ELECTRIFICATION OF GROUND SUPPORT EQUIPMENT

Thesis

Air Cargo Netherlands

Author: Wessel Mel
Date and location: 31-07-2020 Schiphol
Version: 3.0
Electrification of Ground Support Equipment

The possibilities and effects of electric Ground Support Equipment

Thesis

Author

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wessel Mel</td>
<td>Graduate Student at Air Cargo Netherlands</td>
</tr>
<tr>
<td>Student number</td>
<td>E-mail</td>
</tr>
<tr>
<td>500747284</td>
<td><a href="mailto:Wessel.Mel@hva.nl">Wessel.Mel@hva.nl</a></td>
</tr>
<tr>
<td></td>
<td>Graduation Track</td>
</tr>
<tr>
<td></td>
<td>Aviation Logistics</td>
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Reviewers

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artsie Heuvel</td>
<td>AUAS Thesis Advisor</td>
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Acceptance (by client)

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibility</th>
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<tbody>
<tr>
<td>Artsie Heuvel</td>
<td>AUAS Thesis Advisor</td>
</tr>
<tr>
<td>Ben Radstaak</td>
<td>Director Innovation and Compliance</td>
</tr>
<tr>
<td></td>
<td>Examiner 2</td>
</tr>
</tbody>
</table>

1 Author agrees with the content, did take notice of the review comment and applied it to his/her own insight.
2 Reviewer declared that he reviewed the report on the basis of his expertise and provided the author with comment.
3 The client uses or applies the result of the report, only applicable clients sign.
Preface

This report has been written as part of my graduation thesis internship at Air Cargo Netherlands during my fourth-year bachelor Aviation with the graduation track Aviation Logistics at the Amsterdam University of Applied Sciences. This bachelor focusses on the daily operations of the Aviation industry such as airports, airlines and ground handlers.

During my internship at Air Cargo Netherlands I researched the possibilities and effects of electric ground support equipment for cargo handling. This enabled me to learn more about the use of ground support equipment and its electrical versions.

I would like to thank my company supervisor Ben Radstaak for his support and guidance during my internship. I would also like to thank my university supervisor Artsie Heuvel for his support and guidance during my internship. Finally, I would like to thank the employees and other interns at Air Cargo Netherlands for their support during the internship.

Wessel Mel

Axel, 31-07-2020
Summary
Currently the aviation sector produces +/- 6.5% of the total annual emissions in the Netherlands. In order to meet the goal of a 2°C increase limit of the global warming, which is stated in the Paris Agreement, the aviation sector needs to decrease their emissions. Multiple aviation companies in the Netherlands have published an action plan together called ‘Slim én Duurzaam’ which goal is to reduce CO₂ emissions with 35% in 2030. The successful realisation of this action plan should result in less CO₂ emissions in 2030 than the CO₂ emissions in 2005.

The air freight sector at Amsterdam Airport Schiphol transported 1.57 million tons of cargo in 2019. The airfreight sector also needs to decrease their emissions to help reach the goal that is stated in the action plan. One of the solutions that is mentioned in the action plan is the use of electric alternatives for ground support equipment. This equipment is used for handling the aircraft when it is at the airport. To find out what the possibilities and effects of electric ground support equipment are the following research question has been identified:

“What are the possibilities and (sustainability) effects of electrical ground support equipment at Amsterdam Airport Schiphol?”

To formulate an answer to the mentioned research question above, research was performed. This research included a literature review of the available formulas to calculate emissions of ground support equipment and a review of previously implemented electric ground support equipment at other airports. Also, interviews were conducted with experts from the sector and desk research was performed to get an overview of the currently available electric equipment and its effects.

The main effects of electric ground support equipment are:
- A reduction in emissions, because the electric engine of the equipment does not produce any emissions itself. The only emissions are indirect emissions which are produced during the production of the batteries needed to power the electric engines. Also, the emissions which are produced when generating electricity in a non-green manner, like when burning coal to produce electricity. If the electricity is produced in a green manner, such as using solar panels, the emissions will decrease even further.
- A reduction in maintenance, because electric ground support equipment requires 2.5 times less maintenance than conventional powered equipment. Electric ground support equipment doesn’t require oil changes, cooling system changes, belts or fuel injectors. This also decreases the amount of spare parts that are needed to be kept in stock.
- A reduction in costs, because the total costs during the lifespan of the electric ground support equipment are less than conventional powered equipment. Electric equipment does have a higher initial price than the conventional powered equipment, but because it requires less maintenance and the price of electricity is currently lower than fossil fuel the operational costs are lower than conventional powered equipment.
The possibilities of the researched electric ground support equipment are:
- The lower deck loaders can be replaced by electric lower deck loaders. Electric lower deck loaders are already being used at Amsterdam Airport Schiphol and provide the same lifting capacity as the fossil fueled lower deck loaders and a full day of heavy operations on one battery charge. While there are multiple brands that provide electric lower deck loaders, it is unknown if all of them provide a full day of heavy operations on one battery charge, which means not all available versions might be suitable for use. The TLD TXL-838-reGen is the best suitable option for a full day of heavy operations.
- The main deck loaders can be replaced by electric main deck loaders depending on the lift capacity. There are a few brands who already produce electric main deck loaders with a maximum lifting capacity of 15 ton, which would be enough to lift the maximum weight of a main deck ULD. But it is unknown if the available electric main deck loaders provide the battery capacity to be operated for a full day of heavy operations on one charge.
- The container transporters can be replaced by electric container transporters if the ground handler doesn’t use side loading as standard process. The currently available versions only provide front and rear loading, because battery packs are stationed at both sides of the vehicle. The transporters also provide enough loading capacity for the maximum weight of a lower lobe ULD, but not the maximum weight of a main deck ULD. It is also unknown if the currently available transporters provide enough battery capacity for a full day of heavy operations on one charge.
- The towing tractors can be replaced by electric towing tractors. Electric towing tractors are already being used at Amsterdam Airport Schiphol and provide a maximum towing capacity up to 80 ton depending on the speed driven. It is unknown if the available towing tractors have the capability to be used for a full day of heavy operations on one charge.

Further research could be conducted into the current used equipment at Amsterdam Airport Schiphol. Also, a cost analysis of the available electric ground support equipment could be made. Further, more thorough calculations of the current emissions and the emissions after implementation of the new electric ground support equipment could be made. Finally, research should be conducted into the operating hours of one battery charge during a full day of heavy operations.
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List of Abbreviations

ACN – Air Cargo Netherlands
APU – Auxiliary Power Unit
AUAS – Amsterdam University of Applied Sciences
CO – Carbon Monoxide
CO₂ – Carbon Dioxide
GHG – Greenhouse Gases
GPU – Ground Power Unit
GSE – Ground Support Equipment
HAPs – Hazardous Air Pollutants
HC – Hydrocarbons
kW – Kilowatt
kWh – Kilowatt-hour
NO₂ – Nitrogen Dioxide
NOₓ – Nitrogen Oxides
PM – Particle Matters
1 Introduction
This research has been conducted on behalf of Air Cargo Netherlands (ACN). ACN is the trade association for the air cargo sector in the Netherlands. Their goal is to connect its members with each other and develop the air cargo sector in the Netherlands (Air Cargo Netherlands, 2019).

To support this development of the Dutch air cargo industry, ACN supports projects that benefit the air cargo industry. ACN also represents the interest of their members in different discussions, for example the amount of cargo slots that are handed out at Schiphol. ACN’s members list consists of airports, airlines, ground handlers, freight forwarders, trucking companies and other companies that are involved in the air freight sector. These are just a few of ACN’s main services. ACN also provides compliance support, performs inspections for IATA and organizes conferences.

