The Impact of Weather Phenomena on Passenger Volumes for Commuter Trains

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SHORT SUMMARY

Weather impacts several aspects of our daily life, of which the way we travel is one. The relationship between weather phenomena and ridership of trains has not received much attention previously. The study we present here aims to understand the impact of temperature, wind, and precipitation on passenger volumes for commuter trains. To do so we make use of automatic passenger count and weather data from over a million unique station stops, spanning two years, in the Southern region of Scania in Sweden. Our findings show that changes in the level of precipitation do not affect the volume of boarding passengers. Statistically significant effects are found for changes in temperature and wind speeds. These effects are most prominent for departures outside of peak hours. The results are useful for planning more accurate dwell times and rolling stock circulations and can serve as inputs during real-time rescheduling problems and demand modelling.

Keywords: Trains, weather, planning, passengers, railway

1. INTRODUCTION

The weather has an impact on many aspects of our daily life and the activities we conduct. One of these activities is how we travel. Spinney and Millward (2011), for example, found that cold weather and precipitation lead to more home-based activities. There is a large body of literature focusing on travel behaviour and mode choices in relation to weather conditions. For an extensive review, we refer to Böcker et al. (2013). However, studies focusing on the effects of weather on rail transport are scarce (Koetse & Rietveld, 2009). The study we present here focuses on changes in passenger volumes for commuter trains in relation to weather conditions to help fill this knowledge gap. Although not explicitly focusing on travel by railway, some indications of changes in passenger demand and weather for public transport can be identified in the literature. Strong winds and warmer weather conditions have been found to reduce the use of public transport for example. On the other hand, it was found that public transport usage increases under cold weather conditions and when precipitation increases (Sabir, 2011). In contrast to this, Cools et al. (2010) found that temperature has a lesser effect on travel behaviour than other weather conditions such as fog and wind. These studies thus indicate a potential relationship between the ridership of commuter trains and weather conditions.

It is relevant to study how different weather phenomena influence the number of people who travel by train since passenger demand has several important implications for railway operations and scheduling, as well as passenger demand modelling. The expected passenger demand affects the necessary rolling stock to be in use, for example. Having insufficient rolling stock in use can lead to high levels of onboard crowding, which is negative in terms of passenger comfort and experiences (Cox et al., 2006). Whereas having too much rolling stock in use results in increased operational costs. The volume of boarding passengers has also been found to influence dwell time punctuality (Kuipers & Palmqvist, 2022; Li et al., 2016). Dwell time, in the case of passenger trains, refers to the time a train is stationary at a station to allow for the exchange of passengers. Dwell time delays reduce the overall punctuality and reliability of railways, and with this the attractiveness of railways as a mode of transport (Brons & Rietveld, 2008; van Loon et al., 2011).

Although it has been shown that weather influences how we travel, and that passenger load factors influence the operation of railways, the possible effect of weather on passenger demand for commuter trains has not received as much attention. The study we present here, therefore, focuses on how the volume of boarding passengers changes under different weather phenomena: wind speed, temperature, and precipitation. This knowledge can help planners to schedule more accurate rolling stock circulations and dwell times. Furthermore, it can serve as important input during real-time rescheduling problems and demand modelling. The latter is relevant since demand modelling is commonly based on data from travel surveys, aggregated over multiple days, which excludes nuances such as changes in weather conditions (Lepage & Morency, 2021).

2. METHOD

To study we present here makes use of automatic passenger count data collected on board commuter trains in the Southern region of Scania in Sweden during 2018 and 2019. A simplified line map of the region is shown in Figure 1. The commuter train sets consist of four carriages, with a total of 240 seats available and five doors on either side of the train. Individual trainsets can be combined to increase capacity, increasing the available seats and doors. The automatic passenger counters make use of infrared beams to count both the number of boarding and alighting passengers on a door-by-door level, with a minimum detection height of one meter. For the purpose of this study, we only make use of the volume of boarding passengers. The number of boarding passengers is a good reflection of the number of people who choose to use the train as a mode of transport. The weather data used in this study is collected by the Swedish Meteorological and Hydrological Institute on an hourly basis. The weather data has observations for the same period as the automatic passenger count data, from several different weather stations. The number of weather stations per weather variable is shown in Table 1, along with the aggregation steps for the weather data.

