A Study on Relationships between Environmental Risk and Demographic Characteristics Using GIS

GIS를 이용한 환경 위험과 인구적 특성의 관계에 대한 연구

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요 약 이 연구는 홍수, 허리케인, 위험물질 누출에 대한 과학적으로 측정된 환경위험지수와 가계의 특성간의 상관관계를 조사하였다. 이 연구는 인구적 특성(연령, 가족 수, 결혼 상태, 거주 기간)과 두 가지 자연재해(홍수와 허리케인)의 위험지수 사이에는 통계적으로 유의미한 관계가 없음을 보여주었다. 이 결과는 Drabek의 연구 결과를 지지하는 바, 사람들은 그들의 나이, 성별, 가족수, 결혼 상태, 거주기간과 관련 없이 그들의 주거를 선택하는데 자연재해의 가능성을 과소평가하거나 무시하는 경향이 있음을 보여주고 있다. 대조적으로, 위험물질 누출에 대한 환경위험지수는 위에 열거한 인구적 특성과 통계적으로 유의미한 상관관계를 보여주었다. 이는 가난하고 학력 수준이 낮은 사람들이 인적 재난에 더 노출된 지역사회에 사는 경향이 있음을 보여주고 있다.

키워드 : GIS, 방재, 환경재해, 홍수위험, 도시계획

Abstract This research examined relationships between Scientifically Estimated Environmental Risks (SEERs) of floods, hurricanes and hazardous material releases, and household characteristics. This research showed that there were no statistically significant relationships between most of the demographic characteristics (age, household size, tenure at the present home) and SEERs of the two natural hazards (a flood and a hurricane). These results support Drabek's findings (1986) that people tend to underestimate or ignore natural hazards in selecting their residence regardless of age, household size, and house tenure. Educational attainment and yearly household income were positively correlated with hurricane risk, but not with flood risk. By contrast, SEER of hazardous materials was correlated with all demographic characteristics mentioned above. This result may show that those who are relatively poorer and have lower educational level tend to be limited to living in communities more vulnerable to human-made risk.

Keywords : GIS, Emergency Management, Environmental Hazard, Flood Risk, Urban Planning

1. Introduction

Extreme natural and technological hazards have continually claimed many deaths and caused enormous economic losses. Conard and his colleague[8] estimate average annual federal expenditure for disaster relief and preparedness at $7 billion. In addition to the economic and human losses resulting from environmental hazards, there are significant social costs, like personal stress from evacuations, life in temporary emergency shelters, and disruption of neighborhoods. This increased vulnerability raises questions about people's perceptions of, and response to, these environmental hazards.

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This study considers three main hazards (i.e., floods, hurricanes, and technological hazards related with hazardous materials) to examine relationships between environmental hazards (estimated and perceived) and household characteristics.

First, flooding is a prominent natural hazard that has continually caused many deaths and enormous economic losses. Furthermore, many urban areas of the United States are intensively developing flood prone areas, causing the human and property vulnerability to flood hazards to rise. In fact, floodplains are occupied and utilized due to the economic advantages of level ground for transportation, fertile soils for agriculture, and available water supplies[24].

Second, a hurricane is a cyclone that originates in tropical oceans, accompanied by thunderstorms and circulating winds over tropical waters. Tropical storms occur approximately ten times per year between June 1 and November 30 over the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico, and six of these storms usually become hurricanes that pose serious risk to the Atlantic or Gulf coast.

Lastly, technological hazards can be defined as "the origins of incidents that can arise from human activities such as the manufacture, transportation, storage, and use of hazardous materials"[12], and that can arise from fire, and failure of structures and infrastructure. According to Cutter[10], technological hazards can be referred to as the interaction between technology, society, and the environment. Technological hazards, unlike natural hazards, were once believed to have little or no potential for causing catastrophic levels of death and property damage[22]. However, during recent decades, the growth of chemical and nuclear technologies has been accompanied by the possibility of catastrophic and long term harm or damage to people, and property[23]. During recent decades, high profile hazardous material accidents stimulating environmental concern and research activity have included the 1984 Bhopal, India toxic chemical release; The 1979 Three Mile Island, Pennsylvania nuclear power

plant accident; the 1986 Chernobyl, Soviet Union nuclear power plant accident; and the 1989 Exxon Valdez oil spill, Alaska[6, 19, 21].