The current problem is that Schiphol is not allowed to grow. This is due to multiple issues, but one of the largest is the environmental impact of the aviation industry. This impact has to be decreased in order for Schiphol to keep up with the growing demand of air transport including air freight. ACN wants to be the leading player in this issue for the air freight sector which is why research was performed into one of the possible solutions. This possible solution could decrease the environmental impact of air freight.

Chapter 1.1 describes the background of this problem and chapter 1.2 provides the problem statement. The research objective and the research relevance can be found in chapter 1.3 and chapter 1.4 respectively. The main, sub and background research questions can be found in chapter 1.5. The research scope can be found in chapter 1.6 and the thesis structure can be found in chapter 1.7.
1.1 Background of the problem

The Netherlands has to decrease its CO$_2$ emissions with 25% by the end of 2020 compared to 1990 (Hoge Raad, 2019). All sectors need to contribute in order to reach this goal, including the aviation sector. The aviation sector produces +/- 6.5% (CBS, 2018) of the total annual emissions in the Netherlands since the last few years and +/- 2% (Royal Schiphol Group, 2018) of the worldwide emissions on a yearly basis.

Royal Schiphol Group has published a plan called “Slim én Duurzaam” to achieve this goal together with 19 other companies. The goal of this plan is to emit 35% less CO$_2$ in 2030 and should result in less CO$_2$ emissions in 2030 than the CO$_2$ emissions which were measured in 2005. Graph 1 represents a graph of the emissions with and without the implementation of the “Slim en Duurzaam” plan.

![Graph 1](image)

Graph 1 Aviation emissions in the Netherlands (Luchtvaart Nederland, n.d.)

The “Slim én Duurzaam” plan consists of seven themes that will decrease the emissions. These themes are about optimising routes & procedures, stimulating cleaner aircraft, sustainable fuel, radical fleet renewal, other modalities for short distances, efficient first and last miles and emission free airports. (Luchtvaart Nederland, n.d.) (Faber & van Velsen, 2018)
The last one, emission free airports, is the most relatable to the air freight sector. Schiphol has already implemented multiple initiatives to get to the emission free airport (Luchtvaart Nederland, n.d.):

- Schiphol has equipped 74 aircraft stands with installations that deliver 400hz electricity and pre-conditioned air while the aircraft is at the stand for a turn around. This means that the aircraft does not need to use its APU which reduces CO₂ emissions with a maximum of 1,3 ton per hour (Luchtvaart Nederland, n.d.). The aircraft also doesn’t need a GPU, because the electricity for the aircraft is delivered through the aircraft stand. This reduces the CO₂ emissions, if the GPU is fossil fuelled. Schiphol also has started using Electric GPU’s which reduce CO₂ emissions with 90% and NOₓ with 95% compared to the diesel fuelled GPU’s (Royal Schiphol Group, 2019).
- Schiphol has also introduced 35 electric busses on airside to transport passengers from and to a remote stand which has reduced CO₂ emissions with 1,3 million kilos in 2,5 year after it was introduced (Luchtvaart Nederland, n.d.).
- Schiphol has also implemented multiple solutions to decrease their emissions from their buildings. These solutions contain heat and cold storages which lower the gas consumption, sustainable and recycled building materials, and green energy which comes from wind farms in the Netherlands (Luchtvaart Nederland, n.d.)

The planning for an emission free airport is the following, according to the action plan:

- More solar panels and heat and cold storages
- Emission free taxiing to and from the runway
- Electric alternatives for ground support equipment

The solar panels and storage initiative could be implemented in the air freight sector. The air freight sector consists of ground handlers and freight forwarders that use large warehouses. These warehouses could use a large solar roof to induce their own electricity which would mean that they would be completely energy neutral and emission free. Also, the heat and cold storage could be used for cooling/heating the warehouses and areas within the warehouse that require certain temperatures, such as medical storages.

The emission free taxiing concept could be implemented in the air freight sector. Currently there are little to none systems or solutions available that would make it possible to completely taxi emission free with a wide body full freighter aircraft. But the emissions are already being reduced, because the pilot is able to taxi with only one or two engines depending on the aircraft type.

The electric alternatives for ground support equipment is the most applicable to the air cargo sector. Ground handlers are a large part within the air cargo sector and their emissions are mainly from burning fossil fuels with their ground support equipment (ICAO, 2015). These emissions can be reduced by implementing electric ground alternatives that would have the same capabilities as the current equipment and would possibly produce less emissions.

The problem is that it is currently unknown if it would be possible to implement electric ground support equipment alternatives in the current environment at Schiphol. It is also unknown what problems could arise and what the (sustainability) effects would be when this electric ground support equipment would be implemented.
1.2 Problem statement

Based on the previous stated problem, the following problem statement has been defined:

“The CO₂ reduction of 35% in 2030 according to the ‘Slim en Duurzaam’ plan would not be achieved if the ground handlers would keep working with the current ground support equipment as it is the largest CO₂ contributor for ground handlers.”

1.3 Research Objective

The goal of the research is to find out what electric ground support equipment is currently available, what its possibilities would be at Amsterdam Airport Schiphol and what would be the effects if it is implemented at Schiphol. Therefore, it is necessary to map the current situation at Schiphol which is the base for the following research into the effects of implementing the electrical equipment.

This research will be a mixed research of both quantitative and qualitative research. This research will be based on a literature review, interviews and data analysis which makes it a mixed research (Taalwinkel, 2015).

This research will result in this document where the results of this research will be stated and the recommendations for the involved companies can be found. This document will also be handed in as final thesis which will be the graduation product for the AUAS. Besides this, the research will also be summarized and attached to a document that will be a type of air freight appendix to the “Slim én Duurzaam” action plan.

1.4 Research relevance/significance

The research into the implementation of electric equipment is relevant, because the CO₂ emissions of the aviation industry need to decrease. This means that all parties involved need to lower their CO₂ emissions, including the ground handlers. For ground handlers, the fossil fueled ground support equipment is the largest part of their emissions. This equipment needs to be replaced with more sustainable equipment in order to decrease their CO₂ emissions. Electric equipment could be the solution to decrease these emissions, but as of now almost no research has been conducted into the replacement and benefits of this equipment which is why this research is relevant.

1.5 Research questions

This sub-chapter contains the main and sub research questions and background questions which are answered in this research.

1.5.1 Main Research Question

The following main research questions has been identified:

“What are the possibilities and (sustainability) effects of electrical ground support equipment at Amsterdam Airport Schiphol?”
1.5.2 **Sub-Research Questions**
The following sub-research questions have been identified:

1. Has the available electrical ground support equipment the needed capabilities?
2. Is electric ground support equipment already implemented or researched at other airports?
3. What are the effects of electrical ground support equipment?
4. Is electrical equipment commercially viable in comparison with the current ground support equipment?
5. Is the industry willing to use the electrical ground support equipment?

1.5.3 **Background Questions**
The following background questions have been identified:

1. What ground support equipment is currently used?
2. What are the current capabilities of the ground support equipment?
3. How much does the current ground support equipment emit?
4. Which electrical ground support equipment is currently available or in production?

1.6 **Research scope**
The assignment has the possibility to become too big within the timeframe of 20 weeks which is why the project needs to have certain boundaries:
- The project will only focus on electricity as fuel source for ground support equipment. The use of hydrogen or any other alternative fuel source will not be included in this research except the current used types of fuel for comparison with the electrical equipment.
- The types of ground support equipment that will be included in the research are baggage/cargo tractors, lower deck loaders, main deck loaders and container transporters. The equipment that not will be included are ground power units, portable water trucks, lavatory support vehicles, de-icing trucks, passenger steps and pushback tugs. Dollies will only be included in the research for researching the capacities of the baggage/cargo tractors.
- The research will only focus on Amsterdam Airport Schiphol and will exclude Rotterdam The Hague Airport, Lelystad Airport, Maastricht Aachen Airport and Groningen Eelde Airport.

