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WINTER CLIMATE ON TRAIN OPERATIONS

The Department of Mathematics and Mathematical Statistics at Umeå University is working on a study that investigates how winter climate factors affect the occurrence of cumulative delays and the transition rates between delayed and non-delayed states for high speed passenger trains between Umeå and Stockholm.

The climate factors of interest include temperature, humidity, snow depth and atmospheric icing.

The result shows that all the climate factors have impacts on train operations.

INTRODUCTION

There are two kinds of delays used in the study. One is called cumulative delay which monitors the running time within each measured section in a train line. It occurs if the running time has a delay of 3 minutes or more compared to the planned running time. The other one is called (current) delay which monitors the arrival time at each measuring spots. It happens if the arrival time is 5 minutes late or more than the scheduled arrival time.

In this study, the train line under the investigation is shown in *Figure 1*. The total length of the train line is about 711 km including 116 measuring spots, and the operational data is provided by the Swedish Transport Administration. The winter period is restricted to January and February 2017.

The weather data is provided by the atmospheric science group at Luleå University of Technology via simulations simulated from Weather Research and Forecasting (WRF) model with a spatial resolution of 3 km and a temporal resolution of 1 hour in the region of interest. The nearest grid points of the weather data are matched with all the measuring spots. Four climate factors are chosen for the analysis, i.e. temperature, humidity, snow depth and atmospheric icing.

Figure 1: Train line in the region with simulated weather data

STATISTICAL MODELLING

Two statistical models are used in the analysis. *Cox proportional hazard model* is used to analyze the cumulative delays, and *Markov model* is chosen to analyze the transition rates between delayed and non-delayed states.

Since a large number of the atmospheric icing values are zero along the train line, a categorical variable is used instead of the continuous atmospheric icing variable, i.e. 0 if atmospheric icing is zero, 1 otherwise.

RESULTS

Table 1: Estimates from Cox model

Variable	Hazard ratio
Temperature (0-150 km):	0.83
Temperature (150 km-end):	0.94
Humidity	1.026

Table I shows the results from *Cox proportional hazard model* and includes only the significant estimates. The variable temperature is divided into two parts so that the proportional hazard assumption is valid. For the first 100 km, as the temperature increases 1 °C, the risk of being cumulatively delayed decreases 17%. For the remaining trip, as the temperature increases 1 °C, the risk of being cumulatively delayed decreases 6%. With respect to humidity, as it increases 1%, the risk increases 2.6%.

Table 2: Estimates from non-delayed to delayed states via Markov model

Variable	Hazard ratio
Temperature	0.97
Atmospheric icing	1.46

Table 2 shows temperature and atmospheric icing are significant in the model. The hazard ratios indicate that as the temperature increases 1 °C, the transition rate from non-delayed to delayed states decreases 3% and the transition rate from non-delayed to delayed states increases 46% with the occurrence of atmospheric icing.

Table 3: Estimates from delayed to non-delayed states via Markov model

Variable	Hazard ratio
Temperature	1.033
Humidity	0.98
Snow depth	0.95

Table 3 shows the estimates of hazard ratios from delayed to non-delayed states. Temperature, humidity and snow depth are significant in the model. It indicates that as the temperature increases 1 °C, the transition rate from delayed to non-delay states increases 3.3%, as the humidity increases 1%, the transition rate decreases 2%, and as the snow depth increases 1 m, the transition rate decreases 5%.

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