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An analysis of air mass effects on rail ridership in three US cities

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ABSTRACT

This paper examines whether daily weather affects ridership in urban transportation systems. When examining human–weather relationships, it is often advantageous to examine air masses, which take into account the entire parcel of air over a region. Spatial synoptic classification characterizes air masses based upon numerous meteorological variables at a given location. Thus, rather than examining temperature or precipitation individually, here we compare daily ridership to synoptic air mass classifications for three urban rail systems: Chicago Transit Authority (CTA), Bay Area Rapid Transit (BART), and the Hudson–Bergen light-rail line in northern New Jersey. Air masses are found to have a significant impact on daily rail ridership, with usage typically increasing on dry, comfortable days and decreasing on moist, cool ones, particularly on weekends. Although the comfort of a particular air mass changes throughout the year, seasonality is not a significant factor with respect to the air mass–ridership relationship. The results of this study can benefit rail system managers who must predict daily ridership or in the development of cost-benefit analyses for station improvements.

1. Introduction

Cities in the United States are increasingly turning to rail transit, particularly light rail, to provide an attractive alternative to driving and revitalize urban areas. Since 1980, two cities have built heavy-rail systems, and 17 have built light-rail systems, while one heavy-rail and 40 light-rail systems are currently proposed (American Public Transit Association, 2007). Controversy swirls around many projects, with some claiming that ridership forecasts are systematically inflated (Pickrell, 1992; Flyvbjerg et al., 2005) while others question these assertions (Demery, 2002). A host of factors are believed to affect ridership, including accessibility, congestion, density, size of central business district, car ownership, mixed-use transit-oriented development, parking costs, fares, gas prices, employment levels, travel times, park-and-ride spaces, intermodal connections, sporting and special events, and shopping opportunities (Pushkarev and Zupan, 1982; Cervero, 1993; Parsons Brinckerhoff Quade Douglas and Inc, 1996; Filion, 2001; Kuby et al., 2004; Pucher, 2004). Some of these factors affect spatial variations in ridership at the neighborhood or metropolitan scale, while others affect temporal variations on a daily, weekly, annual, or long-term scale. It is imperative to understand all the factors that influence system ridership, but one factor in particular requiring increased attention and research is weather.

Transit agencies have long recognized that weather conditions affect human comfort, which in turn affects transit ridership. Investments in bus shelters, sheltered pedestrian walkways in Minneapolis (Fielding, 1995), cooling towers and shade structures in Phoenix (Levine, 1990), and other investments in weather protection provide evidence of planners' concerns about the effect of weather on ridership. Guo et al. (2007) described a scenario in which a greater understanding of weather's impact on transit ridership could assist in developing a cost-benefit analysis for transit station investments. Despite the generally accepted relationship between weather and ridership, studies attempting to qualify or quantify this relationship are limited and somewhat contradictory, as described below.

Traditionally, research relating weather and climate to urban transportation has focused on safety and accidents (Changnon, 1996; Andrey et al., 2003) or on maintenance issues (Arlinghaus and Nystuen, 1985). Concerns about weather's effect on safety have led some researchers to investigate weather's effects on traffic volumes. Keay and Simmonds (2005) found a roughly 1–3% reduction in road traffic volume in Australia, depending on the amount of rainfall and the season. Knapp and Smithson (2000) found that wet or snowy weather in Iowa discourages driving, with winter storms reducing traffic by 16–47%. Maze et al. (2006) estimated the effect of rain, snow, fog, cold, and wind on traffic volumes, safety, and speed-flow relationships and noted that inclement weather greatly increases the chances of accidents.

If weather causes a reduction in traffic volumes during adverse weather conditions, as indicated in the aforementioned studies, it

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is possible that people turn to alternative forms of transportation during these times. A survey-based study in Geneva found that over 50% of respondents indicated that weather was an important factor in determining what mode of transportation to use, while 73% said it affects their departure time (de Palma and Rochat, 1999). Khattak (1991) and Khattak et al. (1995) found that mode switching – from automobile to public transit – occurred in Chicago and the Bay Area during adverse weather conditions. Aaheim and Hauge (2005) found small positive correlations between public transportation and precipitation in Bergen, Norway, but only for certain groups of people and areas of the city. High winds and high temperatures also made people slightly more likely to prefer public transportation over driving, biking, or walking, although the correlations for wind and temperature were even weaker and more inconsistent than for precipitation. Finally, Khattak and de Palma (1997) found that transit ridership increases during periods of bad weather in Brussels, Belgium.