1.7 **Thesis Structure**
This chapter contains the structure of this thesis. The thesis consists of the following elements:

- Introduction
- Literature review
- Methodology
- Results
- Conclusion
- Discussion
- Recommendations
- Implementation plan
- References
- Appendices
2 Review of the Literature

Aviation accounts for about 3% of the European Union’s total greenhouse gas emissions and more than 2% of the global emissions. In 2020, the global annual international aviation emissions were approximately 70% higher than the 2005 global annual international aviation emissions (European Union, 2017). According to ICAO, if the aviation industry doesn’t implement measures the emissions could grow by more than 300% in 2050 (European Union, 2017) (ICAO, n.d.)

In the Paris Agreement a global warming increase limit of 2°C has been set, compared to pre-industrial levels. The aim however is to limit the global warming increase to 1.5°C. These pre-industrial levels are the temperature levels between 1850 and 1900 according to the International Panel on Climate Change (International Panel on Climate Change, 2018). This agreement is the first universal, legally binding global climate change agreement between 190 parties including the EU and its Member States (European Union, 2019). To achieve this goal the aviation industry needs to do their part and also reduce their emissions.

2% to 5% of these aviation emissions are airport related emissions (Bylinsky, 2019). The airport-related emissions consist of the following emission categories:

- Aircraft emissions
- Aircraft handling emissions
- Infrastructure- or stationary-related sources
- Vehicle traffic sources

Aircraft emissions include the following emissions: Aircraft main engine emissions and auxiliary power unit emissions.

Aircraft handling emissions include the following emissions: Ground support equipment emissions, airside traffic, aircraft refueling and aircraft de-icing.

Infrastructure and stationary-related sources include the following emissions: power/heat generating plant, emergency power generator, aircraft maintenance, airport maintenance, fuel, construction activities, fire training, surface de-icing.

Vehicle traffic sources only includes the vehicle traffic on the airport access roads, curbsides, drive-ups and on- or off-site parking lots. (ICAO, 2015)

The previously mentioned term emissions is a collective of multiple types of emissions. The following types of emissions are produced during aircraft handling by ground support equipment according to the National Academies of Sciences, Engineering, and Medicine (National Academies of Sciences, Engineering, and Medicine, 2015):

- Carbon Monoxide (CO)
  Carbon Monoxide is produced due to incomplete fuel combustion.
- Nitrogen Dioxide (NO₂)
  Nitrogen Dioxide is produced due to high temperature/pressure combustion.
- Particulate matter (PM)
- Hydrocarbons (HC)
  Hydrocarbons are also produced due to incomplete fuel combustion
- Hazardous Air Pollutants (HAPs)
  Hazardous Air Pollutants include benzene or naphthalene but can also contain heavy metals such as mercury and chromium.
- Greenhouse Gases (GHGs)
  Greenhouse Gases are produced when burning petroleum-based fuels. Greenhouse Gases are pollutants that are of concern because of their role in climate change and include carbon dioxide (CO₂), methane, etc.
According to ICAO (ICAO, 2015) NOx, HC, CO, PM and CO2 are the types of emissions that are produced during aircraft handling by ground support equipment. Nitrogen Oxides (NOx) is the term for a mix of nitrogen monoxide (NO) and nitrogen dioxide (NO2). NOx is mostly produced during combustion. (RIVM, n.d.)

There are multiple ways to calculate the amount of emissions that are produced during aircraft handling. At Zurich Airport, for example, approximately 5% of their emissions are aircraft handling emissions. These emissions are based on a number of factors:
- Aircraft type
- Airport stand
- Airport APU operations
- Ground support equipment (GSE) operations

Based on these factors, Zurich Airport has created an emission factor table which can be found in Appendix II. This table contains standard values for the amount of NOx, HC, CO, PM, CO2 in kilogram per aircraft group, based on the type of stand and GPU operation. The aircraft groups are split into Large Aircraft, Medium Aircraft, Small Aircraft, Commuter Aircraft, Turboprops, Business Jets, General Aviation Propeller Aircraft and Helicopters. The stands are split into Pier Stands and Open Stands. The stands determine the type of ground support equipment operation that will be performed and what equipment is used. Also, there are values for the use of a GPU. For example, if a Boeing 747 lands at Zurich Airport which is parked at an open stand, the aircraft requires a GPU and the turnaround takes 2 hours. The following emission amounts will be emitted:

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>GPU</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>0.535 kg</td>
<td>2 * 0.06 = 0.12 kg</td>
<td>0.547 kg</td>
</tr>
<tr>
<td>HC</td>
<td>0.046 kg</td>
<td>2 * 0.006 = 0.012 kg</td>
<td>0.058 kg</td>
</tr>
<tr>
<td>CO</td>
<td>0.241 kg</td>
<td>2 * 0.025 = 0.05 kg</td>
<td>0.291 kg</td>
</tr>
<tr>
<td>PM</td>
<td>0.032 kg</td>
<td>2 * 0.003 = 0.006 kg</td>
<td>0.038 kg</td>
</tr>
<tr>
<td>CO2</td>
<td>51,272 kg</td>
<td>2 * 19.51 = 39.02 kg</td>
<td>90,292 kg</td>
</tr>
</tbody>
</table>

ICAO also provides 4 methods to calculate the amount of Ground Support Equipment emissions that are produced (ICAO, 2015).

**Primary Simple Approach**

With this method, no analysis of the GSE fleet and GSE operation is necessary. This method is based on default emissions factors which can be found in Appendix III. These emission factors are multiplied with the number of movements by aircraft category and the building year of the GSE technology. For example, if an airport has 30,000 narrow-body movements, 10,000 wide-body movements and all the equipment was built between 2000 and 2015. The following emissions will be emitted (ICAO, 2015):

<table>
<thead>
<tr>
<th></th>
<th>Narrow-body</th>
<th>Wide-body</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>NOx</td>
<td>30,000 * 0.260 = 7800 kg</td>
<td>10,000 * 0.510 = 5100 kg</td>
<td>12,900 kg</td>
</tr>
<tr>
<td>HC</td>
<td>30,000 * 0.020 = 600 kg</td>
<td>10,000 * 0.045 = 450 kg</td>
<td>1050 kg</td>
</tr>
<tr>
<td>CO</td>
<td>30,000 * 0.100 = 3000 kg</td>
<td>10,000 * 0.225 = 2250 kg</td>
<td>5250 kg</td>
</tr>
<tr>
<td>PM</td>
<td>30,000 * 0.015 = 450 kg</td>
<td>10,000 * 0.030 = 300 kg</td>
<td>750 kg</td>
</tr>
<tr>
<td>CO2</td>
<td>30,000 * 20 = 600,000 kg</td>
<td>10,000 * 48 = 480,000 kg</td>
<td>1,080,000 kg</td>
</tr>
</tbody>
</table>
Secondary Simple Approach
This method is based on the fuel-use data of the GSE at an airport. The emissions are calculated by multiplying the amount of fuel used with the default European emission factor for aircraft handling, which can be found in Appendix IV. For example, if the total amount of diesel fueled used by the GSE is 150,000 kg. The following emissions will be emitted (ICAO, 2015):

Table 3 Example emissions ICAO Secondary Simple Approach

<table>
<thead>
<tr>
<th>Emission type</th>
<th>Amount of emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.0328 * 150,000 = 4920 kg</td>
</tr>
<tr>
<td>HC</td>
<td>0.0034 * 150,000 = 510 kg</td>
</tr>
<tr>
<td>CO</td>
<td>0.0107 * 150,000 = 1605 kg</td>
</tr>
<tr>
<td>PM</td>
<td>0.0021 * 150,000 = 315 kg</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>3.160 * 150,000 = 474,000 kg</td>
</tr>
</tbody>
</table>

Advanced Approach
This method uses the actual operating time or fuel usage during a defined period of time for each type of GSE. The emissions are calculated with the following formula's (ICAO, 2015):

- Emission<sub>Pollutant</sub> [g/GSE] = fuel flow [kg/h] × emission factor<sub>Pollutant</sub> [g/kg fuel] × time [h] (× Deterioration Factor (DF))
- Emission<sub>Pollutant</sub> [g/GSE] = power (size of the engine) [kW] × load [%] × emission factor<sub>Pollutant</sub> [g/kW] × time [h] (× Deterioration Factor (DF))
- Emission<sub>Pollutant</sub> [g/GSE] = fuel flow [kg/a] × emission factor<sub>Pollutant</sub> [g/kg fuel] (x Deterioration Factor (DF))

Note: the deterioration factor is an optional variable in the formula.

