How do fires affect the railway?

- A Swedish study on what factors influence fire risk and how it affects railway traffic.

LUNDS UNIVERSITET
Lunds Tekniska Högskola

LTH School of Engineering at Campus Helsingborg
Railroad engineering

Bachelor thesis:
Jonatan Gustafsson

Foreword

This thesis, which consists of 22.5 credits, is the final phase of the engineering education which is specified on the railway at Lund University of Technology. The topic was chosen because climate change is expected to have a negative impact on train traffic due to an increase in fires in the future. As a result, it appears vital to examine how the weather currently affects trains in order to anticipate how the future climate may affect them and, potentially, establish solutions that ease future railway operations.

I'd like to express my gratitude to Carl-William Palmqvist for his assistance during the project. I'd also like to thank my main supervisor, Michelle Ochsner, for her guidance and expertise that helped me complete this project. Without her, I would not have written in English and learned a lot about working and creating a project of this size in another language, which I believe will benefit me in the future.

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Jonatan Gustafsson

Thanks for everything: Janina Stupiec, Jimmy Gustafsson and Gert Gustafsson.

LTH School of Engineering
Lund University
Box 882
SE-251 08 Helsingborg
Sweden

LTH Ingenjörshögskolan vid Campus Helsingborg
Lunds universitet
Box 882
251 08 Helsingborg

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Abstract

Forest fires can start in a variety of ways. "Fires started deliberately" and "fires started by sparks generated from a train braking" were two of the most common causes of fires between 2010 and 2020. Train braking accounted for 1.1% of all fires, whereas fires created by unknown reasons accounted for 43% of all fires.

The climate is expected to change in the future, and since different weather factors affect the risk of fire differently, it is interesting to observe how train traffic is currently affected by fires and where these fires occur, in order to prepare for and ease the consequences of future weather changes. In this thesis, the number of rescue missions reported was compared to two databases containing information concerning fires near the railway. They were compared because rescue operations imply that the fire was so broad at the time that aid was required, which makes it interesting to examine. Between 2010 and 2020, these comparisons produced 1,337 matches. Where matches represent how many times a fire was reported on one of these databases on the same day and location that a rescue mission was established. When delays were calculated, just one database was compared to the number of rescue missions, because the other one did not possess information about delays. This comparison produced 621 matches with a total delay of 203,821 minutes.

The distribution of the counties where the matches and delays occurred was observed in order to determine which additional variables might have contributed. The population and land area were compared to the proportion of matches and delay minutes, and it was noticed that the counties of Stockholm, Västra-Götalands, and Skåne, which had the most people, were also in the top four for the most matches and the top eight for the most delay minutes. The municipalities with the largest values were also examined more closely, for both the 1,337 and 621 matches. For the 1,337 matches, the average temperature and average precipitation for the ten municipalities with the largest values in each category were compared to the average value for all 161 municipalities that were affected. For the 621 matches, the matches, the delay minutes and the number of affected trains for the ten municipalities with the largest values in each category were compared to the average value for all 130 municipalities that were affected.

Regressions were used to calculate the impact of various weather events on the number of matches and the number of delay minutes. In the regression for the number of matches, temperature and precipitation were used as the independent variables which were taken from the 1,337 matches, these gave a result that both variables explain a portion of the matches. The regression performed for the number of delay minutes used the same independent variables but instead took them from the 621 matches, this showed that the variables did not explain the outcome of the number of delay minutes.

Weather factors other than temperature and precipitation that have not been studied, such as relative humidity and wind speed, appear to have an impact on the number of matches, according to various sources. Where, for example, records on relative humidity from prior years correspond quite well with when a match occurs. Furthermore, the locations of matches and delays appear to be connected to the population, with more individuals implying a larger risk.

Keywords: Train, railway, fire, forest fires, delays, weather, Sweden.

Sammanfattning

Några utav de vanligaste orsakerna till att en brand uppkom mellan 2010 och 2020 var ”bränder som medvetet startades” samt ”bränder som startats av gnistor vid tågbromsning”. Av den totala mängden bränder som uppkom stod tågbromsning för cirka 1.1 % av dem och den anledning som stod för absolut störst andel bränder var ”bränder startade utav okänd anledning” vilket stod för 43%.

Klimatförändringar är beräknade att ske i framtiden vilket gör det intressant att observera hur dagens olika väderfenomen påverkar antalet bränder vid järnvägen samt var dessa bränder förekommer, detta för att förbereda och lindra konsekvenserna av de framtida väderförändringarna. Detta arbete genomfördes genom att två databaser innehållande information angående bränder runt järnvägen jämfördes med antalet rapporterade räddningsuppdrag. Jämförelsen gjordes då ett utfört räddningsuppdrag med största sannolikhet inneburit att branden vid tillfället varit utbredd till den mån att hjälp behövts, och därför indikerar att branden varit större vid detta tillfälle. Detta resulterade i 1,337 matchningar under de 11 åren mellan 2010 och 2020, där en match representerar att en brand rapporterats i minst en av dessa databaser under samma dag och plats som ett räddningsuppdrag har utförts. När beräkningar gjordes på förseningar jämfördes endast en utav databaserna med räddningsuppdragen då den andra databasen inte innehåller någon information angående förseningar. Jämförelsen mellan de två databaserna gav 621 matchningar som resulterade i totalt 203,821 förseningsminuter.

Distributionen för både matchningarna för de tre databaserna samt matchningarna för de två databaserna undersöktes, detta för att utvärdera hur matchningarna var uppdelade i de svenska länen. Genom att erhålla denna information kunde fler variablers påverkan studeras. Population samt landarean jämfördes med andelen matchningar och andelen förseningsminuter vilket visade att Stockholms, Västra-Götalands samt Skånes län vilka har störst befolkningsmängd också var bland de fyra länen med flest matchningar. Dessa var också bland de åtta länen med mest förseningsminuter. Närmare studerades också kommunerna med störst medelvärden för de olika variablerna för både de 1,337 matchningarna och de 621 matchningarna. För de 1,337 matchningarna jämfördes matchningar, medeltemperatur samt medelnederbörd för de tio kommunerna med störst värden i varje enskild kategori med medelvärdet för alla 161 kommunerna som blivit påverkade. För de 621 matchningarna jämfördes istället matchningarna, förseningsminuterna och antalet påverkade tåg för de tio kommunerna med störst värden i varje enskild kategori med medelvärdet för alla 130 kommunerna som blivit påverkade.

För att bedöma väderfenomenens påverkan i antalet matchningar och antalet förseningsminuter gjordes två separata regressioner. Regressionen för antalet matchningar undersökte temperaturens samt nederbördens påverkan vilka togs från de 1,337 matchningarna. Detta visade att båda variabler hade en påverkan över en del av matchningarna. Den andra regressionen som undersökte hur antalet förseningsminuter blivit påverkad använde samma oberoende variabler fast från de 621 matchningarna istället och visade att dessa variabler inte hade någon påverkan över antalet förseningsminuter.

Väderfaktorer som inte undersökts då information inte fanns att tillgå, däribland relativ fuktighet och vindhastighet, verkade ha en inverkan på antalet matchningar enligt olika källor.

Exempelvis har relativ fuktighet från tidigare år överensstämt väldigt väl med när matchningarna inträffat. Utöver detta verkade lokaliseringen av matchningar och förseningar förekomma där befolkningsmängden varit större vilket kan tyda på en större risk för bränder vid större populationer.

Nyckelord: Tåg, järnväg, brand, skogsbrand, förseningar, väder, Sverige.

Word list

Abbreviation	Meaning in Swedish	Meaning in English
MSB	Myndigheten för samhällsskydd och beredskap	Swedish Civil Contingencies Agency
IDA	Statistik om olyckor, skador och räddningsinsatser	Statistics about accidents, damages and rescue operations
SMHI	Sveriges meteorologiska och hydrologiska institut	Swedish Meteorological and Hydrological Institute
RCP	beskriver forskarnas prognoser för hur och hur mycket vårt klimat kan komma att förändras i framtiden (beskrivning)	Representative Concentration Pathways
ERCC	Samordningscentralen för nödsituationer	Emergency Response Coordination Centre
TSB		Transportation Safety Board of Canada

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1 Introduction

Sweden has one of the world’s highest proportions of forests, with 279,000 km^2 of its 410,000 km^2 land area covered in some form of forestry (Statistikmyndigheten, 2023). In terms of percentage, this translates to 68% of the nation, with just two other European Union countries having comparable proportions. In comparison, the European Union's average percentage is 37.7% (European Parliament, 2023a). According to Poljansek et al. (2017), approximately 4 % of the world’s vegetation burns up each year. However, these are high figures compared to Sweden. As Skogsindustrierna (2020) states that Swedens total land surface fires annually amount to only 0.16 ‰ of the total landmass.

Fires have a negative influence on private individuals, businesses, and society in many ways. If a fire happens, people may lose their homes or places of employment. This can lead to people feeling compelled to relocate in order to find a new home or workplace. The trees that are burned down in the forest will not be able to produce new oxygen and will instead release carbon dioxide as they break down (European Parliament, 2023:b). Trains running on a railway in a forest with a fire must come to a halt and wait for the fire to be extinguished and the situation to be declared safe. As a result, rail services may be disrupted, preventing passengers from travelling. Palmqvist & Ochsner (2023) demonstrate this in their study where numerous trains are delayed due to fires along the railway. Where these trains caused a total of 11,600 hours of delay due to fires between 2010 and 2020. The absolute worst consequences are that if a fire begins and a person is in the wrong position at the wrong time, severe damage or death might occur, as proven by the fire in 2014, in which one person died (Lidskog et. al. 2019).

Sjöström & Granström (2020) describe how various factors can influence the size and frequency of fires, with fires happening more frequently and getting larger in certain months and less frequent and smaller in others. This is shown in *Figure 1* with data collected from 1996 to 2018. Palmqvist & Ochsner (2023) illustrate the same for train delays caused by fire, where a majority of which occurred in May, June, and July. And according to their observation of railway delays, storms were the most common source of extreme weather-related railway delays in Sweden between 2010 and 2020, and fires were not far behind as the second leading cause of delays because of extreme weather.

Fires occur, and various factors influence how frequently they appear and how large they are. These fires could disrupt rail traffic, causing delays. As a result, it may be useful to evaluate how much the weather influences and how many delays have occurred because of fires.

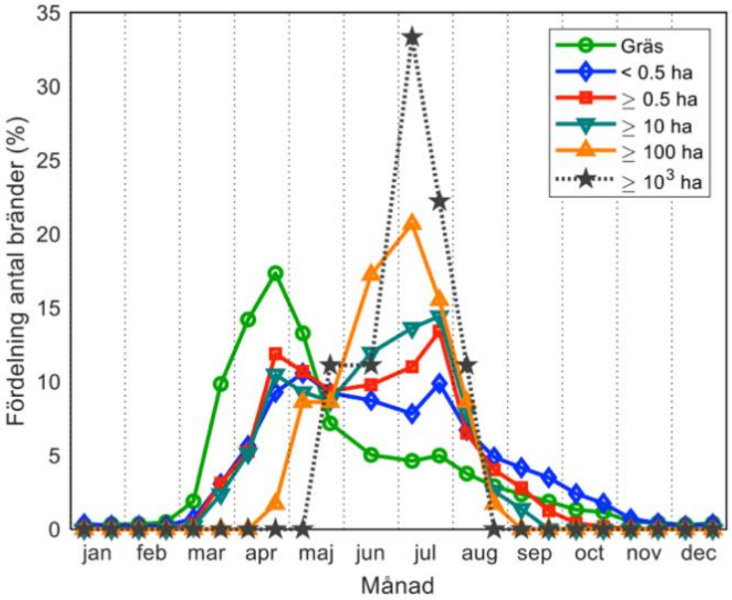

Figure 1: Fördelningen antal bränder translates to the distribution of the number of fires and månad translates to month. This figure depicts the distribution of fires that destroy various sizes of land, where the distribution is in percentage across the various months and the size is estimated in hectares. Source: (Sjöström & Granström. 2020).

1.1 Aim and research questions

The aim of this thesis was to discover how fires affect the railway, as well as what variables influence the number of fires and where they occur. Simultaneously, observe how the proportion of delay minutes was affected by the same variables, as well as how the delays were spread across the country. This was done because climate change is projected in the future, making it important to study how various weather variables are currently influencing fires.

The locations of these larger fires and delays are essential to investigate in order to analyse additional variables that may have had an impact. All of this knowledge is intended to ease the process and prepare for future climates by offering insight into which variables have an impact and by how much.

The following questions will be addressed in this thesis:

1. How many of the fires in the databases line up with the rescue missions reported on MSB?
2. In which counties in Sweden do these fires occur, and how are the delay minutes distributed throughout these counties?
3. How does the weather impact the number of fires and the number of delay minutes around the railway?