Adverse weather conditions, however, do not always lead to increased use of public transit. In contrast to the preceding studies, Changnon (1996) found reduced ridership of public-transportation systems on rainy days, especially during mid-day periods. Consistent with Changnon's (1996) results, de Palma and Rochat (1999) found that adverse weather prompts some commuters who usually take transit to drive their cars instead. Guo et al. (2007) also found that bad weather, including decreased temperature, increased precipitation, and windy conditions, caused significant decreases in transit ridership in Chicago. The degree of change was stronger for bus than for rail, and on weekends than weekdays.

Researchers are also beginning to look at long-term climate effects rather than short-term weather effects. For example, Ruth and Kirshen (2001) addressed the effects of climate change on urban transportation. Kuby et al. (2004) found a strong relationship between temperature extremes and light-rail ridership. They developed a multiple regression model to explain average weekday ridership at 268 stations in nine cities across the United States and found average monthly heating-plus-cooling degree-days to be highly significant, accounting for differences of plus-or-minus several hundred riders per station per day. The implication is that cities with extreme hot or cold climates experience lower ridership than peer cities with more moderate climatic conditions.

As the prior research shows, the relationship between transportation and weather appears to be complex. Several studies cite decreases in traffic volumes during bad weather, but there are also several studies citing increased traffic volumes during similar weather conditions. Similarly, some studies report increases in public transit ridership during adverse weather conditions, whereas others claim bad weather leads to decreased ridership. These inconsistencies may be related to the general focus on single-variable weather conditions, such as precipitation, temperature, wind speed, etc. It is possible that a more encompassing weather variable may provide a better explanation for the weather–transportation relationship.

In light of the mixed prior results, this paper attempts to answer the question: is there a relationship between weather, as represented by air mass type, and rail-transit ridership? When examining human–weather relationships, it is often advantageous to use an air mass approach. Air masses are large, relatively homogeneous parcels of air that are classified based upon numerous meteorological variables such as temperature, humidity, cloud cover, and wind speed. Air masses account for many meteorological variables simultaneously and present a more accurate picture of the actual weather conditions that were present. Also, by examining air masses, researchers can focus on a single category that takes into account many weather variables (Kalkstein, 1991; Sheridan, 2002). Guo et al. (2007) thought it was important to analyze the effect of weather that was substantially cooler or warmer than the historical average (by >12 °F). When their cool and warm dummy variables turned out to be generally insignificant or inconsistent, they stated that a "better definition which combines both temperature changes and human perceptions is necessary to explore the possible effects of extreme temperature on transit ridership" (p. 17). Air masses may satisfy this need because they simultaneously encompass many variables that affect public perception of weather conditions.

Air masses have been shown to have a large influence on human health, and certain air masses have been correlated with sharp

Table 1
Information on rail systems across the United States

Rail system	Rail type	Annual ridership 2004 (million unlinked trips)[a]	Directional track miles[a]	Stations[a]	Households with no vehicles, 2005 (%)[b]	Metropolitan transit commuting share, 2005 (%)[b]	Annual delay per traveler, 2003 (h)[c]
Chicago (CTA)	Heavy	64,328	206.3	144	10.6	10.8	58
SF-Oakland (BART)	Heavy	62,373	209.0	43	11.3	13.7	72
New Jersey Transit (NJT)[d]	Light	7801	27.2	23	29.9	37.7	49
Other Systems							
Atlanta (MARTA)	Heavy	69,089	96.1	38	5.3	3.3	67
New York City (MTA)	Heavy	339,819	493.8	468	28.4	29.8	49
Washington DC (Metro)	Heavy	58,205	206.6	83	9.5	13.2	69
Dallas (DART)	Light	5153	87.7	34	4.6	1.5	60
Salt Lake City (UTA)	Light	2969	37.3	23	4.9	3.6	31
Cleveland (GCRTA)	Light	1012	30.4	34	9.4	4.1	10
San Diego Trolley	Light	6983	96.6	49	5.5	2.9	52

[a] *Source*: American Public Transportation Association: http://www.apta.com/research/stats/rail/index.cfm (last accessed 11 June 2007). Directional miles counts double-tracked lines twice.
[b] *Source*: US Census Bureau: factfinder.census.gov (last accessed 11 June 2007).
[c] *Source*: Texas Transportation Institute: mobility.tamu.edu/ums/congestion_data/tables/national/table_1.pdf (last accessed 11 June 2007).
[d] Ridership data for the NJT Hudson–Bergen line are from the NJT website for 2005. Census data are for Hudson County, NJ. Delay data are for New York metro area.