For example, if all passenger stairs at the airport, with diesel engines of 95 kW, an emission factor of 6.0 g NO<sub>x</sub>/kWh and a load factor of 25 per cent, total 3500 operating hours, and a deterioration factor of 3 per cent is assumed, the total amount of NO<sub>x</sub> emissions is:

95 kW x 0.25 load factor x 6.00 g/kWh x 3500 hours x 1.03 deterioration factor = 514 kg NO<sub>x</sub>

Sophisticated Approach
This method is almost the same as the advanced approach, the only difference is the time factor in the formulas. The time [h] changes into time<sub>AC-Ops</sub> [h] which is the amount of time that has been spent on the specific activity, such as arrival activities or departing activities. For example, if a passenger stair is operated 10 minutes for a Boeing 737 size aircraft at an open stand upon arrival. The stair has a 45-kW engine, operated at 25 per cent load, with a NO<sub>x</sub> emission factor of 6.0 g/kWh and a deterioration factor of 3 per cent. The total NO<sub>x</sub> of this GSE operation would be (ICAO, 2015):

45 kW x 0.25 load factor x 6.0 g/kWh x 1.03 deterioration factor x (10 minutes * (1 hour / 60 minutes)) = 11.61 g NO<sub>x</sub>

Electric Ground Support Equipment
Electric ground support equipment has been used by American Airlines since 1996 (Smith, 2013). Delta Air Lines has replaced 35 diesel powered ground support equipment units with electric variants (The Center for Transportation and the Environment, 2013). KLM will replace all of their lower deck loaders with electric versions from TLD (Belhamou, 2017). Swissport targets to have a minimum share of 50% of its global fleet to be electric vehicles in 2025 (Swissport International AG, 2019).
Effects

- Charlotte Douglas International Airport implemented 10 battery-powered tugs to replace their old diesel-engine counterparts which reduced the N₂O emissions by 70 tons.
- John Wayne Airport added eTug electric tow tractors and eCart baggage carts to their fleet in 2009. The eCart enables the eTug to be operated 24 hours/day without the need for a stationary charge period. This potentially reduces the number of tractors required, because they don’t need to be parked for charging.
- Lehigh Valley International Airport purchased six hybrid vehicles to replace older, conventional-fuel vehicles. This project is expected to save over 65,000 gallons of fuel and an estimated cost saving of $165,000 annually.
- Delta Air lines replaces their diesel GSE at New York LaGuardia Airport which reduced emissions with 19.2 ton per year.
- Westchester County Airport replaced their gasoline and diesel GSE with electric baggage and aircraft tractors, water trucks and baggage belt loaders which reduced emissions by 330 tons per year and a saving of $240,000 annually in fuel costs.

These are some examples of the effects of implementing electric ground support equipment at an airport. In 2012, approximately 10 percent of the 72,000 GSE units in the United states were electric. This is because of multiple effects such as the operational costs of electric GSE. The operational costs of electric GSE are lower due to the price difference between electricity and fuel. It is also more energy efficient than a fuel engine. Electric vehicles are much quieter and the speed and handling mostly equals or exceeds the conventional fuel powered vehicles. Its maintenance is less than conventional vehicles as it has less parts and no oil changes which results in lower costs, less downtime and less spare parts necessary. One of the down sides of electric GSE is the smaller range and longer downtime for charging. Where a conventional vehicle is fueled quickly, a full charge for an electric vehicle could take 4 to 8 hours (National Academies of Sciences, Engineering, and Medicine, 2012). Solutions such as the eTug with an eCart could provide a solution for this problem, as the eCart can be disconnected when it is empty and the eTug can just connect to a charged eCart or drive on its own set of batteries. (eTug LLC, 2009)

Conclusion

Emissions need to be reduced in order to meet the goals set by the parties involved. This also includes the airport emissions which can be calculated in simple ways with very little information or very thoroughly with very much information. These emissions can be reduced by using electrical ground support equipment which reduces operational costs and emissions.
3 Research Methodology
This chapter will provide information on the methods used during this research. Chapter 3.1 will give insight into the used research types. Chapter 3.2 will describe the set hypothesis. Chapter 3.3 will describe the framework which was used.

3.1 Research Design
To be able to form a correct answer to the questions in chapter 1.5, research needs to be conducted. To guide this, methodologies need to be used. Every sub- and background question has its own method(s) to find the correct answer which can be found in table 4. These methods are described in this chapter.

<table>
<thead>
<tr>
<th>Table 4 Research Methodologies</th>
<th>Sub Questions</th>
<th>Background Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>Desk Research</td>
<td>X X X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>Literature Research</td>
<td>X X X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>Field Research</td>
<td>Interviews</td>
<td>X X</td>
</tr>
</tbody>
</table>

Desk Research
Desk research is collecting secondary data from existing sources. Secondary data is existing information and data that has been collected by others (Krul, 2017). Desk research is very effective. It is often considered as a low-cost technique and it is quick and cheap and most of the basic information could be easily fetched (MSG - Management Study Guide, n.d.).

Desk research is applied to sub questions 1, 3 and 4 and all the background questions, because these questions can be answered by information that is already available or researched. The main information and data that will be used during this desk research is information about the equipment and its capabilities.

Literature Research
“Literature research is a survey of scholarly sources on a specific topic. It provides an overview of the current knowledge, allowing you to identify relevant theories, methods and gaps in existing research. Conducting a literature research involves collecting, evaluating and analyzing publications (such as books and journal articles) that relate to your research question.” (McCombes, 2020)

The literature research is applied to sub questions 2, 3 and background question 3. Sub question 2 is about previous research into the subject of electric ground support equipment at airports, which can be answered by doing literature research into previous research. Sub and background question 3 are about the effects and emissions of the current ground equipment and its electric equivalent. Literature research will provide methods to calculate the effects of the current and the electric ground support equipment.

Field Research
Field research is collecting data in the “field” using observations or interviews. The field in this matter is the place where the subject of your research is taken place. In this research, for instance, the apron where the ground support equipment is used or involved companies. Field research is the opposite of desk research as desk research is focused on already available data and information, where field research is based on data and information that is collected by the researcher (Dingemanse, 2019).

Field research is applied to sub question 5 and background question 1. The information that is gathered from the interviews conducted are used to answer both sub question 5 and background question 1.
3.2 Research Hypothesis

The following hypothesis has been identified before performing the research:

“The implementation of electric ground support equipment decreases emissions and lowers the total costs in comparison with the currently used, fossil fuelled ground support equipment.”

This hypothesis has been set, because other electric driven vehicles consume no fuel and require less maintenance. This means less emissions and lower costs for the owner of the vehicle. Electric ground support equipment is comparable to these which would also mean less emissions and lower costs for the owner of the equipment.

3.3 Framework

This sub-chapter provides information about the different methods that were used during this research. These are the methods for calculating the emissions of the ground support equipment, the interviews that were held with the ground handlers and the structure of the implementation plan.

Emission calculations

The different methods of calculating the emissions are explored in the literature review which can be found in chapter 2. This provides multiple ways of calculating the emissions which are produced by ground support equipment.