1.2 Scope and Limitations

This study is not restricted to any specific geographical location in Sweden, instead, the study focuses on the entire country. All statistics and analyses include data from Sweden between 2010 and 2020, this is because the values gathered from the databases Ofelia and Luppdata were limited to those years. Luppdata and Ofelia are Swedish Transport Administration-owned databases that were used because they contain information on train fire reports, with Ofelia focusing on infrastructure issues and Luppdata containing data on railway operations, this data is then used by the Swedish transport administration. Because of the limited access to Ofelia and Luppdata, as well as the fact that both databases (particularly Ofelia) also indicate errors on the railway that may be misinterpreted as a fire, exact results cannot be guaranteed and instead, the result should be regarded as a good estimate. Luppdata and Ofelia are independent databases, so there is a chance that a fire recorded on Luppdata also was reported on Ofelia. Consequently, there could be fires that are counted more than once.

MSB statistics are provided to determine when a rescue mission was conducted. The information did not specify the precise location of the rescue operations, just the municipality involved. As a result, the fire locations in Luppdata and Ofelia were reduced from a more specific position to just identifying which municipality the fire was reported in.

1.3 Thesis Structure

Chapter 2. The background will address factors that affect the number of forest fires, such as climate change, how fires occur and the impact of fires.

Chapter 3. Contains information on databases that were used in the thesis and what information they contain.

Chapter 4. Specifies the calculations and variables that were used, as well as provides information on what was done to obtain the result.

Chapter 5. Part one will be about the result when comparing Luppdata, Ofelia and MSB. This will give an outlook on how many fires that happened. Part two will instead be the comparison between Luppdata and MSB and will give a view of how delays are impacted by fires. In addition, regressions on various independent and dependent variables will be performed.

Chapter 6. Explain the result while also providing suggestions for how the future may look. Additionally, share hypotheses that arose during the course of the assignment.

Chapter 7. Proposals for additional research and new questions that developed during the course of the work.

Chapter 8. Some brief conclusions related to the study.

Chapter 9. All sources used throughout the project.

2 Background

2.1 Causes of forest fires

“Precipitation, temperature, humidity and wind speed have the greatest impact on the fire risk.” (SMHI, 2015).

Certain circumstances must be followed for a forest fire to occur. According to Granström (2018) the initial requirement is suitable dry fuel and a source of ignition. In Sweden, this fuel typically consists of moss or lichen, which requires less than 25% humidity to ignite and takes about a week to get below 25% without precipitation. The relative humidity is therefore frequently checked when the precipitation has been low to clarify the risk. If the relative humidity is low and extended periods of heat occur, marshlands and swamps will eventually dry out, causing them to catch fire and burn. As these become drier and more vulnerable to fire, their value as natural barriers decreases and fires can move through them.
The drier grounds make it more difficult to extinguish the fire and normally is it the weather that gets hold of the bigger fire rather than human factors. In addition, there are variables from which the fire can benefit. Drier vegetation, and higher windspeed, contribute to greater fire spread by transporting the fire more easily, where twice the speed of the wind is commonly considered as twice the speed of the fire spread. As a result, the risk is lessened or raised depending on the time of day, as humidity and wind strength follow a daily pattern. Where the wind is generally at its greatest and the humidity is at its lowest during sunrise and the opposite during the afternoon. Nezval et. al. (2022) states that even the smallest changes could have a significant impact on the risk of fire. If the average temperature climbs by one degree over ten days, the likelihood of a fire increases by 26%. Instead, increasing the precipitation by one millimetre reduces the risk of fire by 36%.

Figure 2 illustrates the most common causes of forest and land fires in Sweden between 2010 and 2020. Where “Unknown reasons” accounted for about 40% of the total. Other factors included fires caused by a BBQ/campfire, smoking, and fires created on purpose. The only natural cause of a forest fire in this list was lightning strikes, which accounted for 5% of all fires. This suggests that human factors were responsible for 95% of all fires during this time period (MSB, 2023). This is similar across Europe, where over 95% of fires are caused by negligence or arson (Poljansek et al, 2017).

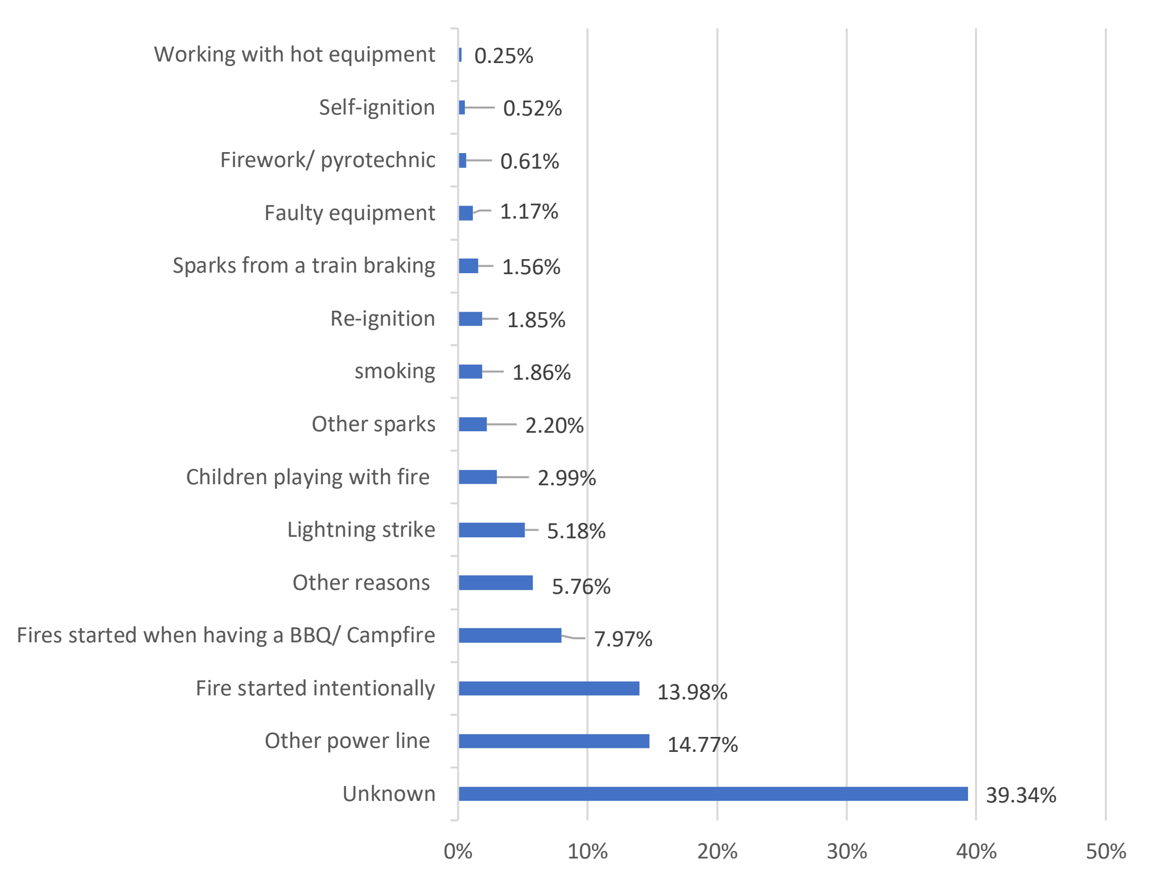

Figure 2: Percentage of all fires caused in Sweden`s forest and land between 2010-2020. Data in this figure has been processed from data available on MSB's website (MSB, 2023)

The greatest forest fire in Sweden since before the 1950s occurred in 2014 (SMHI, 2015). The environmental circumstances prior to the start of the fire played a significant role in the fire getting as large as it did. The first heat wave began approximately 25 days before the fire ignited. This heat wave lasted for five days with temperatures closing to just below 30 degrees Celsius. A second heatwave began ten days later (15 days before the wildfires erupted) and this time the temperatures reached 30 degrees Celsius. This second heatwave continued until the end of the month when the fire began on July 31st. The fire grew by 460% on the fifth day before being brought under control on the eighth day due to weather changes. After six weeks, the fire was declared extinguished on September 11th (Lidskog et. al. 2019). Throughout this month the humidity ranged from dry and very dry where some locations only received a fifth of typical precipitation. The relative humidity did not exceed 30% on the worst days, while the average for the month during daytime was closer to 50-60% (MSB, 2015).

For a long time, the risk of operating steam locomotives was the primary cause of train fires. Since the usage of steam locomotives has declined, less research has also been conducted on train-caused fires (Nezval et. al. 2022). At present time, train braking has become the leading cause of train fires. According to Wasilewski (2020), this occurs because friction develops when brake discs are pushed on the railways tracks. Friction generates heat, which causes the temperature of the track and brakes to rise, resulting in the generation of sparks.
This scene is portrayed In Kutsarova-Dimitrova's (2020) text, where a spark from a braking train landed on the wooden sleepers and ignited them.
According to Fabella & Szumczak (2021), the probability of this grows with the number of trains passing, particularly the number of goods trains passing. Simply said, the risk of a fire grows with each train that passes under specific conditions.

If a spark is produced, the risk of fire is determined by the conditions surrounding the railway. This could be the presence of combustible material and the nature of its temporary qualities. This is explained by Garmabaki et al (2021) and Garmabaki et al (2022) who describe how the chance of sparks igniting the vegetation grows as the temperature rises and the drought worsens.

Transportation Safety Board of Canada or TSB (2023) shows that in addition to train braking, another cause of train fires is railway maintenance, which includes:

- Sparks are generated by tracks being sawed off and a new one welded on again, during repairment.
- Sparks are created when grinding the tracks to the right profile.
- Materials left in the workplace after a job can act as fuel for a fire.

A deeper look at *Table 1* shows the 16 leading reasons for forest and land fires, and it can be observed that the 12 most common reasons consist of train braking, with 772 fires between 2010 and 2020.

Table 1: Statistics on the number of rescue missions and the proportion of land damaged by fires between 2010 and 2020. Data in this table has been processed from data available on MSB's website (MSB, 2023)

Cause of fire	Number of rescue operations	Area of productive forest m^2	Other forest land m^2	Land without trees m^2
Unknown	19,485	32,872,343	12,599,601	11,146,399
Other power line	7,313	3,526,234	3,477,948	16,592,633
Fire started intentionally	6,925	2,427,356	1,530,206	2,132,201
Fires started when having a BBQ/Campfire	3,946	1,756,327	2,519,208	722,188
Other reasons	2,854	8,948,059	3,769,391	3,096,356
Lightning strike	2,564	153,528,877	6,134,518	11,822,587
Children playing with fire	1,481	857,665	154 ,393	419,570
Other sparks	1,090	101,914,654	15,879,122	19,808,158
Smoking	922	127,300	56,171	94,800
Re-ignition	916	48,741,663	424,199	5,413,850
Sparks from a train braking	772	549,632	381,776	653,019
Faulty equipment	577	1,634,932	393,406	729,527
Firework/ pyrotechnic	302	16,741	35,084	129,663
Self-ignition	256	130,206	161,224	84,832
Working with hot equipment	123	375,531	30,425	46,203

2.2 Climate change

“The climate is a description of how the weather characteristic averages under a couple of decades, the subjects that usually stand in focus are temperature and precipitation. Climate change is therefore about how these characteristics change between two periods of time” (Mobjörk, 2011).

When it comes to predicting how the climate will change in the future, there is no definitive answer. Human approaches to situations today and in the future can affect the outcome in any direction. Representative Concentration Pathways (RCP) are one technique for predicting how the climate will change. RCP has four intensity levels: RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5. These contain four different calculations of how much CO_2 will be emitted before the year 2100. RCP 2.6 is the best of these four options, and RCP 8.5 has the highest emissions and is, therefore, the least favourable alternative (SMHI, 2013; Morel et al, 2020; Ds 2014:11). This is due to the fact that carbon dioxide is harmful to the environment as it warms the earth by preventing heat from the sun from being reflected back out (European Commission, n.d).

Approximations that have been made by using RCP 4.5 and RCP 8.5 in the region around Stockholm show a raise of temperature with three respective five degrees between 1960 and 2100 (Asp et al, 2015). Statistics taken from SMHI (2023) displayed in *figure 3* is a broader more general approximation throughout the country and the likely mean temperature in Sweden between 1951 and 2100 is depicted. According to data and estimations, the mean temperature climbed by 1.5 degrees Celsius between 1951 and 2019. And according to SMHI`s estimations the mean temperature will keep increasing with a final result depending on the size of the emissions. The best scenario based on RCP 2.6 will have little effect on the temperature. The other two scenarios, RCP 4.5 and RCP 8.5, will raise the temperature by about 1.5 degrees and 4.5 degrees Celsius, respectively, between 2019 and 2100.