Compared to natural hazards, technological hazards have several distinctive attributes. First, technological hazards are different from natural hazards, wars, and terrorism because they result from human error or mismanagement of technology. Technological hazards are products of our society that result from failures in technological systems as well as failures in the political, social, and economic systems that manage the use of those technological systems[10]. Technological hazards are interwoven with the elements of complexity, surprise, and interdependence. Therefore, technological hazards should be understood in terms of political, economic, social, and historical contexts within which they occur[10]. Second, some technological hazards can lead to insidious diseases that may not become evident until many years later[15]. For example, Hoetmer[15] mentions that high toxic radioactive leaks that occurred from 1944 to 1947 at the Hanford Nuclear Reservation, Washington are now being regarded as the cause of high incidences of cancer and heart problems among residents of the area. Third, many technological hazards are highly related to certain geographical areas. Geography helps us identify which areas are subject to the potential impacts of technological hazards, and who bears the risk of technological hazards[10]. Fourth, unlike most natural hazards, technological hazards such as invisible leaks and releases of hazardous materials can be preceded by little or no warning[15]. Finally, technological hazards are induced by industry and the widespread use of science[10]. The occurrence of technological events is increasing, as the creation of hundreds of new substances each year causes more chances for human error[15].

In the present study, environmental risk associated with floods, hurricanes, and technological(or chemical) hazards will be scientifically estimated, based upon location of a house within an area that is expected to be affected by an extreme event with

a specified recurrence interval or intensity. For example, being located within the 100 year flood plain means that the property has a chance of getting flooded once per 100 years. This will be regarded as the highest flood risk area, a 500 year flood as the second highest, and the other areas as essentially flood risk free areas. Similarly, the risk of a hazardous material release is measured by the likelihood of a major release; the nearer to a hazardous material facility, the higher likelihood of an event severe enough to threaten the residents' health and safety. Finally, the risk of a hurricane is measured by being located in an area that is vulnerable to one of the five different categories of hurricane intensity. That is, hurricane risk is defined directly in terms of intensity rather than recurrence interval. To examine the spatial distribution of the three risks, the risk area for each of the hazards will be defined and described in the section of methods and data. The study objective is to test whether scientifically estimated risk of multiple hazards is related to residents' household characteristics.

2. HYPOTHESIS

In deciding on their residences, households emphasize three attributes, given their budget and time constraints. These are space, accessibility, and environmental amenities[13]. Assuming these non-marketed attributes to be normal goods, we can expect that more affluent households will purchase more positive externalities instead of avoiding more negative externalities[18]. This implies that there will be a relationship between the spatial distribution of environmental risk and social/economic/demographic characteristics because there is empirical evidence that the more affluent put a higher value on environmental amenities, whereas the poor choose their homes in the communities more vulnerable to environmental risk[18]. In regard to chemical risk, Hamilton (1995) provides several arguments to explain why the level of exposure to the

chemical risk may vary by ethnicity. Namely, owners of chemical facilities try to locate in communities with disadvantaged ethnic minorities, where compensation due to economic loss is unlikely, and where heterogeneous income and ethnic groups have different propensities for political participation. These arguments are supported by several studies showing that technological hazards such as toxic waste sites and industrial pollution are more likely to be found in areas with high proportions of minority households[6, 4].

Hypothesis : Scientifically estimated environmental risks of floods, hurricanes, and toxic chemical releases are related to household characteristics.

3. METHODS AND DATA

The study consists of: 1) mail survey data on respondents' perceptions of environmental risks, their hazard mitigation measures, and their socio/economic/demographic characteristics; and 2) spatial data on three types of environmental risks (i.e., flood, hurricane, and chemical risk). Correlational analyses were implemented to empirically test relationships of household characteristics with scientifically estimated environmental risk(SEER)

The target population for this research consisted of single family dwelling owners residing within Harris County in 2002. The unit of analysis used to test the hypothesis was the single family housing unit and the household that owned it.