During this research only the primary simple approach from ICAO (ICAO, 2015) was used. The other calculations were not performed, because the required data could not be shared or was not available. Also, in order to calculate the emission reduction from implementing electric ground support equipment, the current data of the ground support equipment was needed. But, because this data was not available or could not be shared, no reduction calculations could be made.

Interviews

Interviews were held during this research to receive information which was required for this research and could not be found in any document.

The interviews are based on a list of main questions which contains sub-questions per main questions for more detailed information about the main question. The list of main questions and sub questions can be found in appendix IX.

The interviews were held via digital platforms forms such as Microsoft Teams, Zoom or a normal phone call due to COVID-19. The interviews were held together with other graduate students at ACN in order to efficiently use the available time of the interviewees. The interviews had an approximate duration of an hour to 1.5 hours.

Three interviews were conducted with three of the five ground handlers at Schiphol to retrieve information about their currently used equipment and their willingness regarding the implementation of electric ground support equipment. The information they provided is valid information for this research, because the interviewees are responsible for the ground support equipment of their companies.
Implementation plan
The implementation plan that is attached in chapter 8 is based on the structure of Ms Benders (Benders, 2020). The implementation plan consists out of a SMART goal, the prerequisites, a risk analysis, the activities and the stakeholders involved which follows the same structure as Ms Benders’ structure. The risks, communication plan, budget and organisation are not included into this implementation plan, because the information is unknown.

The goal is set as a SMART goal. A SMART goal can be divided into the following items (Mind Tools, n.d.):
- **Specific:** Create a clear and specific goal;
- **Measurable:** Make it measurable, to keep track of the progress;
- **Achievable:** Make it a realistic goal;
- **Relevant:** Make it relevant, to make it matter;
- **Timebound:** Add a timeframe to have focus and something to work toward;

Also, the DMAIC cycle is used to keep improving the planning and operations of the electric ground support equipment that is being implemented. The DMAIC cycle consists of the following items (Lean Six Sigma Groep, n.d.):
- **Define:** Define the activity;
- **Measure:** Measure relevant data;
- **Analyse:** Analyse the collected data;
- **Improve:** Improve the activity based on the analysed data;
- **Control:** Maintain the improved activity;
4 Results

During 2019, Amsterdam Airport Schiphol processed 496,908 flights at its airport according to the national statistical office, CBS (CBS, 2020). 248,451 of these flights were arrival flights and 248,457 were departure flights. 14,156 of the 496,908 flights were full freighter flights. This means that 2.85%, of all the flights that were processed at Schiphol during 2019, were Full Freighter flights. Although this is a small percentage of the number of flights, these Full Freighter flights carried 54% of the total processed cargo at Amsterdam Airport Schiphol. The other 46% of these flights were carried by passenger flights that carried the cargo in the belly of the aircraft, also known as belly freight (Dutch Plane Spotters, n.d.). In total Schiphol handled 1.57 million tons of cargo which helped maintain their position in the top 5 of European cargo hubs (Royal Schiphol Group, 2020).

The full freighter aircraft are aircraft that are only used to carry cargo from one airport to another airport without any passengers on board. These are mainly aircraft which are purchased as full freighter aircraft from the manufacturer, but it is also possible that an aircraft that was previously used as a passenger aircraft is converted into a full freighter aircraft because it is no longer viable as a passenger aircraft. For example, Boeing offers a conversion program for the Boeing 767-300, the Boeing 747-400 or the Boeing 737-800 (Boeing Commercial Airplanes, n.d.). This program converts used all-passenger aircraft into a full freighter by stripping away all the passenger elements of the aircraft and adding all the full freighter elements to the aircraft which enables the aircraft to be used as a full freighter aircraft. At Schiphol, the most used freighter aircraft in 2019 with 2692 arrivals was the Boeing 777-200 Freighter (777F) aircraft followed by the 747-400F freighter aircraft which had 2192 arrivals. The most used passenger aircraft in 2019 at Schiphol was a Boeing 737-800 with winglets which had 55,196 arrivals (Dutch Plane Spotters, n.d.).

This chapter describes the results of each sub question which are stated in chapter 1.5.2. Chapter 4.1 provides insight in the needed and available equipment for a turn around. Chapter 4.2 describes the effects of electric ground support equipment. Chapter 4.3 provides an insight in the willingness of the ground handlers to implement the electric ground support equipment and what would be the requirements.
4.1 **The equipment**

Chapter 4.1.1 gives an overview of the equipment which is needed to turn around the two most used freighter aircraft at Schiphol Airport and the most used passenger aircraft at Schiphol Airport. Chapter 4.1.2 provides an overview of the equipment, and its specifications.

4.1.1 **Which equipment is needed?**

Every aircraft has its own servicing arrangement which is stated in the Airplane Characteristics for Airport Planning manual. This states the necessary equipment to turn around an aircraft. The Airplane Service Arrangement for the Boeing 777-200 Freighter is pictured below in figure 1.

![Figure 1 777F - Service Arrangement (Boeing Commercial Airplanes, 2015)](image)

According to the Airplane Service Arrangement from Boeing, the Boeing 777F requires the following equipment:
- 1x Tow Tractor,
- 1x Ground Power Unit,
- 1x Access Stairs,
- 1x Lavatory Servicing,
- 1x Air Start,
- 1x Fuel Truck,
- 1x Main Deck Loader,
- 3x Pallet Train,
- 1x Bulk Cargo Loader,
- 1x Bulk Cargo Train,
- 2x Lower Lobe Loader and
- 1x Air Conditioning
The Boeing 747-400F Service Arrangement is pictured below in figure 2.

According to the Airplane Service Arrangement from Boeing, the Boeing 747-400 Freighter requires the following equipment:
- 1x Loading Dock,
- 1x Electrical Service,
- 1x Crew Access Stand,
- 2x Container Loader,
- 1x Container Train,
- 1x Portable Water,
- 2x Fuel Truck,
- 1x Container Transporter,
- 1x Bulk Cargo Loader,
- 1x Bulk Cargo Train,
- 1x Pallet Trailer,
- 1x Main Deck Loader,
- 1x Air Start,
- 1x Air Conditioning,
- 1x Tow Tractor and
- 1x Lavatory Service

The Boeing 737-800 with winglets Service Arrangement is pictured below in figure 3.
According to the Airplane Service Arrangement from Boeing the Boeing 737-800 with winglets requires the following equipment:

- 1x Tow Truck,
- 1x Electrical,
- 1x Galley Truck,
- 2x Baggage Handling,
- 1x Fuel Truck,
- 1x Portable Water,
- 1x Vacuum Lavatory,
- 1x Air Conditioning,
- 1x Pneumatic and
- 1x Forward Airstair

Figure 3 Boeing 737-800 with Winglets Service Arrangement (Boeing Commercial Airplanes, 2013)
The previous mentioned equipment is necessary to perform a turnaround for these aircraft. This research will only focus on the equipment that is necessary to load, unload and transport the cargo from the warehouse to the aircraft and back. In particular the main deck loaders, the lower deck loaders (previously mentioned as lower lobe loader or container loader), the cargo tugs (previously mentioned as cargo train, container train or pallet trailer) and the container transporters.

4.1.2 Which equipment is available?

Schiphol Airport houses five main cargo ground handlers: Dnata, Menzies, Swissport, KLM Ground Services and World Flight Services. These companies are mainly responsible for the handling and transport of cargo at airside. During interviews with three of these companies, Menzies (1, 2020), KLM Ground Services (2, 2020) and World Flight Services (3, 2020), the following list of cargo ground support equipment manufacturers was created: Trepel, Mulag, Charlatte, TLD and Volk. The equipment from these manufacturers is currently being used at Amsterdam Airport Schiphol.

Besides the mentioned companies which are currently being used, JBT Aerotech, Laweco and a list of some smaller manufacturers are listed below. The equipment from all these companies was analysed, because they are the only companies who produce electric high and lower deck loaders, container transporters and/or towing tractors.