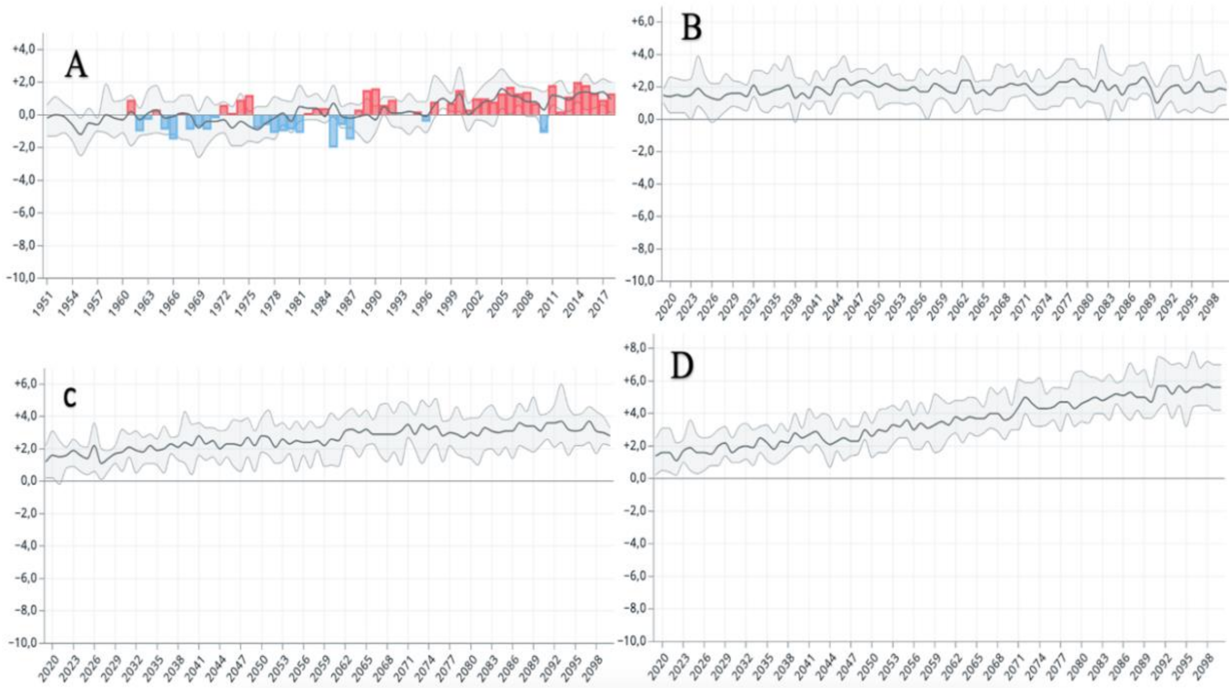

Figure 3: A: Demonstrates how the temperature in Sweden has increased between 1951-2019. B: Demonstrates the increase in temperature that will occur according to RCP 2.6. C: Demonstrates the increase in temperature that will occur according to RCP 4.5. D: Demonstrates the increase in temperature that will occur according to RCP 8.5. For all figures, the temperature is expressed in degrees Celsius. Data in this figure has been processed from data available on SMHI's website (SMHI, 2023).

Eklund et al (2015) estimate that precipitation increases with increasing temperature. Two different emission levels, RCP 4.5 and RCP 8.5, are compared, and their impact on precipitation is calculated using a reference period between 1961-1990. The nearest calculated decade is 2021-2050 where both quantities show a similar increase of 8-12%. Meanwhile, the latter decade (2069-2098) shows a noticeable difference where RCP 4.5 promises a rise of 16-20%, whereas RCP 8.5 provides a rise of 24-28%. All of these estimates indicate that precipitation will increase, and *Figure 4* illustrates that this is a continuation of the current curve, which has been steadily increasing since 1880.

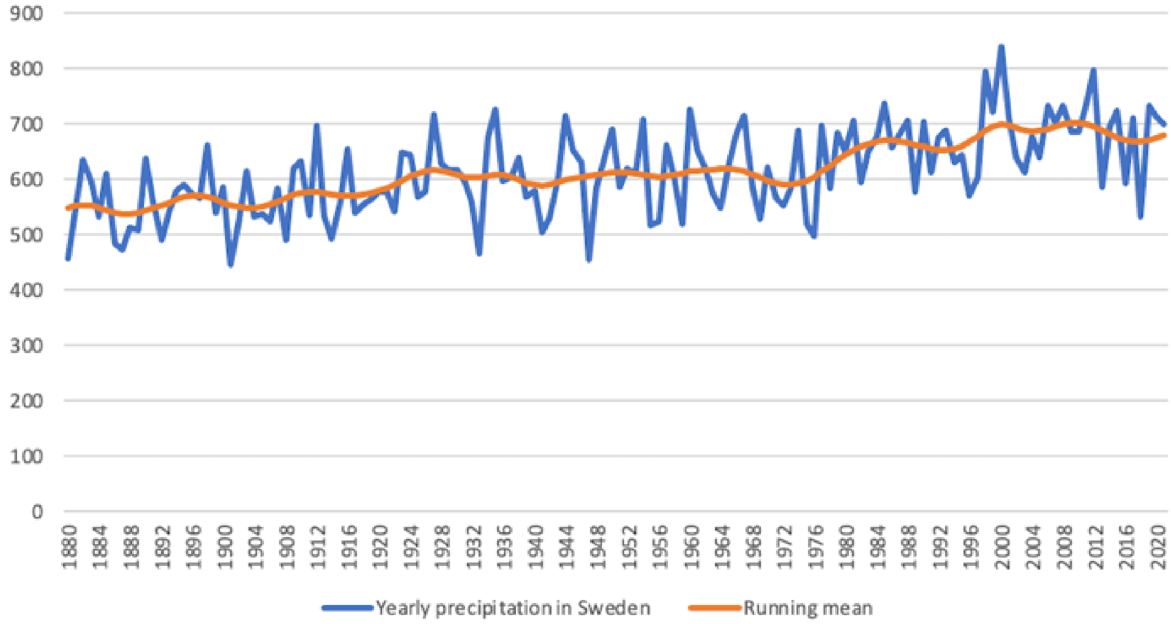

Figure 4: Yearly mean precipitation (mm) in Sweden between 1880-2021. Source:(SMHI, 2010)

Tropical nights are defined as nights in which the lowest temperature does not fall below 20 degrees Celsius (Sillmann et. al. 2013). *Figure 5* depicts the irregularity of the number of tropical days. However, the frequency of tropical days is increasing, and by 2020, the average had risen to more than ten days a year. With an increasing curve of nights where the temperature does not fall below 20 degrees Celsius, periods of high temperature are extended, resulting in more hours during the day when the risk of fire is increased.

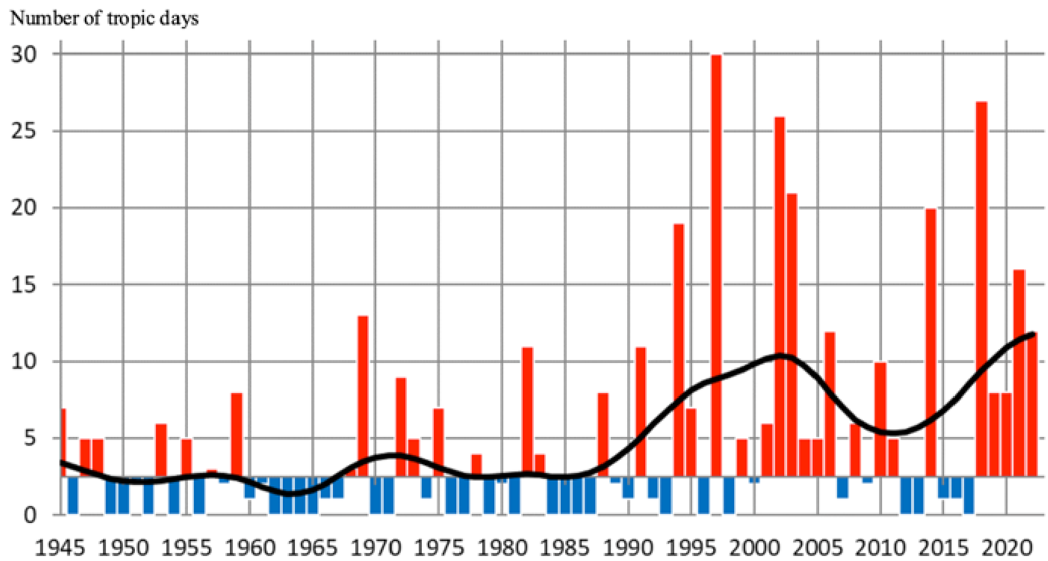

Figure 5: This graph depicts the annual number of tropical days between 1945 and 2020. As seen on the trend curve, the number of tropical days grew by 400% during these years, from around three to about twelve. Where a tropical day occurs when the temperature does not fall below 20 degrees Celsius during the course of the day. Source: (SMHI, 2013:b).

Forest and vegetation fires are expected to rise in the future as risk factors change. Temperatures are expected to rise and snowfall decrease, resulting in extended fire seasons that begin earlier and end later, according to (MSB, 2022). Based on Sjökvist et. al. (2013) and MSB (2022) are the risk season for wildfires expected to increase by 100% in a large portion of the country by 2100, from 50 days presently to 100 days. The highest increase is projected to occur in Gotland and Öland, resulting in a fire risk season that lasts 120 days of the year.

Low soil moisture is another example of what might happen during dry periods. where low moisture is defined as soil moisture that is less than the yearly average. Drier soil is predicted to become more common in Sweden in the future, with forecasts based on RCP 4.5 and RCP 8.5 indicating that the number of days with low humidity in the soil would increase over the coming decades, from the current 5-10 days. By 2021-2050, RCP 4.5 is projected to grow to 15 days, while RCP 8.5 is expected to rise to 20 days. Between 2069 and 2098, these are expected to increase to 20-25 days for RCP 4.5 and 40-45 days for RCP 8.5 (Eklund, 2015).

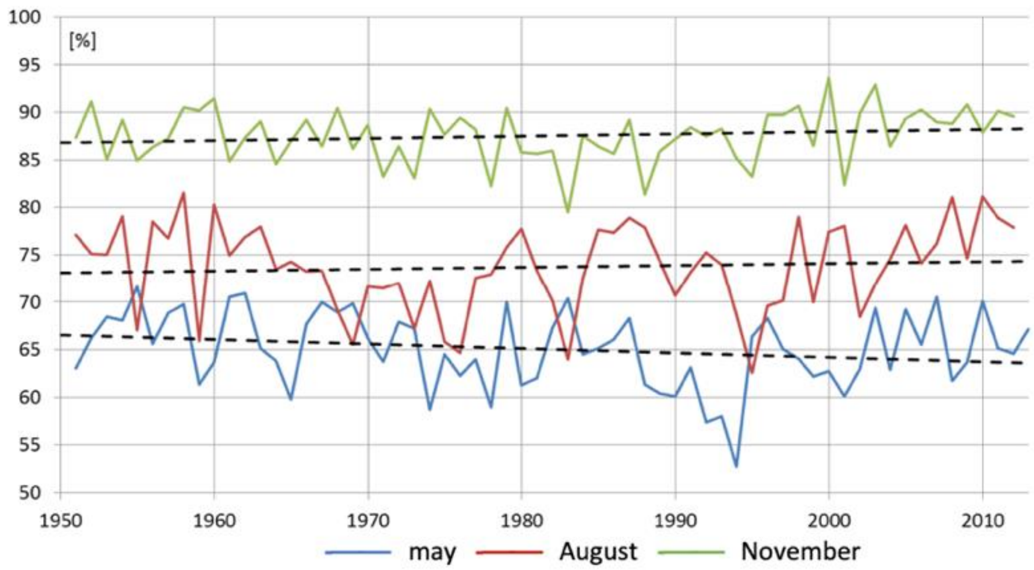

Figure 6: Monthly average relative humidity during May, August and November from ten different stations between 1950 and 2010. (Wern, 2013).

“The relative humidity describes the quantity of steam present in the air at a given temperature in relation to the maximum amount of steam available at the same temperature.” (Wern, 2013).

The relative humidity has followed a pattern over the last 60 years, as seen in *Figure 6*. Late spring has nearly always had the lowest humidity over the course of a year, with an average value of roughly 64%. This is compared to late summer (August) and early winter (November), both of which had higher humidity, with average values of 74% and 88%, respectively. Just as relative humidity varies with the seasons, it also varies with the time of day and temperature. This is demonstrated in Wern (2013) text which describes how the relative humidity varies depending on the time of the day and the temperature. The humidity level is often lower in the spring and early summer, and higher in the winter. Similarly, as the humidity is higher in the cold seasons and lower in warm seasons are the humidity also higher at night-time and lower during the day. This demonstrates how strongly linked the temperature is to the humidity where a higher temperature lowers the relative humidity, and a colder temperature raises the relative humidity.

2.3 The impact of delays and how forest fires cause them

Palmqvist & Ochsner (2023) illustrate how various weather events cause delay hours in train traffic between 2010 and 2020. According to this data, storms created the most delays with 13,950 hours, this was followed by fires which stood for 11,600 hours. The data focused on delays caused by fires shows a rising curve, indicating that delays caused by fires have increased over the years as illustrated in *Figure 7*.

