rail transportation.

While the percentage decreases in ridership were small, they did have some economic impact on the transportation companies. A typical rainy weekday, for instance, reduced Chicago Transit Authority bus revenues by $13,193 and rail revenues by $3,619 for a total of $16,812. (These are averages for the three summers and slightly underestimate costs at current fares.) While these values were small compared to daily revenues (representing about a 3% decrease in the day's income), the total reduction in revenues for the summer from the area average of 40 rain days is in excess of $0.6 million. Most of the rain-day reductions cannot really be considered losses, since occasional rainy days can be expected in Chicago and rate structures and yearly budgets have been developed over the years which, at least implicitly, allow for such fluctuations in revenue. The revenue reductions, however, could be important if an urban area experienced unexpectedly large numbers of rain days because of recent or increasing urban weather modification.

4. Boating emergencies

Records of calls for assistance on and near southern Lake Michigan were provided for the summer of 1978 by the Coast Guard Stations at Michigan City, Indiana and Calumet Harbor, Chicago. Calumet Harbor emergencies were divided into those involving recreational vessels and those involving nonrecreational vessels. Differentiation was not possible for the Michigan City statistics, but most emergencies involved recreational vessels. False alarms, hoaxes and drownings unrelated to boating accidents were eliminated from all analyses.

The role of the weather in emergencies handled by the Michigan City station was relatively small. Weather was listed as a contributing cause in only about 16% of 164 emergencies. Rainfall itself was never listed as a factor in an emergency (only one emergency even occurred during rain), although fog and high winds, the most common weather causes of emergencies, may accompany summer rainstorms.

The major reason for the relatively small impact of the weather on boating emergencies was probably that recreational boaters are most apt to be on the water on pleasant, non-stormy days. The U.S. Coast Guard (1978) revealed that most 1977 recreational boating accidents occurred when the sea was calm, the wind was light and/or the visibility was good. This leads to the interesting speculation that the types of weather produced by a city, particularly rainfall, might actually lead to reduced numbers of boating accidents. And, in fact, the Michigan City station assisted in slightly more emergencies on non-rain days than on rain days (days were not matched). This was also true at Calumet Harbor for recreational vessel emergencies.

Despite the slight decrease in the number of emergencies on rain days, it can probably be assumed that the accident rate per boater was higher. The necessary statistics were not available to answer this question, but Calumet Harbor statistics on non-recreation vessel emergencies suggested the potential impact of the weather on vessels whose operations were not restricted to pleasant Sunday afternoons. Of 15 emergencies occurring between 0900 and 2100 CDT during the summer of 1978, 10 occurred during 25 rain days and 5 during the 67 non-rain days (0.40 emergencies/rain day, 0.075 emergencies/non-rain day). The sample is small but clearly implies that weather conditions accompanying rainfall have an

Table 6. Power interruptions in the Chicago area.[a]

Area	Mean yearly number of interruptions due to storms during third quarter	Percent of total interruptions caused by storms (%)	Mean yearly equivalent time of storm interruptions[b] (min)	Mean yearly equivalent time of all interruptions (min)	Percent of total interrupted time due to storms (%)
Chicago North[c]	76.3	33.3	3.12	9.55	32.7
Chicago Central[c]	66.0	38.1	2.71	7.38	36.7
Chicago South[c]	142.7	40.7	12.39	19.99	62.0
Crestwood[d]	201.3	44.4	23.13	28.48	81.2
Harvey[d]	343.7	51.8	20.46	29.22	70.0
Des Plaines Valley[d]	167.0	42.2	13.39	29.95	44.7
North Shore[d]	158.0	36.9	9.10	18.14	50.2
Northwest[d]	173.3	28.7	15.45	40.13	38.5

[a] Figures are calculated from Commonwealth Edison Company records covering the periods of July, August, and September of 1976, 1977 and 1978.

[b] See text for method of computation.

[c] Central densely populated urban areas.

[d] Suburban and partially rural areas.

important impact on the vessels which must be exposed to them.

Another obvious impact of rain days on boating is the reduction of recreational opportunities. There is no doubt that this impact is substantial, but a quantitative description of decreases in boating could not be made since statistics on the daily number of recreational boats in use on southern Lake Michigan were not available.

Summary

The expected effect of urban weather modification would be a small reduction of recreational boating accidents, because the additional precipitation means additional periods unsuited to boating use. However, to the extent that additional rainfall is accompanied by fog or high winds, there would perhaps be increased rates of accidents for those who by choice or necessity were still on the water. Further, recreational opportunities would be decreased.

5. Delays in flight departures at O'Hare Airport

Weather was responsible for 85% of the delayed arrivals and departures at O'Hare Airport during 1975, according to an available summary by the Federal Aviation Administration.[3] The responsible weather conditions included thunderstorms, low ceilings and poor visibility, wind, snow and ice.

