Energy efficiency optimization for railway switches & crossings: a case study in Sweden

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Abstract

With increasing environmental concerns and mounting financial and legislative pressures on the railway industry, monitoring and optimizing energy consumption are becoming crucial. The northernmost track in Sweden, the Iron Ore Line (Malmbanan), is operating in a sub-arctic climate. Effective snow and ice protection ensures the successful operation of this line, especially the railway switches and crossings (S&Cs). One strategy is to remove snow and ice with electrical heating; however, the task consumes a great deal of energy. According to the Swedish Transport Administration, the total energy consumption for the 6800 S&Cs in Sweden equipped with electrical heating is 200–130 GWh/year, at costs of approximately 10–15 M€/year. The next generation of S&Cs now being introduced are equipped with almost triple the effect of S&C heating, from about 10kW to almost 30kW. This project tested enhanced and with the ambition to have a more energy efficient snow and ice protection equipment for the S&Cs. The currently installed equipment was tested using a two-sample t-test, i.e., comparing enhanced snow and ice protection equipment and normal equipment for two different S&Cs at the same station. In addition, a paired t-test was done to test the previous energy consumption. The results show a 30% increase in efficiency with the new type of snow and ice protection equipment.

1. Introduction

Switches and crossings (S&Cs) are a key part of railway infrastructure. They make it possible for trains to take different routes on the tracks, thereby making train operation more efficient. Functional failures on S&Cs often result in delays, with a big impact on the quality of service [1]. Therefore, the transport system needs robust and reliable S&Cs. However, the asset type with the most failures for 2015 in Sweden is the S&Cs, accounting for 13% of all the failures. The biggest cause of failure is snow or ice. Electrical heating is often used to remove snow and ice with electrical heating, but this consumes a great deal of energy. The Swedish Transport Administration (Trafikverket) have about 12 000 S&Cs; 6 800 are equipped with electrical heating. The energy consumption is approximately 200 to 130 GWh/year, at calculated costs of approximately 10 to 15 M€/year. The next generation of S&Cs now being introduced are equipped with almost triple the effect of S&C heating, from about 10kW to almost 30kW [2]. According to the European
program Horizon 2020, an important challenge in transport infrastructure is to reduce the impact of infrastructure on the environment [3]. This makes the need for more effective use of the electrical heating even more important.

The northernmost track in Sweden, the Iron Ore Line (Malmbanan), has trains operating in a sub-arctic climate, including heavy snow in the winter and extreme temperatures ranging from -40 °C in the winter to +25 °C in the summer. The main reason for S&Cs failure is snow and ice. Such failures account for 35% of the total failures per year. Hence, effective snow and ice protection has a significant influence on successful operation. Since it is the northernmost line with the lowest temperatures and most snow, its use of electrical heating is consuming the most energy.

The energy is transformed to heat in the rails to melt snow. The heat is lost through convection, conduction and radiation [4]. Personnel at the Swedish Transport Administration (Trafikverket), together with their maintenance contractors and suppliers, developed a new type of snow and ice protection equipment for S&Cs. Among other things, the equipment is encapsulating the S&C to lower the convection and insulated to lower the radiation. A partnership project was started in cooperation with Luleå University of Technology to test and evaluate the new equipment.

The methods used to compare the energy efficiency of the new and the normal snow protection equipment included a two-sample t-test for testing two different S&Cs in the same station and a paired comparison using a paired t-test to compare historical data of an S&C before and after the installation of the new snow and ice protection equipment.

The rest of this paper is organized as follows. Section 2 presents the background for the project and provides details of both the normal S&Cs snow and ice protection and the new tested version. Together with the description of data collection, Section 3 explains the project methodologies, its implementation and methods. Section 4 discusses the results, and Section 5 offers a conclusion.

2. Background

2.1 Iron ore line (Malmbanan)

![Geographical location of Iron ore line (Malmbanan)](image)
The Iron Ore Line (Malmbanan) is the only existing heavy haul line in Europe; it stretches 473 kilometers and has been in operation since 1903. It is mainly used to transport iron ore and pellets from the mines in Kiruna and Malmberget, close to Gällivare, in Sweden to the harbors in Narvik (Norway) in the northwest and in Luleå (Sweden) in the southeast; see Figure 1. As the map shows, the line is situated well above the Arctic Circle. The climate is sub-arctic with extremely harsh conditions at times. The track section on the Swedish side is owned by the Swedish government and managed by the Swedish Transport Administration (Trafikverket). The trains are part of the government owned company LKAB; the iron ore line is part of its production line, resulting in high demands for constant flow.

2.2 Snow and ice protection equipment for S&Cs

The new (named Kia 766) and normal (named Kia 751) S&Cs snow protection equipment and their respective orientations in the S&Cs are shown in Figure 2; the upper ones are the new ones. The alterations include the following. First, a rubber coating on the top and on the sides of the snow and ice protection boards, on top a fine gravel is added for friction. The boards are positioned, as can be seen, on the outer side of the rails for the switch panel, over the point machines and the stretcher bars. Finally, polyurethane is layered as insulation underneath the boards. Some S&Cs have a moveable crossing; these are equipped with the new snow and ice protection on the outside of the wing rail.