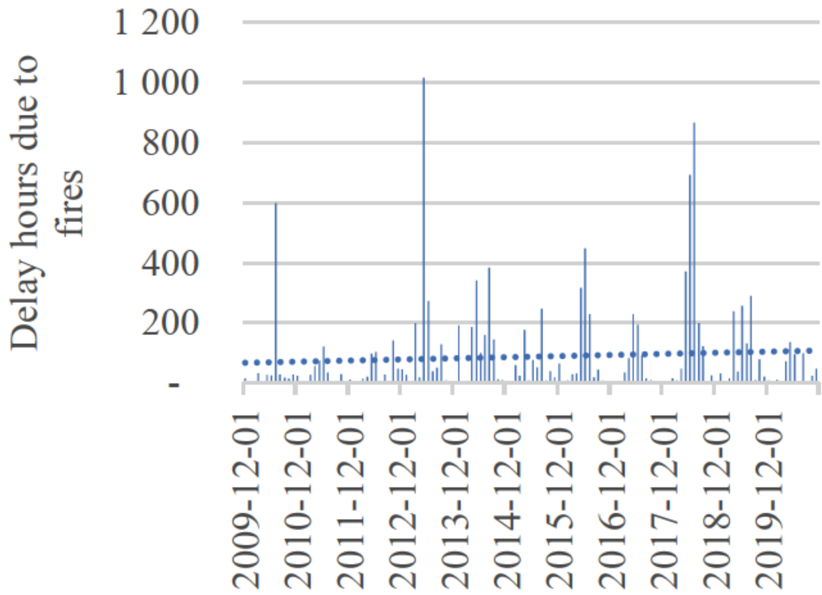

Figure 7:Delay hours between 2010-2020 with a rising trend curve. Source: (Palmqvist & Ochsner, 2023).

Delays caused by fires are usually brief. This is stated in Fabella and Szymczak (2021) research, which compares various natural hazards in Germany, one of which is slope fires. They conclude that just 13 of the 924 documented slope fires, or 1.4%, resulted in delays lasting over 24 hours. In comparison, 32.7% of all recorded flooding delays lasted more than 24 hours.

One of the primary reasons Swedes avoided trains, according to Sundin (2019) was a lack of trust in the trains ability to arrive on time. A poll done by them revealed this reality, with one-third of those who responded claiming that they had previously chosen not to use the train and instead travelled by other means. According to the findings of this poll, it is vital to uphold as good of punctuality as possible in train traffic in order to gain people's trust. Pettersson (2020) report that Sweden aims for 95% punctuality when arriving at the intended location. When compared to actual values made by Lennefors (2020) between 2008 and 2019, the average punctuality for trains on 30 separate routes in Sweden was estimated at 85.5%.
This was the result when a train was considered late if it arrived at the last station six minutes later than it should have, with cancelled trains excluded from this statistic. Newer numbers from Trafikverket (2023) for 2021 had the same conditions and revealed that roughly 964,000 trains travelled on the Swedish railway network with 92% punctuality. This means that the 77,120 trains did not arrive on time, it should be noticed that this included all delays in railway traffic and not just fires. Other negative consequences of delays include longer travel time for customers, the possibility of overcrowding when other trains are delayed, and the operator incurring more expenditures (Nelldal et al. 2022).

2.4 Why it is important to avoid forest fires

Fires are powerful and their potential for damage is enormous.
As shown in *Table 2* more than 72 million m^2 of land burnt down over 11 years between 2010-2020. It can also be observed that two of the years were particularly noteworthy, accounting for 82% of all forest fires.

Table 2: The annual impact of fires on the number of rescue missions and the amount of destroyed land area between 2010 and 2020. Data in this table has been processed from data available on MSB's website (MSB, 2023)

Year	Number of rescue missions	Area productive forest land m^2	Other forest land m^2	Land without trees m^2	Total area of destroyed land m^2	Annual distribution of damaged land
2010	3,060	1,437,615	1,451,662	2,388,806	5,278,083	1%
2011	3,480	3,445,463	3,064,624	2,840,499	9,350,559	2%
2012	2,184	1,086,166	852,064	2,885,086	4,823,316	1%
2013	4,847	4,771,086	3,150,972	7,108,449	15,030,507	3%
2014	4,323	104,980,838	21,230,929	20,416,571	146,628,338	31%
2015	2,664	2,569,494	955,413	2,437,144	5,962,051	1%
2016	5,381	7,091,139	2,603,184	3,238,439	12,932,762	3%
2017	5,180	4,365,561	1,678,379	8,111,066	14,155,006	3%
2018	7,974	215,827,102	8,515,909	18,661,445	243,004,456	51%
2019	5,317	7,903,667	2,131,808	2,506,912	12,542,387	3%
2020	5,118	3,929,416	1,911,738	2,297,573	8,138,727	2%
Total	49,528	357,407,520	47,546,682	72,891,990	477,846,192	
Average	4,503	32,491,593	4,322,426	6,626,545	43,440,563	

In 2014, there was a major fire in Sweden that destroyed a large portion of the forest. Over 13,000 hectares of forestland were destroyed, resulting in a number of several negative effects. 71 buildings were destroyed, over 1,000 people and almost 2,000 animals had to be evacuated and one person died. The total cost of this fire is estimated to have surpassed 100 million euros, equivalent to one billion Swedish crowns (Lidskoga et.al. 2019).

The fires during the warm summer of 2018 caused major difficulties in the extinguishing work. The extent of the problem became so big that MSB activated the EU's Civil Protection Mechanism and contacted Emergency Response Coordination Centre (ERCC). This contact was about support in the extinguishing work between European countries. Sweden received assistance from a number of countries, including Denmark, Finland, France, Italy, Lithuania, Norway, Poland, Portugal, and Germany, by the time the fire was eventually extinguished (SOU 2019:7).

3 Data

To complete this project, numerous data tools were utilised to collect information. This information was then compared to generate an idea of which elements influence which factors.

3.1 MSB fire data

The Swedish Civil Contingencies Agency, generally known as MSB, exists to protect Swedish society by preventing and managing various risks. MSB's data tool IDA was used for gathering the data, which focuses on statistics regarding accidents, injuries, and rescue operations. Where this study specifically used data from all rescue operations triggered by forest and land fires between 2010 and 2020.

3.2 Luppdata

Luppdata solely contains railway-related information and is used to collect data on punctuality, disturbances, and the railway's status. More specifically, when a train is scheduled to depart and arrive, and the actual time for the departure and arrival. In this thesis, more emphasis was placed on how train traffic was affected by fires. such as delays, the number of trains affected, and the number of fires reported. Luppdata is one of the databases that the Swedish Transport Administration uses.

3.3 Ofelia

Ofelia is a system for reporting railway infrastructure failures. A few examples of what Ofelia includes:

- The area of the facility that was damaged
- What caused the damage
- When the accident was reported and repaired
- What was done to fix it

Ofelia is also one of the databases that the Swedish Transport Administration uses.

3.4 Weather data (SMHI)

The Swedish Meteorological Institute (SMHI) is a government organisation that conducts research in meteorology, hydrology, oceanography, and climatology. With the purpose of forecasting weather, water, and climate changes as well as providing historical information. In this research, SMHI was utilised to investigate past meteorological data such as temperature and precipitation.

3.5 Statistics Sweden (SCB)

Statistics Sweden's purpose is to present Swedish statistics. Some of the information they provided includes population data, counties, municipalities, geographical areas, and other government statistics.

4 Method

As the climate changes, it is interesting to see how railway traffic is currently affected by fires created by various weather occurrences in order to be better prepared for future weather, resulting in this study being performed. To investigate this, the number of rescue operations due to fire was compared to the two databases used by the Swedish Transport Administration. These were compared because if a rescue mission was carried out, it most likely meant that the fire on that occasion was so large that assistance was required, making them more interesting to study. This was accomplished using two alternative approaches, depending on whether the number of matches or the number of delay minutes was calculated. Whereas all of the variables analysed in the three databases were statistics between 2010 and 2020. The book "Examensarbeten att skriva uppdragsbaserade uppsatser och rapporter" by Paulsson (2020) was used as a supplement to current knowledge in report writing throughout the thesis, where concerns about structure and content were studied and applied.

Going through and comparing the databases was the most time-consuming portion of this thesis, which took around 5-7 weeks in total.

4.1 Data from MSB, Ofelia, and Luppdata

The data from MSB was compared to that of Ofelia and Luppdata. This was done to count the total number of railway fires that required rescue operations. Data from each intersection between MSB and the other two databases were analysed to discover if any variable had an effect on the number of matches, and if so, how big of an impact they had. The information obtained included the location of the fire, the date of the fire, and the average precipitation and temperature for the ten days surrounding the date. All these matches were sorted into counties and municipalities to better understand where the fires happened. This enabled observations of the population and land area, introducing two more variables in addition to the temperature and precipitation to examine in order to better understand the distribution of matches. The comparison of all three databases produced 1,337 matches, which were analysed to observe how they were impacted.

4.2 Data from MSB and Luppdata

When calculating delays, only MSB and Luppdata were taken into account. This is due to Ofelia´s absence of information when researching delays. The variables examined were the date of the fire, the location of the fire, the average temperature and precipitation for the five days prior and the five days after the fire, the number of delay minutes and the number of affected trains. These matches were also divided into counties and municipalities to help determine where the delays occurred. This allowed population and land area observations, providing two extra variables in order to better understand the distribution of the delay minutes. The comparison of these two databases produced 621 matches, which were then utilised to investigate the delays.

4.3 Regression model

To determine how much a variable influences or even if a variable influences, a regression analysis was made. The regression analysis works by determining whether or not variables have an impact. This method is useful for determining the relevance of different variables. If more than one variable is counted a multiple regression is performed to see how these variables interact with one another. R-studio was used in this thesis to construct the regressions.

Temperature and precipitation were used as independent variables in this thesis, with the number of matches and the number of delay minutes used as dependent variables, producing two separate regressions.
The regression analysis for the number of matches was the number of observations determined by constructing 7-day intervals between January 1st, 2010 and December 31st, 2020, with the regression only using the 7-day periods that featured one or more matches. Unlike the regression analysis on the number of delay minutes, which included all 621 matches between the two databases as observations.

Table 3: Explanation of what a regression contains.

	Unit	Description
Multiple R-squared	R^2	Tells how strong the linear relationship is. This is scaled from - one to one, with a greater value indicating a stronger relationship.
Adjusted R-squared		If more variables are added the multiple r-squared will always increase. The adjusted R-square adjusts for the number of variables and is better to use for multiple regression.
Standard Error	SE	Shows the precision of your regression analysis by counting on the average distance between the data points and the regression line. A smaller number equals a safer regression.
F-statistic	f	Measures the significance of the overall model where a higher value is better.
P-value	p	A p-value less than 0.05 indicates that the model has statistical significance because the slope is of interest and not equal to zero. If the value exceeds 0.05, another variable should be used instead.
Estimate	β	$\boldsymbol{\beta_0}$ is the value for Y In the formula when X=0. (dependant value) $\boldsymbol{\beta_1}$ is the slope, of the linear regression. (independent values)
T-value	t	Is the estimated value (β) divided by the standard error.

Linear regression equation equals: $Y = \beta_0 + \beta_1 X$

Multi-linear regression equals: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$

Where,
$\beta_1 = slope$
$\beta_0 = intercept\ when\ X = 0$
$Y = vertical\ value$ or the dependant value
$X = the\ independant\ variabels$

Table 4: Variables counted on in the regressions

Variable	What it is	Unit	Data source
Matches	Fires reported on Luppdata or Ofelia on the same day and location that MSB reported a rescue mission	The number of matches	Luppdata, Ofelia, MSB
Delay minutes	The number of delays	Minutes	Luppdata
Temperature	The average temperature of the matches	Degrees in Celsius	Obtained from Luppdata and Ofelia reports, which receive their data from SMHI
Precipitation	The average precipitation of the matches	Millimetre	Obtained from Luppdata and Ofelia reports, which receive their data from SMHI

5 Results

5.1 Number of matches when comparing the three databases

According to MSB statistics, the number of rescue missions performed due to forest and land fires between 2010 and 2020 was 49,528. Statistics from Luppdata and Ofelia show that 1,561 respectively 2,255 fires occurred at the railway during the same time period. A comparison of the number of fires that have occurred on the railway and the number of rescue missions gave 1,337 matches. These are cases where a date and location from Luppdata or Ofelia matches with a rescue mission reported on MSB, and for the sake of simplicity, these will be called "matches" throughout the result section. All of this implies that 2.7% of all forest fires occurred near the railway, where 39.8% of all reported fires in Luppdata and 31.7% of all reported fires on Ofelia matched with MSB. These estimates are reasonable because the majority of fires are not likely to grow to an extent where emergency services are required to contain the fire. However, this has not been confirmed and is merely an educated guess. *Figure 8* depicts this distribution by displaying the number of matches for the individual databases and how they combined results in 1,337 matches.