To randomly sample the required number of respondents, a list of countywide single family residential property records (the sample frame of this study) was obtained from the Harris County Appraisal District. Based upon the residential parcel records, stratified random sampling was employed to select 800 households. There were four stratification variables that were defined by the three environmental hazards(floods, hurricanes and chemical releases) and a no risk area. Two hundred households were selected that were vulnerable

to each hazard. In the cases selected for flood risk, the FEMA's flood insurance map for Harris County was used to randomly select 100 households in the 100 year flood plain and 100 households in the 500 year flood plain. In the cases selected for hurricane risk, 40 cases were selected from households located in each of the five hurricane risk areas. In the cases selected for chemical risk, 40 cases were randomly selected at increments of 0.5 mile from zero to 2.5 miles from the nearest hazardous material facility. The remaining 200 households were randomly selected from an area comparatively free from these three types of hazards. Statistical power analysis showed that a sample size of 800 would have a 95% confidence interval with 0.035 sampling error. A total of 321 out of the sampled 800 single homeowners returned questionnaires for a gross response rate of 40.1%. However, one household was no longer at its original address, and two households turned out to live outside the study area. Because these three households were not replaced, this yielded an adjusted response rate of 40.4%. The household characteristics (namely, social, economic, and demographic characteristics) of the respondents (single family residential owners) are shown in Table 1. By age, respondents were broken into five groups. Because the number of 20 and 29 year old respondents was small, they were combined with the group of 30 and 39 year olds to produce a group of 20s and 30s. Ages 40 49 accounted for 28.7% of the respondents, followed by 50 and 59 year olds (25.5%).

The majority of the respondents were over 40 years old (about 80%; arithmetic mean, M=51.6 years). Educational attainment consisted of five groups. The group with less than high school diplomas had the smallest number (3.7%), whereas 13.4% had high school diplomas and 28.0% had some college. The group with college degrees had the highest number, accounting for 29.3% of the sample, whereas the group with graduate school degrees accounted for 24.3%. About 60% of the respondents were male, while about 36 % were fe-

Table 1. Descriptive characteristics of SEERs

Variable	Group	Freque-ncy	%
Age	20s to 30s	52	16.2
	40s	92	28.7
	50s	82	25.5
	60s	79	24.6
	Missing	16	5.0
Education	Less than high school	10	3.1
	High school/ GED	43	13.4
	Some college	90	28.0
	College graduate	94	29.3
	Graduate degree	78	24.3
	Missing	6	1.9
Gender	Male	193	60.1
	Female	114	35.5
	Missing	14	4.4
Household size	1	49	15.3
	2	116	36.1
	3	66	20.6
	4	49	15.3
	Over 5	41	12.7
Income	Less than $14,000	6	1.9
	$14,000-$23,999	19	5.9
	$24,000-$34,999	28	8.7
	$35,000-$49,999	24	7.5
	$50,000-$70,000	57	17.8
	$70,000-$100,000	73	22.7
	Over $100,000	72	22.4
	Missing		42
Marital status	Married	235	73.2
	Single	21	6.5
	Divorced	43	13.4
	Widowed	18	5.6
	Missing	4	1.2
Ethnic identity	Black	28	8.7
	White	212	66.0
	Hispanic	34	10.6
	Asian	16	5.0
	Others	13	4.1
	Missing	18	5.6
Tenure	1-4 yrs	103	32.1
	5-9 yrs	64	19.9
	10-14yrs	42	13.1
	15-19 yrs	31	9.7
	Over 20 yrs	77	24.0
	Missing	4	1.2

male, and 4% of the respondents did not indicate their gender. A plurality (36.1%) of the respondents was in households composed of two persons, and 20.6% were in households composed of three persons. The most frequent category of marital status was 'Married' (73.2%) whereas the least frequent was 'Widowed' (5.6%). For yearly household income, the respondents were divided into seven groups. 62.9% had an income of more than $50,000 whereas 7.8% of the participants had income of less than $23,999. The distribution of ethnicity was White (66.6%), Hispanic (10.6%), Black (8.7%), Asian (5.0%), and Others (4.1%). Others included American Indians and persons who declined to report their ethnicity. About 47% lived at the current residence for more than ten years.