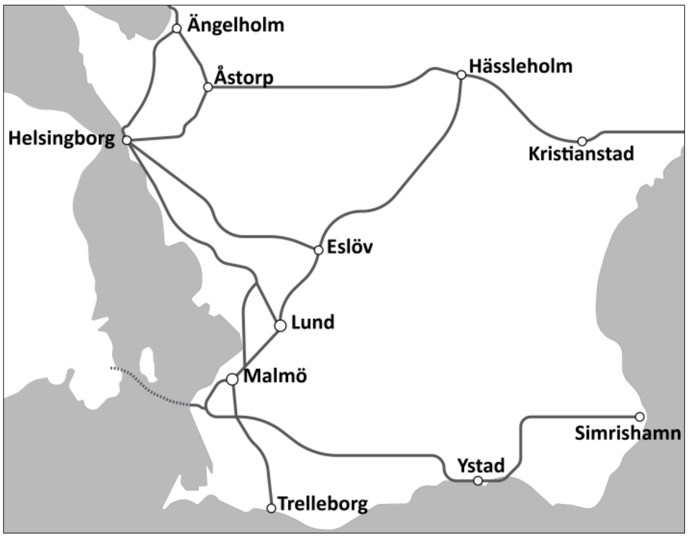

Figure 1: Simplified line map showing the railway network and some stations in Scania, Sweden.

Table 1: Overview of weather data.

Weather type	**Number of weather stations**	**Scale**	**Aggregation**
Temperature	12	Celsius	Bins of five degrees Celsius
Wind	14	Meters per second	Beaufort scale
Precipitation	15	Millimetre per hour	Dry (*0 mm/h*) Slight Precipitation (*0 to 0.4 mm/h*) Moderate Precipitation (*0.5 to 3.9 mm/h*) Heavy Precipitation (>= *4 mm/h*)

To combine the automatic passenger count data and weather data, we matched the data from the weather stations to a train stop in space and time. The first step involved matching the railway stations to the nearest weather station based on their respective coordinates. The upper limit for the distance between a weather station and a railway station was set at 25 kilometres. Matches where this threshold was exceeded were excluded from the analysis. The second step consisted of matching the observations from the automatic passenger count system at each station with the hourly observations from the previously matched weather station. The process of matching the automatic passenger count data and weather data resulted in 1,296,576 data points having information on the volume of boarding passengers for unique station stops.

For this study, we are interested in changes in the frequency of passenger volumes rather than the exact volume. Knowing how often a certain number of people will board a train given a specific situation is more relevant for planning purposes compared to knowing the exact volume. Prior to the analyses, we split the data into peak hour and off-peak hour departures. Studies on trip and mode choices in relation to weather conditions show that it is important to account for the trip purpose, where less flexibility is found for trips made by commuters (Cools et al., 2010; Liu et al., 2014). A trip is considered to be made during peak hours when it departed on a weekday between 06:00 and 08:00 or between 15:30 and 17:30. These times are based on observed passenger volumes.

We make use of a series of pairwise Chi-square goodness of fit tests to determine whether changes in the frequency in the volume of boarding passengers under different weather conditions are statistically significant. To control for a potential familywise error rate for multiple comparisons we corrected the significance levels using the Bonferroni correction, as suggested by (McDonald, 2014). To perform the Chi-square goodness of fit tests we compared the difference between the frequency distribution under different weather conditions and the unconditional frequency distribution of boarding passenger volumes. When weather phenomena do not have an impact we expect the frequency distribution to be the same as the unconditional frequency distribution. When performing a Chi-square goodness of fit, the expected frequencies should at least be five. In order to ensure we fulfil this criterion we aggregated the passenger count data in steps of five passengers. The analyses are limited to a volume of 40 boarding passengers due to a lack of sufficient data points for larger volumes of passengers. This limitation left us with 1,155,266 data points on unique station stops to use for the analyses in this study.

3. RESULTS AND DISCUSSION

The frequency of passenger volumes for different precipitation levels is shown in Figure 2. Visual analysis indicates that the level of precipitation does not influence the number of people boarding a train, except for conditions with heavy rain during peak hours. The results from the Chi-square goodness of fit tests, Table 2, show that there is no statistically significant effect of precipitation on the frequency of passenger off-peak hours. We do find a statistically significant effect of conditions with moderate precipitation on the frequency of passenger volumes during peak hours. Although the visual analysis indicates a difference, this is thus not found to be statistically significant.

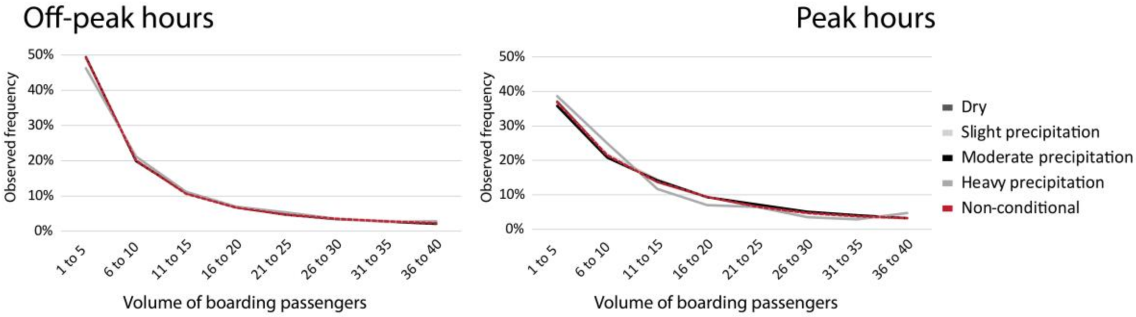

Figure 2: Frequency of passenger volumes under different precipitation levels.