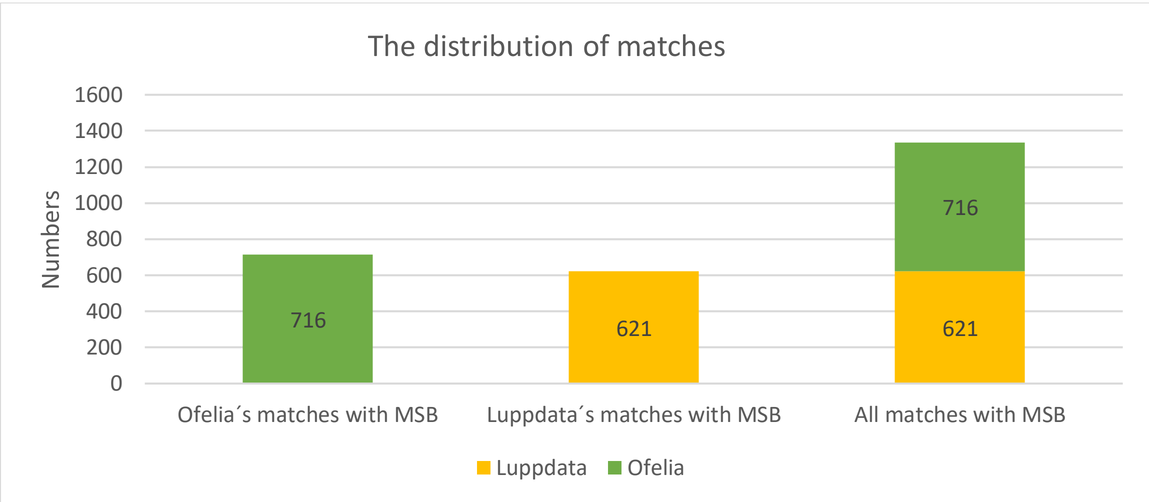

Figure 8: Green was the number of matches between Ofelia and MSB and yellow was the number of matches between Luppdata and MSB, the table on the far right was these results combined value which was equal to 1,337.

Between 2010 and 2020, the average number of matches per year was 121.5. With a peak of 301 in 2018 and a low of 41 in 2012, which represents an 86% difference between the two years. *Figure 9* depicts this as well as the trend curve. This trend curve indicates that the average number of matches has increased from less than 100 to more than 150. However, it should be noted that the excessive number of matches in 2018 increased the angle of the curve.

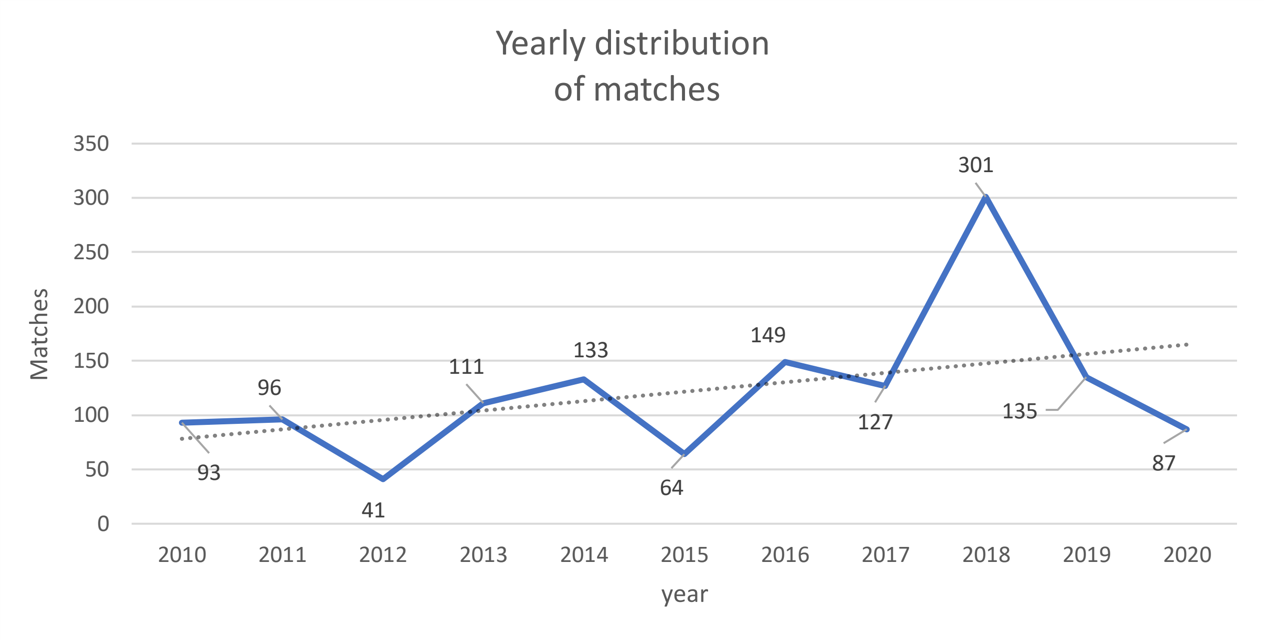

Figure 9: The number of matches annually as well as the trend curve for these values.

Table 5 depicts how the match distribution varied over the months and years between 2010 to 2020. An examination of the matches by month reveals that the four months of April, May, June, and July accounted for 1,130 matches out of 1,337, or around 85%. A more detailed look at *Figure 10*, which depicts the mean temperature and precipitation, reveals that the amount of precipitation is lowest during the month of April, while the second largest temperature increase occurred in May. May was the month which had the highest number of matches, which means that the month with the most matches also was the month with the least amount of precipitation prior to it and the month when the second largest temperature increase happened.

Table 5: Shows the number of matches distributed on an annual and monthly basis.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
January	0	0	0	0	0	1	0	0	3	1	0	5
February	0	0	0	0	0	0	0	0	0	2	0	2
March	0	4	5	1	5	5	6	3	0	5	3	37
April	18	30	4	18	28	16	19	19	16	46	11	225
May	15	32	14	47	31	9	42	49	74	24	29	366
June	17	11	10	19	17	10	40	27	79	21	24	275
July	37	13	3	7	41	11	16	17	101	17	1	264
August	1	5	2	4	8	12	6	9	21	18	17	103
September	2	1	3	11	2	0	15	1	6	1	0	42
October	3	0	0	4	1	0	3	2	1	0	1	15
November	0	0	0	0	0	0	1	0	0	0	1	2
December	0	0	0	0	0	0	1	0	0	0	0	1
Total	93	96	41	111	133	64	149	127	301	135	87	1337

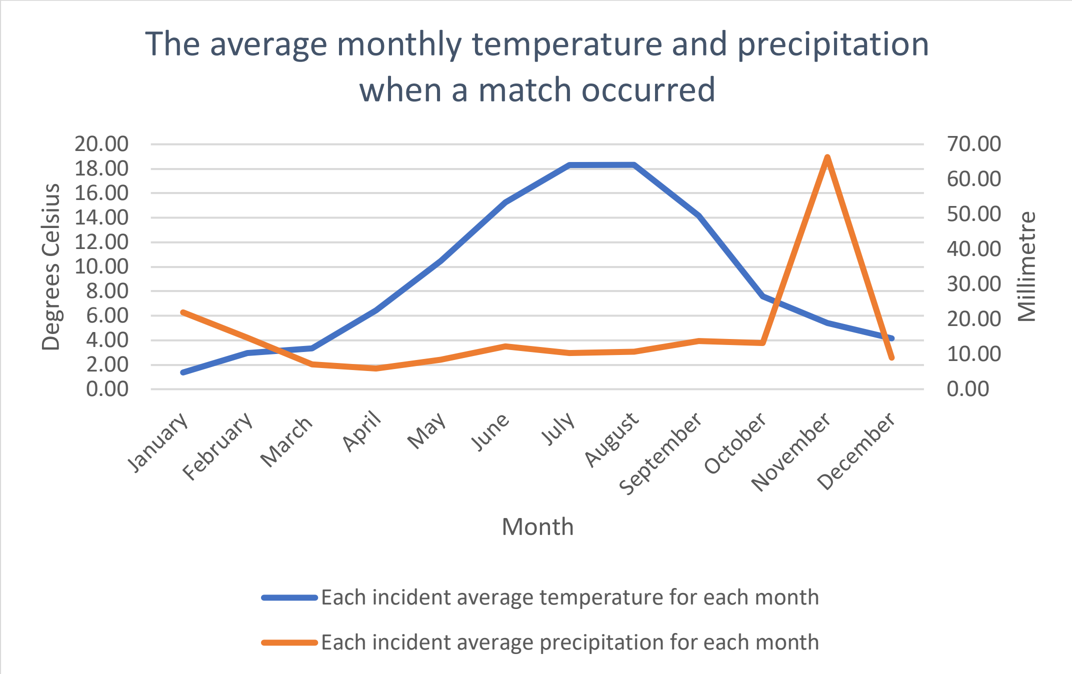

Figure 10: The average precipitation (mm) and average temperature (°C) for all matches, broken down by month between 2010 and 2020.

Because temperature and precipitation vary considerably across Sweden, and only a few matches occurred during specific months, it is critical to look for outliers because fewer observations increase the risk of incorrect values. *Figure 10* illustrates how the month of November stands out in terms of precipitation proportion, with more than three times the amount of rain as the month with the second greatest amount of precipitation, January.

5.2 Number of delays when comparing the two databases

When MSB and Luppdata were compared, 621 matches were identified and *Table 6* shows how these were divided throughout the years. With a high of 157 in 2018 and a low of 15 in 2012. The delay minutes were also spread, with 2018 being the worst year with 71,068 minutes and 2015 having the fewest delay with 1,703.

Over an 11-year period, the average train delay due to fires was fairly consistent, with an average of 19.28 minutes of delay for each train. When the average was compared to the other years, one outliner stood out: 2015. In 2015, the average train arrived 15.04 minutes later than average. compared to 2015 which was the year that was the second farthest away from the average, with a difference of 6.38 minutes.

Table 6: Annual statistics on the consequences of railway fires between 2010 and 2020. Where information regarding the annual distribution of matches, delays, and affected trains can be obtained (Luppdata).

Year	Number of matches	Delays in minutes	Affected trains	Average train delay in minutes
2010	33	4,187	122	34.32
2011	43	6,075	318	19.10
2012	15	4,384	262	16.73
2013	44	30,350	1,839	16.50
2014	60	19,879	1,005	19.78
2015	19	1,703	132	12.90
2016	63	27,555	1,161	23.73
2017	67	10,307	707	14.58
2018	157	71,068	3,245	21.90
2019	68	18,298	1,205	15.19
2020	52	10,015	579	17.30
Average	56.45	18529.18	961.36	19.28

A trend curve between 2010-2020 displayed in *Figure 11* demonstrates how the proportion of delay minutes steadily rises. It should be observed, however, that the extreme year of 2018 amplified this curve.

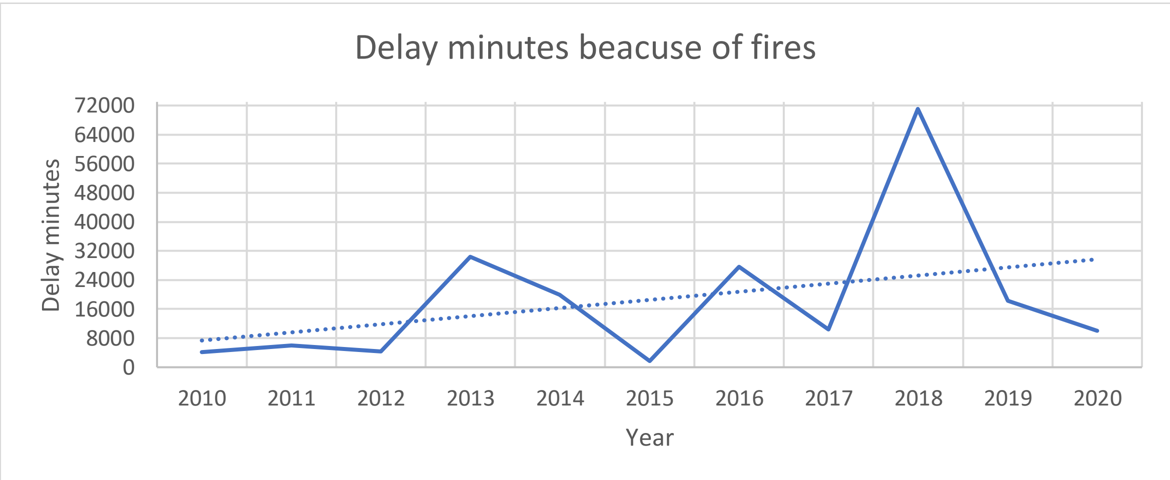

Figure 11: The annual number of delay minutes as well as the trend curve for these values between 2010 and 2020.

Between 2010 and 2020, fires caused a total of 203,821 minutes of delay. The monthly distribution shown in *Table 7* was relatively comparable to the monthly distribution of matches, with the four months of April, May, June, and July accounting for 193,572 minutes, or nearly 95% of the total. In the same period, the average fire delay incident was 152.17 minutes. The four months of April, May, June, and July had a higher average, with the month of July having the longest delays per fire at 502.8 minutes.

Table 7: Displays how each month affects delays. Where information regarding the distribution of matches, delay minutes, and affected trains can be obtained.