3.1 Variables and Measurement

GIS techniques were used to delineate the spatial distribution of risk from flood, hurricane, and hazardous material facilities, and then to overlay each of the risk maps onto the parcel map that contained the locations of sampled housing units. Flood risk was assessed using the Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Map (FIRM) for year 1996 in Harris County. This map identified areas most susceptible to flooding, which correspond to the 100 and 500 year flood plains. The 100 year flood plain (YFP) is the area that has an expected recurrence interval of 100 years, whereas the 500 YFP has an expected recurrence interval of 500 years. Flood risk areas were overlapped with the parcel map of the survey respondents' housing units to determine the level of flood risk at the housing unit level (see Figures 1). The 100 YFP areas were given an indexk of "5" since they were the most susceptible to flooding, while the 500 YFP areas were indexed as "1" since they are less susceptible to flood damage. The areas outside the 500 YFP were indexed "0".

To identify the hurricane risk areas, the hurricane risk area boundary map was used that was developed at the Hazard Reduction & Recovery Center at
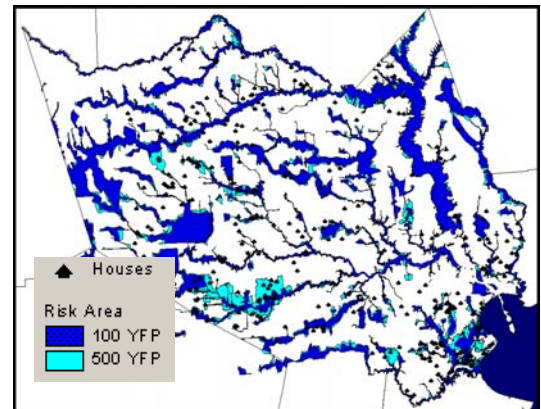

Figure 1. Map of Flood Risk

Texas A&M University for the Texas Division of Emergency Management. Using the Saffir/Simpson scale, this map divides hurricane risk areas into five categories that correspond to a hurricane's intensity. Specifically, hurricane risk areas were estimated using a computer program, called SLOSH (Sea, Lake, and Overland Surges from Hurricanes) to define risk areas from storm surge and the Inland Wind Decay Model to define risk areas from hurricane driven wind. The most susceptible areas are those that lie along the shoreline, at low elevations, or close to the waterfront. Thus, populations living in hurricane Risk Area 1 would be most vulnerable to surge and wind damage in the event of all category hurricanes. As one moves farther inland, populations become less vulnerable to wind and surge action from a hurricane. With the exception of areas free from hurricane hazard, the area identified as Risk Area 5 is least subject to a hurricane and would only be affected by flooding and wind damage in the event of a Category 5 hurricane. The hurricane risk area map was superimposed upon the parcel map to decide each housing unit's hurricane risk level (see Figures 2). Hurricane Risk Area 1 was given a index of "5" since the area was the most susceptible to all categories of hurricanes, while hurricane Risk Area 5 was rated as "1" since the area was susceptible only to a Category 5 hurricane. Areas outside these hurricane categories were indexed as "0".
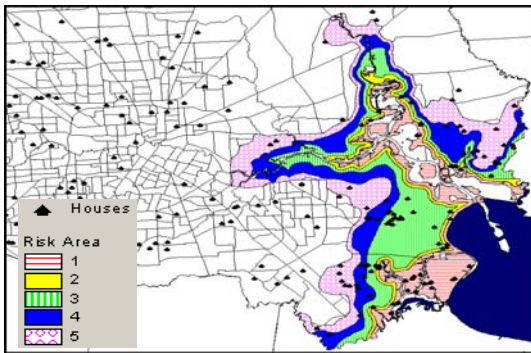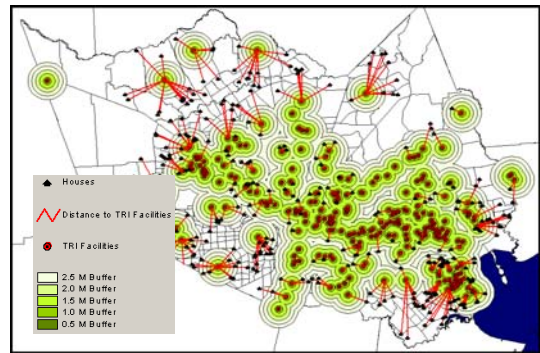
Figure 2. Map of hurricane risk

Figure 3. Map of Chemical Risk

The measure of chemical risk was based upon Toxic Release Inventory (TRI) facility data for 2000. This data base was developed and published on the Internet by the U.S. Environmental Protection Agency. As of 2000, there were 2206 TRI sites in Harris County. The data base has information on the locations, types and quantities of nearly 650 chemicals being stored on site, the types and amounts of toxic chemical annually being released into the environment, and other waste management activities from various industries that use, store, and produce hazardous chemicals or materials.