Table 2: Chi-square goodness of fit test results for the difference in frequency of passenger volumes under different precipitation levels. Significant results indicated with an *, significance level with Bonferroni correction p < 0.013 (0.05/4 = 0.013).

Precipitation level	**Off-peak hours**		**Peak hours**	
	Chi-square	*P-value*	*Chi-square*	*P-value*
Dry	1	0.999	2	0.931
Slight precipitation	5	0.693	14	0.048
Moderate precipitation	8	0.321	18	0.012*
Heavy precipitation	5	0.637	9	0.224

Figure 3 shows the frequency of passenger volumes given different temperatures. The visual analysis shows relatively larger differences in the frequency of passengers during off-peak hours, where the frequency of larger passenger volumes increases as the temperature increases. The frequency of passengers during peak hours is found to be less affected by changes in temperature. The results of the Chi-square goodness of fit tests, Table 3, show that statistically significant effects of the temperature occur during peak hours, but not for all brackets under consideration. In contrast to this, we find that changes in the temperature have a statistically significant effect on the frequency of passenger volumes for all brackets under consideration during off-peak hours. The higher Chi-square values suggest that the effect is strongest when temperatures exceed 20 degrees Celsius.

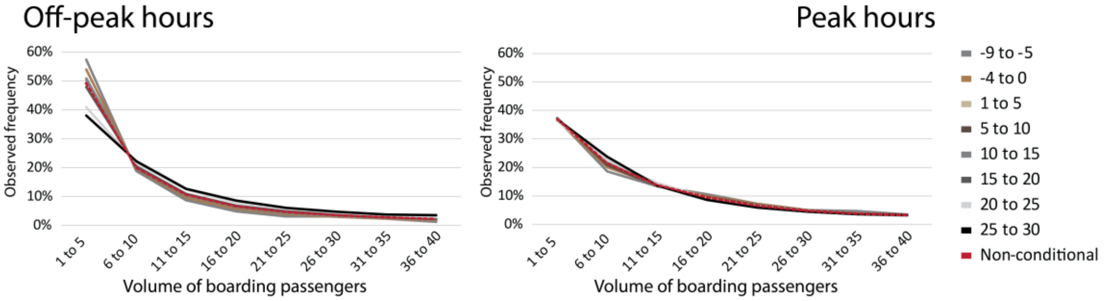

Figure 3: Frequency of passenger volumes under different temperature levels.

Table 3: Chi-square goodness of fit test results for the difference in frequency of passenger volumes under different temperature levels. Significant results indicated with an *, significance level with Bonferroni correction p < 0.006 (0.05/9 = 0.006).

Temperature	**Off-peak hours**		**Peak hours**	
(Celsius)	*Chi-square*	*P-value*	*Chi-square*	*P-value*
-9 to -5	221	0.000*	22	0.002*
-4 to 0	586	0.000*	34	0.000*
1-5	264	0.000*	16	0.028
5-10	178	0.000*	27	0.000*
10-15	224	0.000*	11	0.132
15-20	112	0.000*	23	0.002*
20-25	2653	0.000*	46	0.000*
25-30	1505	0.000*	31	0.000*

The frequency of passenger volumes in relation to the wind speed is shown in Figure 4. As with the changes in temperature, we find the largest effect of wind speed on the frequency of passengers to occur during off-peak hours. Larger passenger volumes are found to be somewhat more common as the wind speed increases, both during peak and off-peak hours. The results from the Chi-square goodness of fit test, Table 4, reveal that there are statistically significant effects of the wind speed on the frequency of passengers with the effect being stronger during off-peak hours.