Month	Number of matches	Delays in minutes	Affected trains	Average delay on a match in minutes
January	1	28	7	28
February	0	0	0	0
March	17	541	37	31.8
April	108	21,780	1,459	201.7
May	172	64,487	3,737	374.9
June	125	62,848	2,729	502.8
July	116	44,457	1,970	383.3
August	52	6,616	436	127.2
September	20	2,759	162	138.0
October	9	300	37	33.3
November	0	0	0	0
December	1	5	1	5

5.3 The distribution of matches when studying the three databases

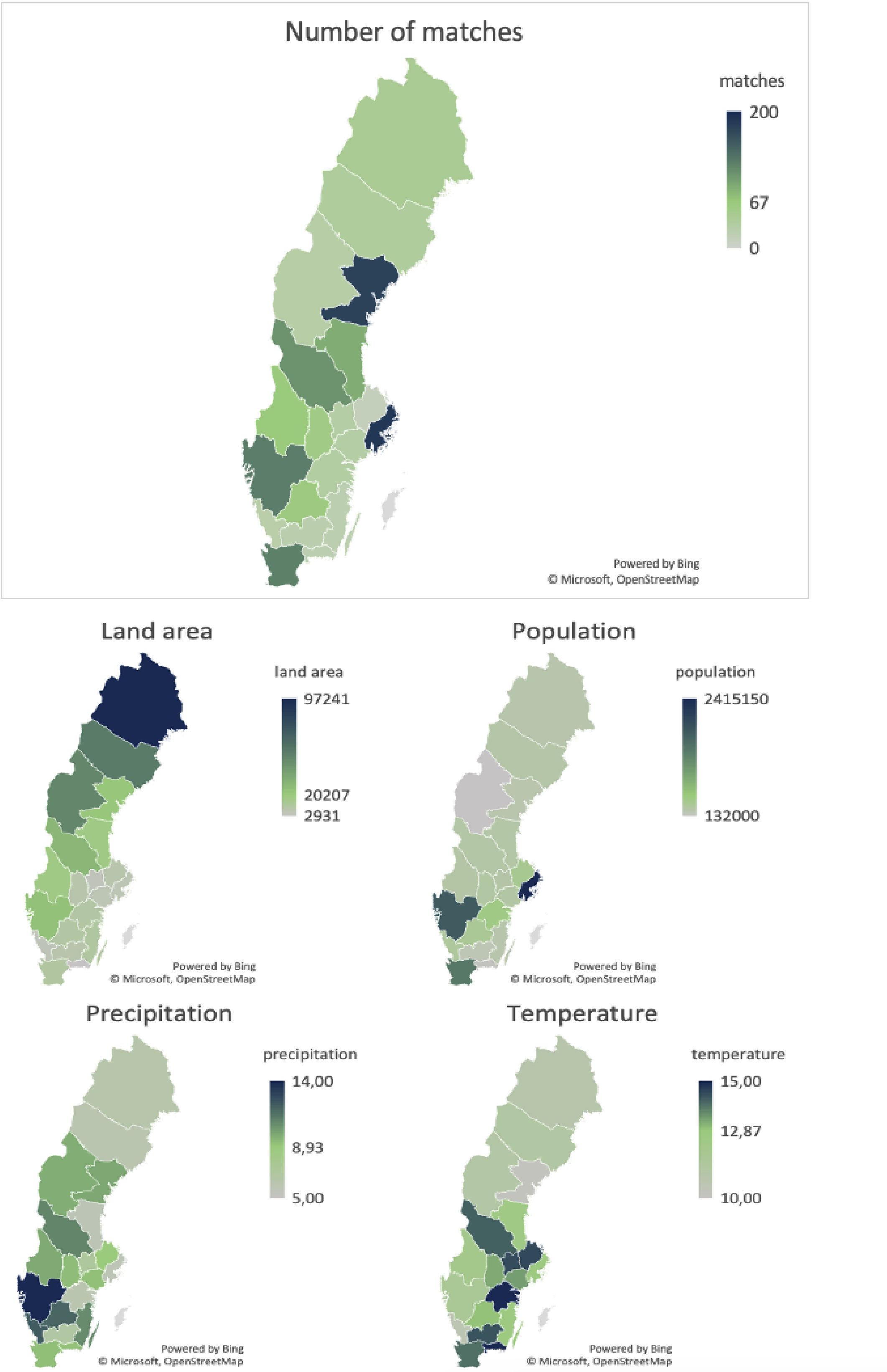

Figure 12: The number of matches, land area (km^2), population, average precipitation (mm) and the average temperature (°C) for each County, where a darker tone equals a higher value.

Figure 12 demonstrates how each variable affects the different counties in Sweden where 20 of the 21 counties had one or more matches. Only the county of Gotland did not have a single match between 2010 and 2020. A comparison of the number of matches to the rest of the maps in *Figure 12,* revealed some similarities in the temperature, precipitation, and population, indicating that they could have had an impact on the number of matches. *Table 8* displays the exact data for what *Figure 12* depicts, According to this table, the five counties with the most matches account for 719, or around 54% of the total.

Where Dalarna County and Skåne County had above-average temperatures, Stockholm County had below-average precipitation, Stockholm County, Västra-Götalands County and Skåne County had above-average populations and Västernorrland County, Västra-Götalands County and Dalarna county had above-average land area. Where the county of Stockholm had the most matches, accounting for 187 out of 1,337, or almost 14%.

Table 8: Exact numbers about the number of matches, average temperature (°C), average precipitation (mm), population and land area for all matches in each county. Statistikmyndigheten:a (n.d.) and Statistikmyndigheten:b (n.d.) were the sources for population and land area.

County	Matches	Average temperature	Average precipitation	Population (2021)	Land area (km^2)
Stockholms län	187	12.63	5.66	2,415,139	6,513.83
Västernorrlands län	176	10.22	9.90	244,193	21,548.49
Västra Götalands län	125	11.75	14.22	1,744,859	23,800.37
Skåne län	123	13.98	9.24	1,402,425	10,965.03
Dalarnas län	108	14.17	10.85	288,387	28,030.15
Gävleborgs län	89	12.48	5.76	287,767	18,113.24
Värmlands län	67	12.23	9.82	283,196	17,519.23
Jönköpings län	63	12.95	11.86	367,064	10,436.45
Örebro län	57	13.25	9.30	306,792	8,503.99
Norrbottens län	47	10.94	6.32	249,693	97,241.89
Västerbottens län	40	11.32	5.98	274,563	54,664.38
Östergötlands län	35	15.35	5.97	469,704	10,557.44
Södermanlands län	33	13.40	9.19	301,801	6,071.83
Västmanlands län	33	14.46	7.08	278,967	5,117.27
Jämtlands län	32	11.17	9.74	132,054	48,935.26
Hallands län	30	10.65	12.19	340,243	5426.6
Kronobergs län	27	14.34	6.78	203,340	8,423.28
Kalmar län	25	12.65	10.71	247,175	1,1159.8
Blekinge län	24	15.00	9.12	158,937	2,931.26
Uppsala län	16	14.50	8.93	395,026	8,189.28
Average	67	12.87	8.93	519,566	20,207

In total 161 municipalities had one or more matches. *Figure 13* depicts the ten municipalities with the most matches. They were responsible for 522 of 1,337 matches, or 39% of all. Stockholm experienced by far the most matches of these ten municipalities, with 124 of them occurring in Stockholm, accounting for around 10% of the total.

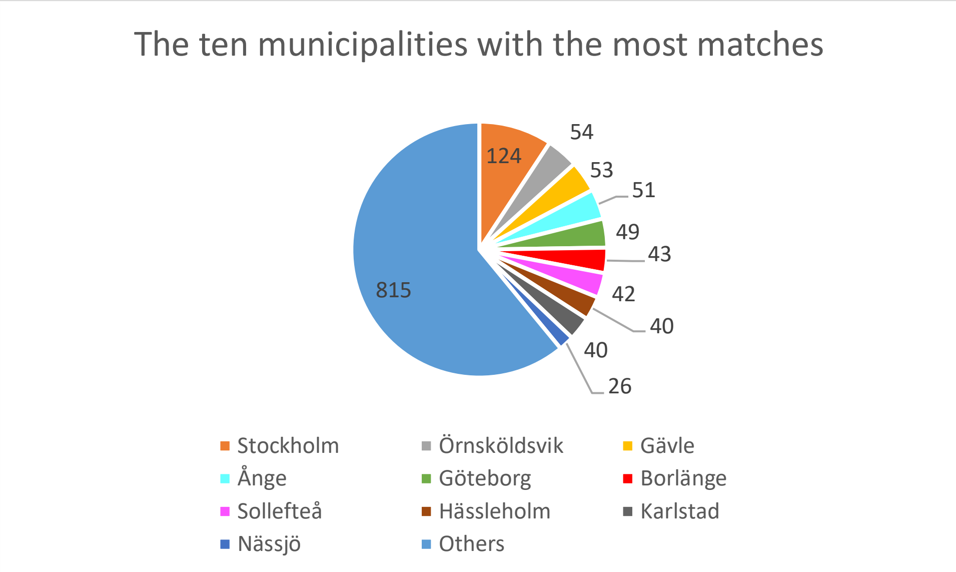

Figure 13: The number of matches in each of the top ten municipalities with the most matches between MSB and Ofelia/ Luppdata.

There were 161 municipalities with one or more matches, a calculated average value for the number of matches, temperature, and precipitation for these 161 municipalities gave an average of 8.3 matches, 12.71 degrees Celsius, and 9.25 millimetres. *Table 9* shows the ten municipalities with the most matches, the ten with the highest average temperature, and the ten with the lowest average precipitation. The average value for each table is determined independently and compared to the average value for all municipalities.

The average value for matches in *Table 9 "A"* was 44.2 greater than the average value for all municipalities (which is shown above), while the average temperature was 0.16 degrees °C lower and the average precipitation was 1.79 mm higher.

Table 9 "B" average values of matches was 6.4 lower than the average value for all municipalities, while the average temperature was 7.16 degrees °C higher and the mean value for precipitation was 0.36 mm lower.

The average value for matches in *Table 9 "C"* was 8.3 lower than the average value for all municipalities, while the average temperature was 2.42 degrees °C higher and the average precipitation was 9.25 mm lower.

Table 9: The ten municipalities with the most number of matches, highest average temperature and the lowest average precipitation between 2010 and 2020.

Municipality	Matches	Average temperature	Average precipitation
A -The top ten municipalities with the most matches			
Stockholm	124	12.89	7.74
Örnsköldsvik	54	11.90	11.12
Gävle	53	9.96	8.59
Ånge	51	11.40	9.58
Göteborg	49	14.25	16.90
Borlänge	43	12.67	8.41
Sollefteå	42	11.61	9.81
Hässleholm	40	15.10	26.36
Karlstad	40	12.88	7.46
Nässjö	26	12.80	4.45
Average	52.2	12.55	11.04
B -Top ten municipalities with the highest average temperature			
Kumla	1	22.73	0.00
Håbo	1	21.51	0.70
Mullsjö	1	19.66	73.00
Gislaved	1	19.53	2.20
Ystad	2	19.40	0.00
Säter	1	19.36	3.10
Ronneby	4	19.34	1.83
Mjölby	3	19.24	3.97
Lomma	2	19.10	3.90
Katrineholm	3	18.80	0.00
Average	1.9	19.87	8.87
C -Top ten municipalities with the lowest average precipitation			
Kumla	1	22.73	0.00
Ystad	2	19.40	0.00
Katrineholm	3	18.80	0.00
Sala	1	18.37	0.00
Boxholm	2	17.69	0.00
Trosa	1	17.34	0.00
Hofors	1	12.00	0.00
Skinnskatteberg	1	11.84	0.00
Jokkmokk	2	7.33	0.00
Svenljunga	1	5.78	0.00
Average	1.5	15.13	0.00