Although rain itself was not listed as a cause of delays, its impact on departure delays was analyzed in this study. This was done because 1) records of rainfall were available which were far more accurate than records for other conditions, 2) many of the weather conditions which are responsible for delays occur during rainstorms, and 3) it was the purpose of this investigation to determine human impacts during rainstorms, whether or not there was a causal relationship between the rain itself and the impact.

Days during the summers of 1976, 1977 and 1978 were divided into those which received a trace or less of rain (225 days) between 0800 and 2000 CDT, and those which received at least 0.25 mm of rain during those hours (51 days). Also, 10 of the 51 rain days were identified as having over 12.7 mm of rain. These groups of days were then compared to Great Lakes Region Federal Aviation Administration records of departure delays $\geq$30 min. Less than 10% of the non-rain days had any 30 min delays, while over 50% of the rain days had delays, and 90% of the 10 heavy rain days had delays.

The FAA data also enabled computation of daily percentages of the 700–900 scheduled departures between 0800 and 2000 CDT which were delayed. These daily percentages of delayed flights, ranging from 0 to 44.7%, were then averaged for the days in each rainfall category. On the average, only 0.35% of scheduled departures were delayed on non-rain days. This rose to 6.36% on rain days and to 18.24% on heavy rain days. The percentages are probably somewhat low, since records are kept by air traffic controllers with a number of more vital tasks to perform.

Summary

The chances of having a departure delayed on a rain day are many times greater than chances on a non-rain day, although the actual cause of the delay

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[3] The summary was part of an unpublished report prepared by Jane Miller of the National Airspace System Communications (NASCOM) staff of the Federal Aviation Administration.

might be the associated winds, low visibility, or local or nearby thunderstorms. Increases in rainfall, and especially in heavy rainfall, could be expected to result in increased numbers of delays.

6. Power interruptions

Records of power interruptions from Commonwealth Edison Company were examined to estimate the relative and absolute impacts of thunderstorms in the Chicago area and to determine whether the impacts varied spatially with either land use type or thunderstorm frequency.

Table 6 summarizes third quarter (July–September) power interruptions during 1976, 1977 and 1978 in several of the Chicago urban and suburban power areas. The first and second columns of Table 6 indicate the number and percentage of power interruptions which were caused by storms in each area. (More than 90% of these interruptions were due to lightning.) Numbers of interruptions, however, may be less important to the functioning of a community than are magnitudes and durations of interruptions. If storm-related interruptions are different in magnitude and/or duration than other types of interruptions, column 2 figures would not fairly indicate the relative impact of the weather.

Columns 3–5 provide additional measures of the relative and absolute power disruptions caused by storms. Column 3 indicates the equivalent time a division would have been without power if interruptions had been divided equally among all customers in the division.[4] Column 4 gives the average time a customer was without power for any reason in each of the divisions, and column 5 shows the percentage of total time without power which was due to storms. Comparison of column 5 values with column 2 values shows that in all areas except Chicago North and Chicago Central (densely populated urban areas), power interruptions due to storms were more serious (affected more customers and/or lasted longer) than power interruptions due to other causes. For example, storms accounted for 44.4% of the total number of interruptions in suburban Crestwood, but accounted for 81.2% of the total time customers were without power.

Results in Table 6 also reveal that the impact of thunderstorms on power supply is markedly affected by land use and other characteristics of individual areas. One of these characteristics is the type and/or exposure of power facilities, which varies from urban to suburban and rural areas. For instance, in the Chicago Central area, which includes downtown Chicago, most power equipment is underground and not exposed to the weather. Thus, the amount of time the average customer was without power due to storms was less than in suburban areas. In general, customers within the city of Chicago (Chicago North, Chicago Central and Chicago South districts) experienced less time without power due to storms than did most suburban customers.

The impact of thunderstorm frequency, as it varies over the metropolitan region, is less easily determined. Changnon *et al.* (1977) have shown that urban added thunderstorm occurrences east of St. Louis produced sizeable increases in power outages. Analysis of Indiana power interruption data (from an area of increased thunderstorms downwind from Chicago) revealed that storms were responsible for 86.4% of the time that the average customer was without power during June, July and August of 1978. This was higher than in any of the Illinois divisions and may be partially a function of the urban-produced increases in thunderstorm frequency downwind from Chicago reported by Huff and Changnon (1973). However, the difference may also be partially due to a different method of computation (Bertness, 1979), and the inclusion of June rather than September data in the study period. Further, the Indiana data included only major interruptions (usually at least 600 customers) and more of the Indiana area is rural and therefore more vulnerable to lightning. For these reasons, it is probable that some of the power interruptions in Indiana were due to the increased thunderstorm frequency, but the amount of additional interruption cannot be determined from the data available here.