GIS made it possible to geocode the TRI sites by means of their latitudes and longitudes. The TRI location map was overlapped with the parcel map to measure the distance from each respondent housing unit to its nearest TRI site (see Figures 3). Multiple TRI sites except for only a TRI site had to be disregarded even if a housing unit was located in an area where there were more than a TRI site. One of the reasons is that it is very difficult to identify the number of the hazardous materials, its amount and its quantity, and to investigate the extent and intensity of their danger in this research.

4. RESULTS

4.1 Scientifically Estimated Environmental Risks

As noted in the previous chapter, three types of environmental risks – floods, hurricanes, and hazardous materials – were scientifically measured by using GIS techniques. Meanwhile, respondents were asked to report their social, economic, and household characteristics in a survey questionnaire. Table 2 shows descriptive characteristics including the means, standard deviations, and minimum and maximum values of SEERs. Table 3 indicates the number and frequency for each level of SEERs. For SEER of floods, respondents' homes were categorized into three groups: 100 year flood plain (YFP), 500 YFP and the no risk areas. Among single family residents who returned their questionnaires, there were 227 houses (70.9 %) outside the two flood plain areas, 50 houses (15.6%) in 500 YFP areas, and 44 houses (13.8%) in 100 YFP areas. Overall, 29.4% were located in an area with an identifiable level of flood risk. The mean for flood risk was 0.84.

For SEER of hurricanes, the respondents' homes were divided into six groups, with the first group residing outside hurricane risk areas, and the remaining five groups residing in areas with an identifiable level of hurricane risk. There were 231 houses (72.2%) with no hurricane risk, and the remaining 90 houses (27.8%) were almost equally

Table 2. Descriptive characteristics of SEERs

Variable	M	SD	N	Min.	Max.
Flood risk	.84	1.698	321	0	5
Hurricane risk	.83	1.535	321	0	5
Chemical risk	2.26	1.41	321	0.18	7.73

Table 3. Number and frequency for each level of SEERs

	Flood Risk		Hurricane Risk		Chemical Risk		
	n	%		n	%	Level	n	%
No risk	227	70.9	No risk	231	72.2	Over 2.5 mi.	122	38.1
500YFPa	50	15.6	5b	18	5.6	2 to 2.49 mi.	32	10.0
100YFP	44	13.8	4	18	5.6	1.5 to 1.99 mi.	49	15.3
			3	21	6.6	1 to 1.49 mi.	64	20.0
			2	14	4.4	0.5 to 0.99 mi.	33	10.3
			1	19	5.9	0 to 0.49 mi.	21	6.6
Total	321	100		321	100		321	100

[a] YFP is Year Flood Plain.
[b] Hurricane Risk Area 5 corresponds to the least vulnerable area except "No Risk" area, whereas Hurricane Risk Area 1 corresponds to the most vulnerable area.
[c] Miles.

spread over different hurricane risk areas. The mean for hurricane risk was 0.83.

For SEER of hazardous materials, 122 houses (38.1%) were found to be comparatively safe, because they were located over 2.5 miles away from any TRI facilities. The mean for chemical risk was 2.26 (miles). The minimum and maximum distances from TRI facilities were 0.18 and 7.73, respectively.

Table 4 shows the correlations among social, economic, and demographic variables, and the three types of SEERs. Not surprisingly, AGE was negatively correlated with INCOME ($r = 0.28$), whereas EDU was positively correlated with yearly household income ($r = 0.42$). Additionally, AGE was positively correlated with TENURE ($r = 0.62$), while HSIZE (household size) was negatively correlated with TENURE ($r = 0.23$).