The S&C heating system is made up of several heating elements ranging range from 100W to 1200W. The elements are placed on the stock rail, on the switch blade, and around the stretcher bars; if the S&C has a moveable crossing, it is also heated. A heating element on a switch blade can be seen in Figure 3. There are two sensors mounted in the S&C to control the energy consumption. For Malmbanan, the sensors are set so that the lowest temperature should be +20 degrees Celsius. There is also a “Turbo” function which means all heating elements are on full power. This is done if it starts to snow, or if it is manually started for some reason.
2.3 Data collection

ÖVV is a new system in Swedish Transport Administration (Trafikverket) which is used to control the switch heating. The system collects data on: outside temperature, temperature of rail for two locations in each S&C, snowfall, times when “turbo” was used, and amount of energy used. The parameters were collected every half hour. The data were collected from a cabinet controlling one or multiple S&Cs.

3. Methodologies

3.1 Project implementation

The project began by preparing a prototype to be tested in a pilot test on one S&C at one station. The location was decided by the group based on the availability of ÖVV data, the existence of a comparable reference S&C of the same type and heating effect, and the geographical distance to the location. The selected location was Kirunavaara station, and the S&C with identification number Kia 766. The reference S&C was Kia 751. After installation, the prototype was tested during operation. This resulted in minor alterations of the design.

The next phase of the study involved choosing another nine locations for the new snow and ice protection equipment. The selection criteria were the same as for the pilot test; however, they had to be placed across the whole Malmbanan line, and S&Cs with more failures had to be chosen. The equipment installation began near the end of 2015 and will be finalized early in 2016.

Data were collected from the pilot test S&Cs at Kirunavaara and then verified. Data included the following: outside temperature, rail temperature from two different sensors, and energy consumption. All were hourly data from the ÖVV system.

Data analysis of the energy consumption of the S&Cs at Kirunavaara was done using data for the outside temperature and the temperature of the rail sensor with the lowest value. The analysis used a temperature span of -12 to -5 degrees Celsius. Data were not used if there were indications of the “turbo” function, and no data were used when there were indications of snowfall. The temperature range was based on the expert knowledge of the project group. The aim was to minimize variability with a sufficient amount of data. The exclusion of data for snowfall and the “turbo” function were also intended to minimize variability; as the heating is operating on full power in both scenarios, unwanted effects could result. Methods used to compare the energy consumption are described below.

3.2 Methods

In this project, to compare the energy efficiency of the new and the normal snow protection equipment, a two-sample t-test is used to test two different S&Cs in the same station; while, a paired t-test is used to compare historical data of an S&C before and after the installation of the new snow and ice protection equipment. Both methods were used in Minitab [5, 6].

For both the two-sample t-test and the paired t-test, a quota for the degrees of Celsius that could be changed by one kWh was calculated using this formula:
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\text{Difference in temperature/kWh} = \frac{\text{Lowest rail temperature} - \text{outside temperature}}{\text{Kwh}}
\]

4. Results

4.1 Results from the two-sample t-test

The two-sample t-test was used to compare Kia 766 S&C with Kia 751 S&C; recall that the former had the new equipment installed. The hypothesis are: \( H_0: \mu_1 = \mu_2 \) and \( H_1: \mu_1 \neq \mu_2 \).

T-tests are not sensitive to the normality assumption. The data for the two S&Cs does not seem to be normally distributed. The p-value is lower than 0.05 and the Anderson Darling value is not low. However the two-sample t-test finds the difference in the means of the two S&C is significant, with a p-value of 0. The results show the mean value for the new equipment is 1.32 and the mean value for the normal one is 1.07. The difference in the means shows the new snow and ice protection equipment is increasing efficiency by almost 30%. This improvement is shown in Figure 4.

4.2 Results from the paired t-test

A paired t-test was used to compare the Kia 766 S&C before and after installation of the new snow and ice protection equipment. The hypothesis are: \( H_0: \mu_1 = \mu_2 \) and \( H_1: \mu_1 \neq \mu_2 \).

The data for Kia 766 before the installation are normally distributed. The results show a difference in mean between the two periods, with a p-value of 0. In this case, the mean value for the new equipment is 1.32 and the mean value for the normal one is 1.03. The difference is 0.28; this means an increased efficiency of almost 30% as shown in Figure 5.
6. Discussion

The study has a number of possible limitations. First, this is an initial test with just one S&C. More data are needed from other S&Cs to learn more about the influence of the new snow and ice protection equipment on energy consumption. In addition, the data used for Kia 766 and Kia 751 are not from the same time period, and this might influence the results. For example, there could be a difference in the wind conditions, and this may affect the findings. However, the samples are quite large: 252 samples for the Kia 766 and 187 samples for the Kia 751.

The paired t-test and the two-sample t-test both conclude the same things. First, the mean for Kia 766 with normal snow and ice protection is close to 1 degree/kWh, as is the mean for Kia 751. This makes the results more reliable. Finally, there is a possibility that the heating effects changed during the test period due to maintenance issues, but as the heating is never on full effect, this should be a minor problem.

6. Conclusion

The new snow and ice protection equipment has a positive effect on energy consumption. The pilot study S&C shows 30% increased efficiency. These are preliminary results from the first of 10 locations using the new snow and ice protection equipment. The results so far are very promising. Further studies with more data including other locations and a larger temperature span will be conducted to optimize the energy efficiency of railway S&Cs.

Reference