An examination of variations in power interruptions among the Illinois power divisions in Table 6 was also inconclusive. Thunderstorm data from Midway Airport in the Chicago South area and from O'Hare Airport, where thunderstorm frequencies are probably comparable to those in the adjacent Northwest power area, revealed that more thunderstorms occurred at the urban Midway site than at the more rural O'Hare site (Changnon *et al.*, 1979a). Comparison of these two power divisions (Table 6) shows, however, fewer minutes of storm-produced interruptions in the urban Midway location (in Chicago South) than in the Northwest division. Chicago South probably experienced more power interruptions than it would have if there had been no additional urban-influenced thunderstorms, but the effect was less important than other characteristics of the power division. However, an examination of columns 2 and 5 shows that in terms of the percentage of interruptions

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[4] Calculated: equivalent time = $(MVA_1 \times t)/MVA_2$, where MVA_1 = mega (million) volt amps of transformer capacity interrupted by storms; MVA_2 = total transformer capacity of division in mega volt amps; and t = the weighted average length of interruptions in minutes of the transformer capacity interrupted.

caused by storms and the percentage of total interrupted time due to storms, Chicago South exceeded the Northwest division. This suggests that although the power systems are better protected in the urban area, and probably less vulnerable to local increases in thunderstorm frequency, the storm-induced outages are still very important.

Summary

Weather, particularly when it includes those phenomena associated with thunderstorms, is a major cause of Chicago area power interruptions. It is reasonable to expect that the urban-induced increase in thunderstorms in Chicago results in larger numbers of power interruptions. However, the amount of this increase depends very much on the characteristics of the power facilities being affected, and the building density. Actually, the number of storm-induced interruptions in Chicago is less than in the rural suburbs, but storms cause a greater proportion of the total time of power interruptions in the south part of Chicago than in the northern and western suburbs.

7. Interruptions in telephone service

Information obtained from the Illinois Bell Telephone Company indicates that summer weather is a relatively minor problem in the Chicago area. Only 0.6% of all trouble reported during April–June 1978 and 1.7% of trouble reported during July–September were due to weather factors. The low figures are partly due to the types of systems in the area with most equipment below ground. But very low figures for the state of Illinois as a whole suggest that summer weather seldom leads directly to a failure of telephone equipment. Urban-produced changes in rainfall and thunderstorms probably would have little damaging effect on the telephone system. However, telephone spokesmen reported that during very severe weather conditions, more calls are placed than the system can handle, and there are resulting delays in service. Data were not available to analyze impacts on telephone service in more detail.

8. Summary and implications

In summary, when it rained in Chicago, the following events occurred:

1) Automobile accidents approximately doubled. Accident rates increased most in areas of high traffic volume, such as inside the city of Chicago. Increases in areas of low population density were smaller, but the severity of those accidents increased by 70%.

2) Weekday city bus ridership decreased on three major transit systems by 3–5%. Ridership on Chicago's rapid transit system also decreased on rain days, but by smaller percentages than bus ridership. There is some evidence that decreases in ridership were due more to changes in travel behavior among discretionary riders than among those traveling to work, but results are inconclusive. While decreases were small in percentage terms, CTA revenues decreased by almost $17,000 on an average rainy day.

3) Recreational boating emergencies decreased slightly on rain days in the Chicago area, but there was a pronounced increase in non-recreational boating emergencies. Apparently, weather conditions accompanying rainstorms (especially high winds and fog) increased the likelihood of a boating emergency for those who were still on the water despite unpleasant conditions.

4) Rains resulted in major inconveniences for airline passengers. The chances of having a departing flight from O'Hare Airport delayed by at least 30 min averaged 0.3% on non-rain days; 6.4% on rain days, and 18.2% on days receiving over 12.7 mm of rain.

5) Thunderstorms accounted for anywhere from 33 to over 80% of the total amount of time people in the Chicago area were without electrical power. The percentage varied greatly by power district, with downtown Chicago (most equipment is underground) having the least amount of time without power due to storms.

6) Telephone service was affected very little by rain in Chicago and the nearby suburbs. This was partly because most equipment is underground.

While the study did not determine the direct effects of the modified component of the weather on these activities, it is reasonable to speculate that the increases in total summer rainfall, heavy rainfall and thunderstorms identified at Chicago cause marked changes in certain transportation-related activities and certain utility services where impacts were found in this study. Since the area where maximum weather modification may be expected (east of Chicago) is over Lake Michigan, the impacts on transportation and utilities are obviously less than found in the suburbs and agricultural areas east of St. Louis (Changnon *et al.*, 1977).

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