Trepel

Trepel is the manufacturer of aircraft tractors, lower deck- and main deck loaders and container transporters. Currently the Trepel Champ 70 and the Trepel Champ 350 are the only used Trepel products at Amsterdam Airport Schiphol (1, 2020).

The Trepel Champ 70 contains a 4-cylinder diesel engine and has a lifting capacity of 7000kg. The Champ 70 is available in three versions the 70S, 70W and 70U. The difference between these versions is the width and length of the vehicle which offers more or less loading area than the other versions or a higher reach of the front platform. The Trepel Champ 70S and the 70W are also available as electric version. This replaces the 4-cylinder diesel engine with 3 electric motors for operating the vehicle. It holds the same amount of lifting capacity and heights as the diesel versions. The Trepel Champ 70 can only be used as a lower deck loader. The Trepel Champ 350 also contains a 4-cylinder diesel engine and has a lifting capacity of 35,000 kg. The Champ 350 is only available in the standard version and can be used as main- and lower deck loader. (TREPEL Airport Equipment GmbH, n.d.)

Trepel also offers container transporter, but these are currently not available as electric version or being used at Schiphol.
Mulag
Mulag is the manufacturer of towing tractors, conveyor belt vehicles and container transporters. Currently, the Mulag towing tractors are used for pulling cargo dollies (container dollies) across the apron and the container transporters are used for moving containers from one point to another point at Amsterdam Airport Schiphol.

The towing tractors currently available are from the type Comet and have all different specifications. Every Comet has the same name structure. For example, the Comet 3D: Comet is the type, 3 is the approximate dead weight in tonnes namely 3500 kg and D is the type of drive in this case Diesel. The Comet 3E, has a dead weight of 3700 kg and has an electric drive. The Comet 4FC uses a fuel cell as drive which is a chemical reaction of hydrogen and oxygen which generates electricity (MULAG Fahrzeugwerk, n.d.). All the available versions are in table 5 below:

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Trailing Load (ton)</th>
<th>Dead weight (approximately in kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comet 3D</td>
<td>Diesel</td>
<td>8.6 (at 30 km/h) 26 (at 6 km/h)</td>
<td>3500</td>
</tr>
<tr>
<td>Comet 3E</td>
<td>Electric</td>
<td>8.6 (at 30 km/h) 26 (at 6 km/h)</td>
<td>3700</td>
</tr>
<tr>
<td>Comet 4D</td>
<td>Diesel</td>
<td>11.5 (at 30 km/h) 35 (at 6 km/h)</td>
<td>4000</td>
</tr>
<tr>
<td>Comet 4E</td>
<td>Electric</td>
<td>11.5 (at 30 km/h) 35 (at 6 km/h)</td>
<td>4470</td>
</tr>
<tr>
<td>Comet 4FC</td>
<td>Fuel cell</td>
<td>11.5 (at 30 km/h) 30 (at reduced speed)</td>
<td>4200</td>
</tr>
<tr>
<td>Comet 6D</td>
<td>Diesel</td>
<td>17.2 (at 30 km/h) 50 (at 6 km/h)</td>
<td>6000</td>
</tr>
<tr>
<td>Comet 6E</td>
<td>Electric</td>
<td>17.2 (at 30 km/h) 50 (at 6 km/h)</td>
<td>6700</td>
</tr>
<tr>
<td>Comet 8D</td>
<td>Diesel</td>
<td>23 (at 30 km/h) 70 (at 6 km/h)</td>
<td>8000</td>
</tr>
<tr>
<td>Comet 12D</td>
<td>Diesel</td>
<td>34.4 (at 30 km/h) 100 (at 6 km/h)</td>
<td>12,000</td>
</tr>
</tbody>
</table>
Mulag also offers container transporters from the type Pulsar. All the types have the possibility to load and unload pallets from the front and the rear, but the Pulsar 7SL also has the possibility to load and unload pallets from the left- or right side of the vehicle depending on the steering configuration. The Pulsar 7SL also has the ability to drive sideways which makes it a very versatile machine (MULAG Fahrzeugwerk, n.d.). The other specifications are mentioned in table 6 below:

Table 6 Mulag Overview Container Transporters (MULAG Fahrzeugwerk, n.d.)

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Load capacity (kg)</th>
<th>Pallet size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsar 7D</td>
<td>Diesel</td>
<td>7000</td>
<td>All types of LD and MD pallets up to a size of 96&quot; x 125&quot;</td>
</tr>
<tr>
<td>Pulsar 7E</td>
<td>Electric</td>
<td>7000</td>
<td>All types of LD and MD pallets up to a size of 96&quot; x 125&quot;</td>
</tr>
<tr>
<td>Pulsar 7SL</td>
<td>Diesel</td>
<td>7000</td>
<td>All types of LD and MD pallets up to a size of 96&quot; x 125&quot;</td>
</tr>
<tr>
<td>Pulsar 14D</td>
<td>Diesel</td>
<td>14,000</td>
<td>All types of LD and MD pallets up to a size of 96&quot; x 125&quot; (special cargo up to 5460 mm(196”))</td>
</tr>
</tbody>
</table>

Charlatte
Charlatte is the manufacturer of towing tractors and belt loaders. Charlatte’s towing tractors are currently being used and tested at Amsterdam Airport Schiphol (3, 2020). The specifications of the available towing tractors are stated below in table 7:

Table 7 Charlatte Overview Towing Tractors (CHARLATTE MANUTENTION, n.d.)

<table>
<thead>
<tr>
<th>Type</th>
<th>Drive</th>
<th>Pulling Capacity (Ton)</th>
<th>Speed for the maximum pulling configuration (Loaded/Unloaded in km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE206</td>
<td>Electric</td>
<td>6 – 7</td>
<td>7/14</td>
</tr>
<tr>
<td>TE206 NEO</td>
<td>Electric</td>
<td>6 – 7</td>
<td>7/14</td>
</tr>
<tr>
<td>TE208</td>
<td>Electric</td>
<td>8 – 10</td>
<td>5/14</td>
</tr>
<tr>
<td>T135 EVO</td>
<td>Electric</td>
<td>20 – 25 – 30</td>
<td>9/25</td>
</tr>
<tr>
<td>TE225L</td>
<td>Electric</td>
<td>25 – 30</td>
<td>9/25</td>
</tr>
<tr>
<td>TE425</td>
<td>Electric</td>
<td>20</td>
<td>11/25</td>
</tr>
<tr>
<td>TD225</td>
<td>Diesel</td>
<td>20 – 25 – 30</td>
<td>9/25</td>
</tr>
<tr>
<td>TG225</td>
<td>LPG</td>
<td>20 – 25 – 30</td>
<td>9/25</td>
</tr>
</tbody>
</table>
TLD
TLD is the manufacturer of aircraft tractors, lower- and main deck loaders, air starters, ground power units, passenger steps, belt loaders, air conditioners, container transporters, towing tractors, lavatory and water trucks, trailers and dollies, catering trucks and maintenance platforms. Currently lower- and main deck loaders from TLD are being used at Amsterdam Airport Schiphol (2, 2020).
TLD has a wide range of loaders available which can be found below in table 8:

Table 8 TLD Overview Loaders (TLD-Group, 2018)