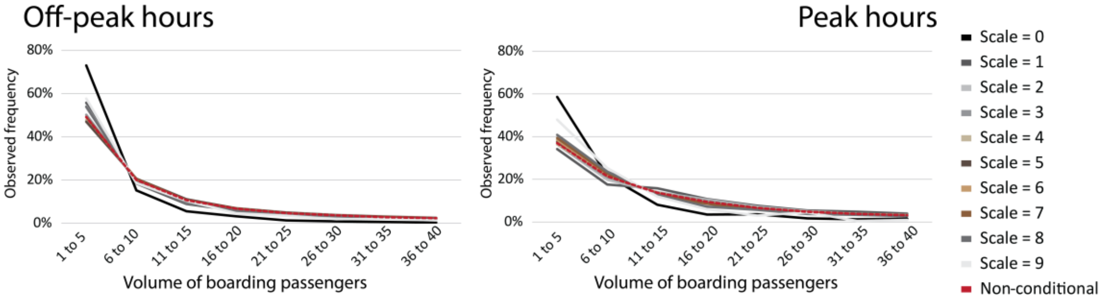

Figure 4: Frequency of passenger volumes under different wind speeds.

Table 4: Chi-square goodness of fit test results for the difference in frequency of passenger volumes under different wind speeds. Significant results indicated with an *, significance level with Bonferroni correction p < 0.005 (0.05/10 = 0.005).

Beaufort scale	**Off-peak hours**		**Peak hours**	
	Chi-square	*P-value*	*Chi-square*	*P-value*
Calm (0)	699	0.000*	117	0.000*
Light air (1)	391	0.000*	92	0.000*
Light breeze (2)	920	0.000*	77	0.000*
Gentle breeze (3)	76	0.000*	30	0.000*
Moderate breeze (4)	269	0.000*	19	0.009
Fresh breeze (5)	417	0.000*	33	0.000*
Strong breeze (6)	5	0.670	41	0.000*
High wind (7)	6	0.490	42	0.000*
Gale (8)	52	0.000*	34	0.000*
Strong gale (9)	30	0.000*	24	0.000*

The findings we present here show that weather phenomena have statistically significant effects on the volume of boarding passengers for commuter trains. Larger Chi-square values for the effects are found during off-peak compared to peak hours for both the changes in temperature and wind speed. Weather conditions thus have a stronger effect on passenger demand during off-peak hours, which is in line with previous remarks regarding the flexibility of trips made by Cools et al. (2010) and Liu et al. (2014). The lack of an effect of precipitation levels on the frequency of passenger volumes can be regarded as somewhat surprising. Previous studies have highlighted a shift from active, mostly open-air, modes towards covered modes such as public transport and private vehicles as a result of increased precipitation (Sabir, 2011). In terms of practical implications, our findings indicate that weather should be taken into account both during tactical and operational planning. The change in passenger volumes can be incorporated into the timetable by adapting dwell time during prolonged periods of warm weather during off-peak hours. A similar notion can be made concerning long-term rolling stock circulation plans. On the operational level, rolling stock circulations can be adapted based on weather predictions. To account for the increase of passengers during periods with higher wind speeds, for example. These changes can also be incorporated into demand modelling and real-time rescheduling problems.

The study we present here does come with some limitations. To account for different responses to weather variables between commuters and non-commuters we split our observations based on the departure time. Although this can be considered a good proxy for the type of trip, it does not capture a shift in travel times for commuters. More detailed information on the individual traveller is required to reveal such responses to changes in the weather. Another limitation is the distance between the weather stations and railway stations and the granularity of the observations in terms of time. As mentioned by Creemers et al. (2015) some caution is advised when making use of data from point sources such as weather stations when analysing changes in space and time. Although hourly weather data is relatively detailed, weather changes can be volatile and change within the hour. Nevertheless, we argue that the data used for this study are of sufficient quality to make meaningful inferences. The study we present here is limited to focusing on the volume of boarding passengers. Although one of the main factors affecting the duration of dwell times, other aspects such as the ratio and spread of passengers influence dwell times as well. Future studies could include these passenger flow characteristics, which can help improve real-time travel time predictions. In addition to this, station design characteristics such as the available roof coverage can be included in a future study. Doing so allows for a more in-depth understanding of the effect of weather conditions, and can highlight whether station characteristics play a role in the effects found here.

4. CONCLUSIONS

The study we present here focuses on changes in the volume of boarding passengers under different weather conditions. The relationship between weather phenomena and the ridership of trains has not received much attention previously. Our study aims to fill this research gap. To do so we make use of automatic passenger count and weather data on over a million unique station stops, spanning two years, in the Southern region of Scania in Sweden. We find that changes in the level of precipitation, in general, do not affect the volume of boarding passengers except for conditions with moderate precipitation during peak hours. Both changes in temperature and wind speeds are found to have a statistically significant effect on the frequency distribution of the volume of boarding passengers. These changes are different depending on whether the trip takes place during peak hours or off-peak hours. Passenger volumes for trips made during off-peak hours are found to be more susceptible to changes in both wind and temperature. The effects we find can serve as input during both tactical and operational planning, by guiding timetable principles as well as rolling stock circulation plans, and serve as input during real-time rescheduling problems.

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