5.4 The distribution of delay minutes when studying the two databases

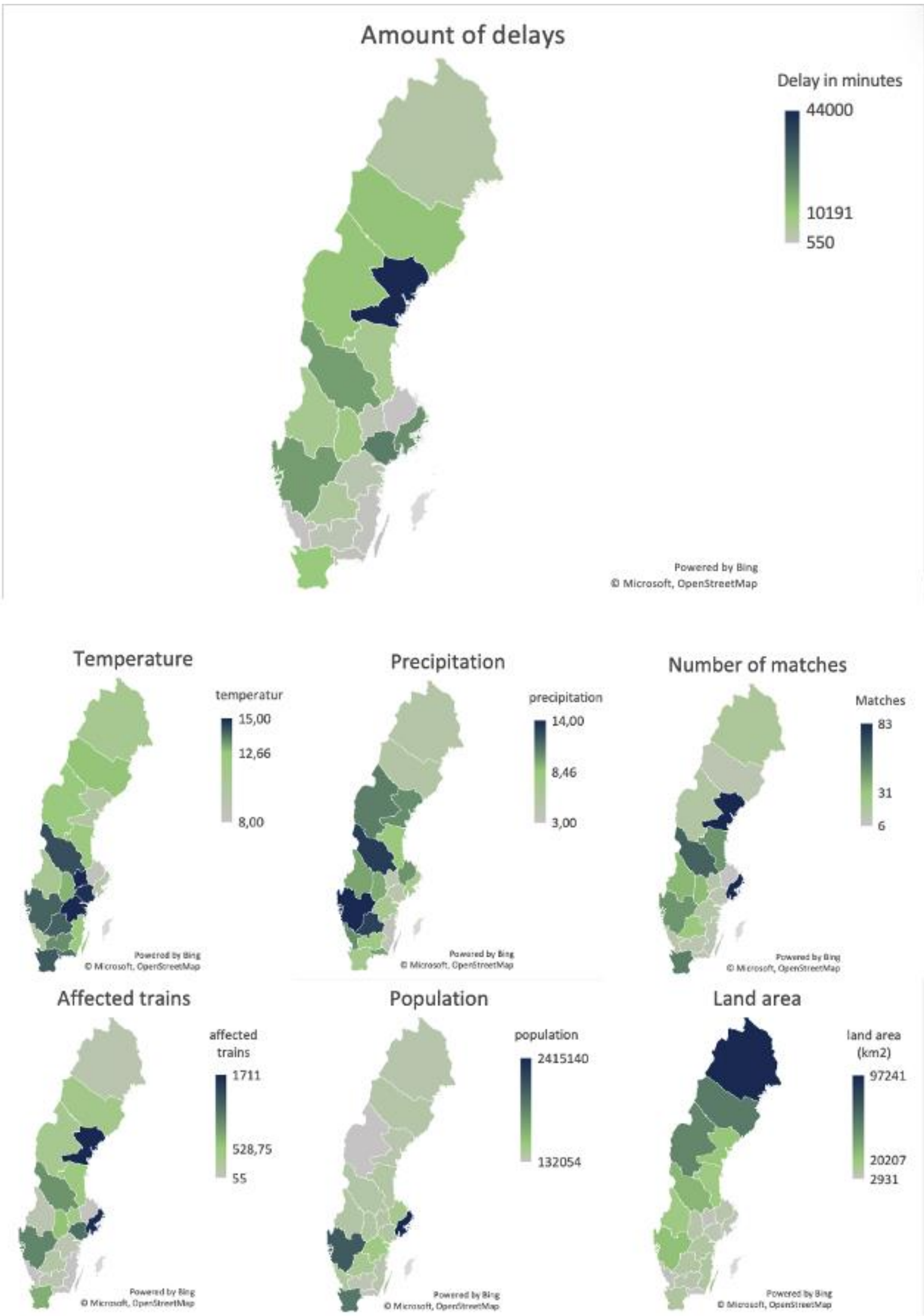

Figure 14: The distribution in each county for the number of delays, average temperature, average precipitation, number of matches, affected trains, population and land area, where a darker tone equals a higher value.

Figure 14 displays the general distribution in the various counties, with a darker tone suggesting that more delay minutes occurred in that county. Because information regarding delay minutes was wanted, the figure for the number of delay minutes was the one with which the other figures were compared to. It was noticeable that the number of affected trains and the number of matches follow the same pattern and that the other figures had no resemblance, but the population figure appears to have the most similarities. *Table 10* displays the exact data for what *Figure 14* depicts, according to this table the five counties with the most delay accounted for 25,298 minutes of delays or 40% of all delays.

Whereas the counties of Västernorrland, Stockholm, Västra-Götaland, and Dalarna had more matches than the national average, Västernorrland, Södermanland, Västra-Götaland, and Dalarna had more delay minutes per train than the national average. Västernorrland, Södermanland, Stockholm, Västra-Götalands, and Dalarna had more affected trains than average, Södermanland, Västra-Götalands, and Dalarna had above-average temperatures, Södermanland and Stockholm had below-average precipitation, and Stockholm and Västra-Götaland had an above-average population. Where the county of Västernorrland experienced the most delays, accounting for 43,912 minutes out of 203,821, or almost 21.5%.

Table 10: Exact numbers about the number of delay minutes, number of matches, affected municipalities, affected trains, average temperature (°C), average precipitation (mm), population and land area for all matches in each county.

County	Delay in minutes	Matches	Average delay for each train	Affected trains	*Average temperature* °C	Average precipitation (mm)	Population	Land area (km^2)
Västernorrlands län	43,912	83	25.66	1,711	9.95	10.31	244,193	21,548.49
Södermanlands län	24,677	12	21.61	1,142	14.86	4.58	301,801	6,071.83
Stockholms län	20,922	83	12.39	1,689	9.40	6.62	2,415,139	6,513.83
Västra Götalands län	18,516	46	18.74	988	14.05	14.24	1,744,859	23,800.37
Dalarnas län	18,464	62	20.89	884	14.34	13.18	288,387	28,030.15
Västerbottens län	11,323	12	27.50	414	12.72	5.09	274,563	54,664.38
Jämtlands län	10,982	17	29.44	373	12.38	10.81	132,054	48,935.26
Skåne län	10,084	53	14.20	710	14.17	6.91	1,402,425	10,965.03
Örebro län	8,400	35	14.66	573	12.94	9.42	306,792	8,503.99
Gävleborgs län	7,340	46	15.42	476	12.31	8.16	287,767	18,113.24
Värmlands län	7,320	36	17.43	420	11.02	9.60	283,196	17,519.23
Jönköpings län	5,551	30	22.16	251	14.08	13.00	367,064	10,436.45
Norrbottens län	4,287	20	24.78	173	11.15	5.02	249,693	97,241.89
Östergötlands län	3,168	16	19.32	164	15.97	6.58	469,704	10,557.44
Kronobergs län	2,477	12	14.49	171	13.44	7.75	203,340	8,423.28
Västmanlands län	2,376	15	14.40	165	15.34	4.25	278,967	5,117.27
Blekinge län	1,631	12	20.14	81	13.84	9.65	158,937	2,931.26
Kalmar län	955	11	17.36	55	12.41	3.60	247,175	11,159.80
Hallands län	846	14	13.22	64	10.34	10.32	340,243	5,426.60
Uppsala län	590	6	8.31	71	8.48	10.13	395,026	8,189.28
Average	10,191.05	31.05	18.61	528.75	12.66	8.46	519,566	20,207.0

There were 130 Swedish municipalities with one or more matches when comparing MSB with Luppdata. A total of 42 of these 130 municipalities experienced an average delay of more than one hour each year due to fire. 29 municipalities experienced more than two hours of delay every year, 25 municipalities experienced more than three hours of delay, 18 municipalities experienced more than four hours of delay, and 12 municipalities experienced more than five hours of delay each year. To identify which municipalities had the most delay minutes, the 12 municipalities with more than five hours per year were displayed in *Figure 15*. The combined delay from these 12 municipalities amounted to 133,624 minutes or 66% of the total 203,821. Which means that 12 municipalities together accounted for two-thirds of all delays during the course of these 11 years. Where Örnsköldsvik was the municipality with the most delay with 23,628 minutes, or almost 400 hours, which represents 12% of the total.

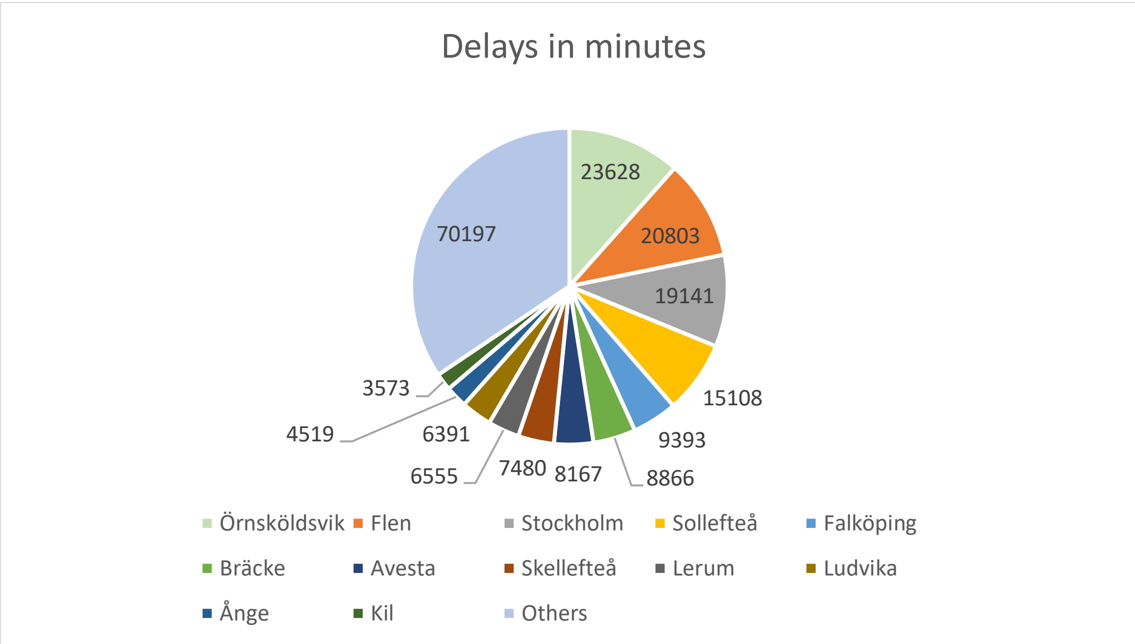

Figure 15: Every municipality that had more than 3300 minutes of delay between 2010 and 2020, which is an annual average of more than 5 hours of delay.

There was no trend in the number of delays and the number of matches in these 130 localities. This is shown in *Table 11* where, for example, Stockholm had an average delay of 348 minutes for each match and Flen had an average delay of 4,160.6 minutes for each match, which is 12 times larger than Stockholm's average.

The average delay for all 130 municipalities was 1,567.9 minutes, the average number of matches was 4.78, the average number of affected trains was 81.3, the average temperature was 12.63 degrees Celsius, and the average precipitation was 9.1mm. The average value for each table was calculated independently and compared to the total average value.

The average value for delay in *Table 11 "A"* was 6,523.5 minutes longer than the average value for all municipalities (which is shown above), while the average number of matches was 19.32 higher, the average number of affected trains was 354.1 higher, the temperature was 0.75 degrees Celsius above average, and the precipitation was 0.11mm above average.

The average delay minutes in *Table 11 "B"* were 10,985.3 greater than the average for all municipalities, the average number of matches was 10.02 higher, the average number of affected trains was 493.6 higher, the temperature was 0.94 degrees Celsius below average, and the precipitation was 2.72 mm below average.

The average delay minutes in *Table 11 "C"* was 10,798.1 greater than the average for all municipalities, the average number of matches was 12.02 higher, the average number of affected trains was 495.1 higher, the temperature was 0.95 degrees Celsius below average, and precipitation was 2.47 mm below average.

Table 11: Different top ten values for the municipalities.

A - The ten municipalities with the most matches

Municipalities	Matches	Delays in minutes	Affected trains	Average delay for each match in minutes	Average delay for each train in minutes	Temperature	Precipitation
Stockholm	55	19,141	1,469	348.0	13.0	12.23	7.54
Borlänge	26	2,041	118	78.5	17.3	12.99	7.69
Gävle	26	1,156	107	44.5	10.8	9.40	8.61
Ånge	25	4,519	281	180.8	16.1	11.46	8.40
Örnsköldsvik	23	23,628	735	1,027.3	32.1	11.55	10.80
Sollefteå	21	15,108	662	719.4	22.8	11.67	5.97
Karlstad	20	1,877	217	93.9	8.6	13.62	7.79
Avesta	18	8,167	403	453.7	20.3	17.57	4.94
Hässleholm	16	2,854	213	178.4	13.4	15.58	22.56
Malmö	11	2,423	149	220.3	16.3	17.73	7.78
Average	24.1	8,091.4	435.4	334.5	17.1	13.38	9.21

B - The ten municipalities with the most delays

Örnsköldsvik	23	23,628	735	1,027.3	32.1	11.55	10.80
Flen	5	20,803	830	4,160.6	25.1	13.20	1.26
Stockholm	55	19,141	1,469	348.0	13.0	12.23	7.54
Sollefteå	21	15,108	662	719.4	22.8	11.67	5.97
Falköping	5	9,393	454	1,878.6	20.7	10.16	7.36
Bräcke	9	8,866	296	985.1	30.0	7.37	11.13
Avesta	18	8,167	403	453.7	20.3	17.57	4.94
Skellefteå	4	7,480	298	1,870.0	25.1	11.57	3.78
Lerum	3	6,555	336	2,185.0	19.5	10.00	5.13
Ludvika	5	6,391	266	1,278.2	24.0	11.62	5.94
Average	14.8	12,553.2	574.9	1,490.6	23.3	11.69	6.38

C - The ten municipalities with the most affected trains

Stockholm	55	19,141	1,469	348.0	13.0	12.23	7.54
Flen	5	20,803	830	4,160.6	25.1	13.20	1.26
Örnsköldsvik	23	23,628	735	1,027.3	32.1	11.55	10.80
Sollefteå	21	15,108	662	719.4	22.8	11.67	5.97
Falköping	5	9,393	454	1,878.6	20.7	10.16	7.36
Avesta	18	8,167	403	453.7	20.3	17.57	4.94
Lerum	3	6,555	336	2,185.0	19.5	10.00	5.13
Skellefteå	4	7,480	298	1,870.0	25.1	11.57	3.78
Bräcke	9	8,866	296	985.1	30.0	7.37	11.13
Ånge	25	4,519	281	180.8	16.1	11.46	8.40
Average	16.8	12,366	576.4	1,380.85	22.47	11.68	6.63

6 Regression

6.1 Regression analysis on the number of matches

A regression composed of different weather effects such as temperature and precipitation was made by comparing the number of fires started around the railway. 7-day intervals from 2010-01-01 to 2020-12-31 were constructed, producing 545 values. Of them, 256 had at least one fire on Luppdata or Ofelia that coincided with a rescue mission on MSB. The regression was performed to see how much of an impact temperature and precipitation had on the number of matches. The first linear regression applied the number of matches to be the dependent variable and the temperature to be the independent variable. This resulted in an F-statistic of (1,254)=12.05 >2.5, which can be considered acceptable and implies that the null hypothesis can be ignored. The p-value was 0.0006084, which is less than 0.05, indicating that the linear regression curve is not zero and that temperature has an effect on the number of matches. The R^2 value was equal to 0.04529, implying that 4.5% of the matches could be explained by the temperature.