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Drive</th>
<th>Deck</th>
<th>Available width (cm)</th>
<th>Lifting Capacity (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TXL-838</td>
<td>TXL-838-STD</td>
<td>Diesel</td>
<td>Lower</td>
<td>-</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-WID</td>
<td>Diesel</td>
<td>Lower</td>
<td>178/254/356</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-UNI</td>
<td>Diesel</td>
<td>Lower/Main</td>
<td>178/254/356</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-SUP</td>
<td>Diesel</td>
<td>Lower/Main</td>
<td>178/254/356</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-STD-reGen</td>
<td>Electric</td>
<td>Lower</td>
<td>-</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-WID-reGen</td>
<td>Electric</td>
<td>Lower</td>
<td>178/254/356</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-UNI-reGen</td>
<td>Electric</td>
<td>Lower/Main</td>
<td>178/254/356</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>TXL-838-SUP-reGen</td>
<td>Electric</td>
<td>Lower/Main</td>
<td>178/254/356</td>
<td>7.6</td>
</tr>
<tr>
<td>TXL-737</td>
<td>TXL-737</td>
<td>Diesel</td>
<td>Lower</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TXL-737-E</td>
<td>Electric</td>
<td>Lower</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TXL-929</td>
<td>TXL-929</td>
<td>Diesel</td>
<td>Lower/Main</td>
<td>178/254/356</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>TXL-929-S</td>
<td>Diesel</td>
<td>Lower/Main</td>
<td>178/254/356</td>
<td>20</td>
</tr>
<tr>
<td>TXL-121</td>
<td>TXL-121</td>
<td>Diesel</td>
<td>Lower/Main</td>
<td>254/356</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>TXL-121-S</td>
<td>Diesel</td>
<td>Lower/Main</td>
<td>254/356</td>
<td>36</td>
</tr>
</tbody>
</table>
TLD also offers multiple container transporters which can be found below in table 9:

Table 9 TLD Overview Container Transporters (TLD-Group, 2018)

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Load Capacity (Ton)</th>
<th>Lift Capability</th>
<th>Loading sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>TF-7-GR</td>
<td>Diesel</td>
<td>7</td>
<td>No</td>
<td>Front/Rear</td>
</tr>
<tr>
<td>TFE-3.5</td>
<td>Diesel</td>
<td>3.5</td>
<td>Yes</td>
<td>Front/Rear</td>
</tr>
<tr>
<td>TF-10-FTC</td>
<td>Diesel</td>
<td>10</td>
<td>No</td>
<td>Front/Side/Rear</td>
</tr>
<tr>
<td>TF-20-GR</td>
<td>Diesel</td>
<td>20</td>
<td>No</td>
<td>Front/Rear</td>
</tr>
<tr>
<td>TFE-7-GR</td>
<td>Diesel</td>
<td>7</td>
<td>Yes</td>
<td>Front/Rear</td>
</tr>
</tbody>
</table>

TLD also offers multiple towing tractors which can be found below in table 10:

Table 10 TLD Overview Towing Tractor (TLD-Group, 2018)

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Drawbar pull (daN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JCT-60</td>
<td>Diesel</td>
<td>4500</td>
</tr>
<tr>
<td>JST-20</td>
<td>Diesel/Gasoline</td>
<td>2000</td>
</tr>
<tr>
<td>JST-25</td>
<td>Diesel/Gasoline</td>
<td>2500</td>
</tr>
<tr>
<td>JST-30</td>
<td>Diesel/Gasoline</td>
<td>2800</td>
</tr>
<tr>
<td>JET-16</td>
<td>Electric</td>
<td>1600 – 2000</td>
</tr>
</tbody>
</table>

Volk

Volk is the manufacturer of towing tractors for airport or industry use. Volk's towing tractors are currently being used at Amsterdam Airport Schiphol (2, 2020). All of the towing tractors that Volk currently has available are powered by an electric drive and its specifications can be found below in table 11:

Table 11 Volk Overview Towing Tractors (VOLK Fahrzeugbau GmbH, 2020)

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Towing capacity (ton)</th>
<th>Cabin</th>
<th>Max. battery capacity (V/Ah)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFZ 6 K</td>
<td>Electric</td>
<td>6</td>
<td>No</td>
<td>24 / 920</td>
</tr>
<tr>
<td>EFZ 8 K</td>
<td>Electric</td>
<td>8</td>
<td>No</td>
<td>24 / 920</td>
</tr>
<tr>
<td>EFZ 10 K</td>
<td>Electric</td>
<td>10</td>
<td>No</td>
<td>24 / 920</td>
</tr>
<tr>
<td>EFZ 12 K</td>
<td>Electric</td>
<td>12</td>
<td>No</td>
<td>48 / 750</td>
</tr>
<tr>
<td>EFZ 20 K</td>
<td>Electric</td>
<td>20</td>
<td>No</td>
<td>48 / 750</td>
</tr>
<tr>
<td>EFZ 20 N</td>
<td>Electric</td>
<td>20</td>
<td>Yes</td>
<td>80 / 930</td>
</tr>
<tr>
<td>EFZ 25 N</td>
<td>Electric</td>
<td>25</td>
<td>Yes</td>
<td>80 / 930</td>
</tr>
<tr>
<td>EFZ 30 K</td>
<td>Electric</td>
<td>30</td>
<td>No</td>
<td>80 / 560</td>
</tr>
<tr>
<td>EFZ 30 N</td>
<td>Electric</td>
<td>30</td>
<td>Yes</td>
<td>80 / 750</td>
</tr>
<tr>
<td>EFZ 30 NT</td>
<td>Electric</td>
<td>30</td>
<td>Yes</td>
<td>80 / 750</td>
</tr>
<tr>
<td>EFZ 30 NT LR</td>
<td>Electric</td>
<td>30</td>
<td>Yes</td>
<td>80 / 1240</td>
</tr>
<tr>
<td>EFZ 30 NT ULR</td>
<td>Electric</td>
<td>30</td>
<td>Yes</td>
<td>80 / 1395</td>
</tr>
<tr>
<td>EFZ 30 NT ULRLi</td>
<td>Electric (Lithium-Ion)</td>
<td>30</td>
<td>Yes</td>
<td>86 / 835</td>
</tr>
<tr>
<td>EFZ 80 N Cargo</td>
<td>Electric</td>
<td>80</td>
<td>Yes</td>
<td>80 / 1550</td>
</tr>
</tbody>
</table>
JBT Aerotech
JBT is the manufacturer of lower- and main deck loaders, pushback trucks, deicing vehicles, ground power units, preconditioned air units, passenger steps and container transporters. The specifications of the lower- and main deck loaders can be found below in table 12:

Table 12 JBT Overview Loaders (JBT Aerotech, n.d.)

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Drive</th>
<th>Deck</th>
<th>Available width (cm)</th>
<th>Lifting Capacity (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranger</td>
<td>Standard / Wide / Universal</td>
<td>Diesel</td>
<td>Lower</td>
<td>98 inch / 127 inch / -</td>
<td>7</td>
</tr>
<tr>
<td>15E</td>
<td>Electric</td>
<td></td>
<td>Lower</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Commander</td>
<td>15i</td>
<td>Diesel</td>
<td>Lower</td>
<td>249 (STD) / 325 (Wide) / 325 (UNI)</td>
<td>7.05</td>
</tr>
<tr>
<td>30i</td>
<td>Diesel</td>
<td>Lower / Main</td>
<td>325</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>40i</td>
<td>Diesel</td>
<td>Lower / Main</td>
<td>325</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>60i</td>
<td>Diesel</td>
<td>Lower / Main</td>
<td>325</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>30i E</td>
<td>Electric</td>
<td>Lower / Main</td>
<td>325</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

JBT also manufactures container transporters which specifications can be found below in table 13:

Table 13 JBT Overview Container Transporters (JBT Aerotech, n.d.)

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Load Capacity (Ton)</th>
<th>Lift Capability</th>
<th>Loading sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPT-7</td>
<td>Diesel or Electric</td>
<td>7</td>
<td>No</td>
<td>Front / Rear</td>
</tr>
<tr>
<td>CLT-8</td>
<td>Diesel</td>
<td>3.63</td>
<td>Yes</td>
<td>Front / Rear</td>
</tr>
</tbody>
</table>

Laweco
Laweco is the manufacturer of lower- and main deck loaders and container transporters. The specifications of the available lower- and main deck loaders can be found in table 14 below:

Table 14 Laweco Overview Loaders (Laweco, n.d.)