Contrary to the hypothesis, there were no statistically significant relationships between most of the household characteristics (AGE, HSIZE, and TENURE) and scientifically estimated environmental risks of the two natural hazards (flood risk – FR and hurricane risk – HR). Only two household characteristics (EDU and INCOME) were positively correlated with HR ($r = 0.13$ and $r = 0.14$ each), but none were correlated with FR. These results indicate that the greater the yearly household income and educational attainment, the greater the hurricane risk. These unanticipated results suggest that households with higher education level and higher income are likely to choose to locate their property at the hurricane risk areas, which usually command beautiful scenery and spectacular views.

Consistent with the hypothesis, scientifically estimated chemical risk (CR) was correlated with all of the household characteristics. It should be noted that a negative relationship between any household

Table 4. Correlation coefficients of household characteristics with SEERs

	M	SD	1	2	3	4	5	6	7	8
1. AGE	51.57	12.88	1.00							
2. EDU	3.59	1.10	0.03	1.00						
3. HSIZE	1.79	1.38	0.30**	0.06	1.00					
4. INCOME	5.20	1.65	0.27**	0.42**	0.12	1.00				
5. TENURE	153.5	139.1	0.62**	0.13*	0.23**	0.31**	1.00			
6. FR	0.84	1.70	0.07	0.01	0.03	0.03	0.10	1.00		
7. HR	0.83	1.54	0.00	0.13*	0.09	0.14*	0.02	0.02	1.00	
8. CR	2.26	1.41	0.11*	0.15**	0.12*	0.24**	0.23**	0.14*	0.18**	1.00

1. age on last birthday; 2: educational attainment; 3: household size; 4: yearly household income; 5: tenure; 6: flood risk; 7: hurricane risk; 8: chemical risk
*. $p < 0.05$. **. $p < 0.01$. N = 279 to 321

characteristic (e.g., AGE) and CR means that the older they are, the greater the chemical risk, because chemical risk, (which was measured by distance), decreases with increments of distance. Specifically, AGE and TENURE were negatively correlated with chemical risk (r = 0.11, and r = 0.23, respectively), whereas EDU, HSIZE, and INCOME were positively correlated with CR (r = 0.15, r = 0.12, r = 0.24, and r = 0.15, respectively). In sum, the study hypothesis was partially supported regarding the relationship between the risk of natural hazards and household characteristics, but was fully supported regarding the relationship between chemical risk and household characteristics.

5. Conclusion

Previous research has found that people, regardless of their' race, and age tend to ignore their vulnerability to natural hazards (Drabek, 1986), and to choose their residence with little or no consideration of the presence of natural hazards. One fundamental reason for neglecting the risk from natural hazards is that people do not have enough knowledge on how hazardous their natural environment is[9]. Meanwhile, other research has consistently documented significant relationships between household characteristics and environmental risk from technological hazards. For instance, empirical findings indicate that Afro Americans, other minority groups, and low income households are more likely to live in health threatening environmental conditions[7, 20]. Adeola[1, 2] also indicated that ethnicity (i.e., Blacks) was significantly related to households' proximity to hazardous waste dumpsites or petrochemical facilities in the Baton Rouge Standard Metropolitan Statistical Area, Louisiana. Another study found that about 60% of Blacks and over 53% of Hispanics lived and worked in neighborhoods with one or more hazardous waste sites[17].

The hypothesis of the present research is that scientifically estimated environmental risks (SEERs) of natural and technological hazards are related to household characteristics. This hypothesis is based upon findings from past research that the affluent tend to choose their home in communities with environmental amenities, whereas the poor tend to be limited to living in communities more vulnerable to environmental risk[18, 14].

The results of this research showed that there were no statistically significant relationships between most of the household characteristics (age, ethnicity, household size, tenure at the present home) and the SEERs of the two natural hazards (a flood and a hurricane). These results support Drabek's findings[11] that people tend to underestimate or ignore natural hazards in selecting their residence regardless of age, household size, and house tenure. Educational attainment and yearly household income were positively correlated with hurricane risk, but not with flood risk.

Consistent with the hypothesis, SEER of hazardous materials was correlated with all household characteristics such as age, educational attainment, household size, yearly household income, and tenure at present home. Specifically, those at greatest risk from chemical hazards are older, have lived longer in their communities, all less educated, have smaller households and lower incomes, and are unmarried. One of the main reasons the elderly have become long-term risk-area residents, it seems, is that they can't afford to move out though their property is vulnerable to risk of flooding, hurricane and chemical hazards.

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