Precipitation significance was determined in the same way with 7-day intervals from 2010-01-01 to 2020-12-31 and 256 observations. The dependent variables were the number of matches and the independent variable was an average of the precipitation values for each 7-day period. This gave an F-statistic of (1,254)=16.33 >2.5 which was an acceptable number and the null hypothesis could be ignored. The p-value was equal to 7.057e-05<0.05 which means that the linear curve was not equal to zero, suggesting that precipitation had an effect on the number of matches. R^2 = 0.06041, implying that 6 % of the matches could be explained due to the precipitation.

The multiple regression was made with both the average temperature and the average precipitation for these 7-day periods, where the number of matches remained the dependent variable. This gave an f-statistic of (2,253)=16.16 >2.5 which meant that the null hypothesis could be ignored. The p-value was equal to 2.491e-07 < 0.05 implying that the curve was not equal to zero and by this, imply that the independent factors affected the number of matches. R^2=0.1133 indicated that these independent variables might explain 11% of the matches. However, because this was a multiple regression, adjusted R^2 was calculated instead to provide an amount that is closer to the truth. Adjusted R^2 was equal to 0.1062, implying that the more likely figure for how much the independent variables truly affect was roughly 10.6%.

Table 12: Values of the regression between matches, temperature and precipitation both separately and in multiple regression.

		Estimate	Standard Error	T-value	P-value	R-squared
Regression Temperature	intercept	2.83091	0.76972	3.678	0.000287 ***	
	Temperature	0.20875	0.06013	3.471	0.000608 ***	0.04529
Regression Precipitation	Intercept	6.59429	0.48073	13.717	< 2e-16 ***	
	Precipitation	-0.10380	0.02569	-4.041	7.06e-05 ***	0.06041
Multiple Regression	Intercept	4.09141	0.79650	5.137	5.59e-07 ***	
	Temperature	0.22600	0.05820	3.883	0.000132 ***	
	Precipitation	-0.11035	0.02506	-4.404	1.57e-05 ***	

*Significant code: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < (nothing) < 1*

6.2 Regression on the number of delay minutes

A regression was also performed to examine how the same weather variables impacted the number of delay minutes. 621 objectives were counted between January 1, 2010, and December 31, 2020.

The regression made with the number of delay minutes as the dependent variable and the temperature as the independent variable made on these 621 observations gave an f-statistic equal to $F(1,619) = 0.7036 < 2.5$ which means that the null hypothesis could not be ignored. The p-value = 0.4019 >0.05 which means that the curve was close to or equal to zero and that the temperature does not affect the number of delay minutes. $R^2=0.001135$.

Regression made with the number of delay minutes as the dependent variable and the precipitation as the independent variable made on the same observations gave an f-statistic equal to $F(1,619) = 1.868 < 2.5$ which means that the null hypothesis could not be ignored. The p-value = 0.1722 > 0.05 which means that the curve was close to or equal to zero and that the precipitation does not affect the number of delay minutes. $R^2=0.003009$. No multiple regression was done because the linear regressions for the number of delay minutes had little to no effect.

Table 13: Values for the linear regressions based on the number of delay minutes, temperature, and precipitation.

		Estimate	Standard error	t-value	p-value	R-squared
Linear regression temperature	Intercept	235.754	120.556	1.956	0.051 .	
	Temperature	7.276	8.674	0.839	0.402	0.001135
Linear regression precipitation	Intercept	380.527	62.007	6.137	1.5e-09 ***	
	Precipitation	-5.657	4.139	-1.367	0.172	0.003009

*Significant code: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < (nothing) < 1*

7 Discussion

The railway only runs through a small portion of Sweden's landscape. The number of matches (1,337) is reasonable given the overall number of rescue missions 49,528 for all forest and land fires between 2010 and 2020. When a rescue mission caused by fire is carried out, it signifies that the fire was out of control and that help was needed to put it out. As a result, one-third, or 1,337, of the 3,816 recorded fires by Ofelia and Luppdata required assistance from emergency services to secure the situation. A closer examination of the number of matches between Luppdata and MSB revealed 621 matches out of the total of 1,561 reported fires by Luppdata. This demonstrates that 40% of Luppdata reported fires required rescue mission support. One thing to keep in mind is that matches could have been missed if there were any reporting issues in the Swedish Transport Administration databases. This suggests that more fires may have occurred along the railway, and rescue operations may have been established, despite the fact that they are not depicted in this thesis.

Because more trains are likely to travel where there are more people, and because human activity stood for 95% of all fires, more densely populated areas are likely to encounter more fires. An example of this is the number of people in each county, where Stockholm County had the most population in Sweden in 2021, as well as the highest number of estimated matches. The three counties with populations greater than one million were all at the top of the list with the most matches, with only the County of Västnorrland having a lesser population yet also ranking in the top four. Because the three most populous counties all have a high number of matches, it suggests that a counties population influences how many fires that occur. There was no proof of any factors that could have influenced the number of delay minutes, but it appears that the number of matches, the number of affected trains, and the population probably had an impact. Both the number of matches and the number of affected trains are likely to affect the delays, as a match is required for a train to be delayed, and a train cannot be affected without any delays. However, when the influence of population was examined, it can be seen that the three counties with the most residents were among the top eight with the most delay minutes, indicating that the population had a small impact even though it was not confirmed.

Rising temperatures, changing precipitation patterns, and extended dry periods are all expected in the future, according to the data in SMHI (2023). Where future conditions are determined by which RCP model humanity eventually succeeds in adopting. The results demonstrated that a noticeable percentage (10.6 %) of matches were affected by the temperature and precipitation. As a result, if nothing changes and the climate keeps warming up, more fires are likely to occur in the future, stopping more trains from running and generating additional delays.

This thesis did not discover a trend in the number of delay minutes as the regression produced poor results, and when comparing the values in the graphs and figures, only the number of affected trains and the number of matches were similar. This could be due to the fact that just a limited amount of data was available on this subject, so it cannot be guaranteed that these variables had no effect, merely that they were not shown to have an effect in this study.

Granström (2018) claims that "once a forest fire has grown large, it is generally put out because of weather changes". Because natural elements, rather than humans, currently get hold of the larger fires. This means that if the climate changes, fires that were previously controlled by natural occurrences will no longer be contained and will instead continue to damage. Wind speed and relative humidity have been hypothesised to influence the spread and risk of fires. Because these variables also are predicted to change, the fire spread and risk of fire will most likely also change, affecting further trains and causing additional delays. However, given there was no data on these aspects, this should only be regarded as an educated assumption.

In 2018, fires destroyed the most productive forest land (215,827,102 m^2), accounting for 60% of all productive forest land lost between 2010 and 2020. When MSB was compared to Ofelia and Luppdata, 301 matches occurred in 2018, accounting for 23% of all matches. Luppdata and MSB had 157 matches in 2018, accounting for 25% of all, and there were 71,068 minutes of delay in 2018, accounting for 35% of all delays. So, in 2018, the fires were the most numerous and had the largest impact. Krikken et. al. (2019) provide a terrific explanation for why 2018 was such an intense year. They explain that the weather was abnormally dry and warm during the spring and summer of 2018, which was caused by prolonged air blocking. This caused higher temperatures and limited precipitation in Northwestern Europe, resulting in an extensive number of fires. This could be interpreted as a terrifying example of what the new standard weather relations in Sweden could be if the climate changes for the worse.

Almost 95% of all delay minutes occurred during the same four months as the majority of matches (April, May, June, and July), which is understandable given that a delay requires a match to occur. Temperatures increased the most during these months, while precipitation was scarce prior. As observed in the current study, these conditions encourage more fires, which leads to more matches and more delays. The number of delay minutes that occurred over the course of those four months, on the other hand, is quite intriguing to examine. The fact that 95% of the delays occurred over those four months indicates that something is affecting the number of delays during that time period. According to the data, the amount of precipitation has recently been at its lowest, the temperature rises most during this time, and the relative humidity is at its lowest during early summer. This implies that the weather has an impact, even if this study could not confirm it.

(Wern. 2013) depicts how the average relative humidity varied during the course of a year between 1950 and 2010. It showed that there was a low in May, a slightly higher value in August, and a high in November. These numbers compared to the values obtained in the result made a noticeable pattern appear. It showed that the month with the most matches (366) was May, which also had the lowest relative humidity with an average value of 66%. November had the highest relative humidity at 88% and only two matches happened in that month. August was in the middle, with a relative humidity of 74% and 103 matches. The distinct pattern suggests that relative humidity had a significant impact on the number of matches, although this could not be verified because relative humidity data for the fire occurrences was unknown.

Train delays caused by fires are a very under-researched topic that could benefit from being investigated more. As a result, references to past studies are scarce, and the results could not be compared to similar studies. The landscape of the regions surrounding the railway was also attempted to be discovered. This may have been used to determine the sort of landscape where the fire started. Unfortunately, this could not be found, although it would have been intriguing to investigate further.

8 Further research

It became apparent during the course of the study that the relative humidity seemed to have a significant impact not only on the number of matches but also on how the proportion of delays changes, and therefore appears to be an important aspect to investigate further to get an accurate understanding of the impact.

Because population appears to have an impact on the number of matches and little impact on the number of delay minutes, this aspect could be worth investigating further by studying residents and fires per municipality rather than the county.

This work does not count for the number of passengers on each train, but it would be interesting to know how long each individual would be delayed. The assumption is that more people are located in Stockholm, and hence more people travel by rail than in Sollefteå, which has a smaller population. These two municipalities had a comparable number of delay minutes. Whereas Stockholm almost had twice the number of affected trains. This means that if they had the same number of passengers, twice as many would be affected in Stockholm, while those in Sollefteå were delayed more. However, if the number of passengers in each municipality is not the same, then the delay per person will be substantially different.

It would also have been fascinating to do studies in which the time of day is used as a variable in predicting fire risk. This is due to the fact that temperature and relative humidity change depending on the time of day. The night has cooler temperatures and higher relative humidity, whereas the day has the opposite effect. By studying the time of the fire, a more accurate collection of data can be acquired, and the regression result may differ.

9 Conclusion

Between 2010 and 2020, MSB documented 49,528 rescue missions, Luppdata reported 1,561 fires, and Ofelia reported 2,255 fires. They resulted in a total of 717 matches between MSB and Ofelia, and 621 matches between MSB and Luppdata, for a total of 1,337 matches.

When looking at where the matches occur, the statistic shows that a large percentage of them took place in densely populated areas, with all three counties with more than one million inhabitants (Stockholm, Västra-Götaland and Skåne County) ranking in the top four most matches. There is no explanation stating why densely populated areas are more vulnerable, although it could be related to the fact that humans cause 95% of all forest fires, and if there are more people, there are also more people who can start a fire. Simultaneously, assumptions can be made that there are more trains in these counties, and hence more trains that can be impacted by a fire. When it comes to where the most delay minutes occur, they tend to follow population density to some extent, as the three counties with more than one million inhabitants were in the top eight counties with the most delay minutes. However, no pattern can be identified, and the delays in this thesis have to be viewed as too random to determine where they occur.

The majority of matches occur in late spring and early summer (April to July), with peaks often occurring in May. Temperature and precipitation both have an impact on the number of matches, according to the regression, although these variables do not explain an extensive percentage of the matches. The regression made on delays revealed that temperature and precipitation had no effect on the number of delay minutes. A closer examination of the delay statistics revealed that the population may have had an impact on the number of delay minutes. This, however, could not be confirmed and is instead an assumption based on the fact that the three counties with the biggest population are all in the top eight counties with the most delay minutes.

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