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Drive</th>
<th>Deck</th>
<th>Available width (cm)</th>
<th>Lifting Capacity (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo Master CML 7</td>
<td>Standard</td>
<td>Diesel or Electric</td>
<td>Lower</td>
<td>248</td>
<td>7</td>
</tr>
<tr>
<td>Wide</td>
<td>Diesel or Electric</td>
<td>Lower</td>
<td>326</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Universal</td>
<td>Diesel or Electric</td>
<td>Lower / Main</td>
<td>326</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Cargo Master CML 14</td>
<td>Diesel</td>
<td>Lower / Main</td>
<td>340</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Cargo Master CML 35</td>
<td>Diesel</td>
<td>Lower / Main</td>
<td>340</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
Laweco also produces container transporters which specifications can be found in table 15 below:

Table 15 Laweco Overview Transporters (Laweco, n.d.)

<table>
<thead>
<tr>
<th>Product</th>
<th>Drive</th>
<th>Load Capacity (Ton)</th>
<th>Lift Capability</th>
<th>Loading sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMT 7</td>
<td>Diesel</td>
<td>7</td>
<td>No</td>
<td>Front / Rear</td>
</tr>
<tr>
<td>CMLT 3.7 – 3.6</td>
<td>Diesel or Electric</td>
<td>3.7</td>
<td>Yes</td>
<td>Front / Rear</td>
</tr>
</tbody>
</table>

Below, in table 16, a list can be found of some smaller manufacturers who also produce electric towing tractors.

Table 16 Others Overview Towing Tractors (Goldhofer, n.d.) (Harlan Global, n.d.) (Harlan Global, n.d.) (Textron GSE, n.d.) (Eagle Tugs, n.d.) (Bradshaw, n.d.) (Jungheinrich, n.d.)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type</th>
<th>Towing capacity (Ton)</th>
<th>Battery capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldhofer</td>
<td>&gt;&gt;Sherpa&lt;&lt; E</td>
<td>80</td>
<td>400V Lithium-ion</td>
</tr>
<tr>
<td>Harlan</td>
<td>Charger Electric HLE</td>
<td>2/2.3/2.7</td>
<td>80V</td>
</tr>
<tr>
<td></td>
<td>Trans-Con HTSBEL</td>
<td>1.4/1.8/2.3/2.7</td>
<td>300-500 amp/hour</td>
</tr>
<tr>
<td>Textron GSE</td>
<td>TUG M7</td>
<td>2</td>
<td>80V</td>
</tr>
<tr>
<td>Eagle</td>
<td>MTT-5</td>
<td>2.3</td>
<td>80V</td>
</tr>
<tr>
<td>Bradshaw</td>
<td>T2500</td>
<td>25</td>
<td>80V</td>
</tr>
<tr>
<td>Jungheinrich</td>
<td>EZS 7280</td>
<td>28</td>
<td>80V</td>
</tr>
</tbody>
</table>

Regulations and requirements
Schiphol’s regulations state the following rules at airside (HSE Office/DVD, 2019):
- A speeding limit of 30 km/hour at the peripheral roads and on the platform
- A speeding limit of 15 km/hour when driving downwards for vehicles with a trailing load, such as towing tractors with dolly’s
- A maximum length of 30 meter including the towing tractor and/or five or six dollies depending on the dolly dimensions.

To provide insight into the towing capacity requirements of the towing tractors the following calculations were made based on the Schiphol regulations mentioned above and dolly specifications of S-P-S international (S-P-S International, n.d.):
- A five foot dolly has a maximum loading capacity of 1600kg and has an average weight of 835kg. If the towing tractor would need to tow six five foot dollies with the maximum loading capacity, this would require a towing tractor which is capable of pulling approximately 15,000kg.
- A ten foot dolly has a maximum loading capacity of 6800kg and has an average weight of 1295kg. If the towing tractor would need to tow five ten foot dollies (because of the length limit of 30 meter) with the maximum loading capacity, this would require a towing tractor which is capable of pulling approximately 40,000kg.
- A twenty foot dolly has a maximum loading capacity between 14,000kg and 26,000kg depending on the type and an average weight of 3150kg. If the towing tractor would need to pull two twenty foot dollies with the maximum loading capacity, this would require a towing tractor which is capable of pulling approximately 58,500kg.
The required lifting capacity of the lower and main deck loaders and the loading capacity of the container transporters can be based on the maximum gross weight of the ULD’s and pallets which can be found in appendix V:

- The maximum gross weight of a lower lobe ULD which can be loaded with a lower deck loader is 6033kg. This would mean that the lower deck loaders’ maximum lifting requirement would be 6033kg.
- The maximum gross weight of a main deck ULD which can be loaded with a main deck loader is 11,340kg. This would require a maximum lifting capacity of 11,340kg for the main deck loaders.
- If the maximum gross weight of a main deck ULD would be 11,340kg, this would mean that the container transporter would also need to have a maximum loading capacity of 11,340kg. But if the ground handler decides to only transport smaller ULD’s, a maximum loading capacity of 6033kg would suffice.

No statements can be made about the operating hours of the battery, because the electricity consumption during operations is unknown.

4.2 What are the effects?

Chapter 4.2.1 gives an insight in the emission effects of electric ground support equipment and chapter 4.2.2 describes the cost and maintenance effects of electric ground support equipment.

4.2.1 Emissions

As stated in the literature review, the global warming increase needs to be limited to 2°C. This requires every industry worldwide to make changes to their work processes to help reach this goal. This also includes the aviation industry. Airlines, airports, ground handlers, etc. worldwide are implementing solutions to decrease the amount of emissions they emit into the air. Ground handling is an important airport-related emissions source (ICAO, 2015), which is why ground handlers are replacing their fossil fueled ground support equipment with electric powered ground support equipment.

Currently, most of the ground handlers at Amsterdam Airport Schiphol are still using fossil fueled ground support equipment (1, 2020) (2, 2020) (3, 2020). A general calculation of the emissions, that were emitted by the ground support equipment in 2019, was made and can be found in table 18.

Note, this is a very simple and not really accurate calculation, because no data was available to perform a more thorough calculation of the 2019 or previous years ground support equipment emissions. This calculation also includes the emissions from other ground service equipment besides the lower- and main deck loaders, towing tractors and container transporters. Finally, this calculation assumes that all the equipment is fossil fueled and not electric.

To calculate the current emissions, the primary simple approach from ICAO is used which was described in the literature review in chapter 2. This approach is based on the number of narrow-body movements and the number of wide-body movements during 2019. After an analysis of the movements of 2019, which can be found in the introduction of chapter 4, (Dutch Plane Spotters, n.d.), the conclusion is that 82% of the total movements were narrow-body movements and 18% were wide-body movements. A movement is a take-off or a landing at an airport (Eurocontrol, 2016).

For this approach, the number of cycles is required to calculate the emissions. One cycle is a landing and take-off of one aircraft (Law Insider, n.d.). This number is required, because it represents the number of aircraft that were handled.

According to the CBS (CBS, 2020), the number of cycles during 2019 was 248,448. This means approximately 203,727 of these arrivals were narrow body aircraft and 44,721 of these arrivals were wide body aircraft. The following default emissions values per aircraft cycle from ICAO (ICAO, 2015) were used for the calculations:
Table 17 Default Emission Values (ICAO, 2015)

<table>
<thead>
<tr>
<th>Type</th>
<th>Narrow-Body (kg/cycle)</th>
<th>Wide-Body (kg/cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>0.260</td>
<td>0.510</td>
</tr>
<tr>
<td>HC</td>
<td>0.020</td>
<td>0.045</td>
</tr>
<tr>
<td>CO</td>
<td>0.100</td>
<td>0.225</td>
</tr>
<tr>
<td>PM</td>
<td>0.015</td>
<td>0.030</td>
</tr>
<tr>
<td>CO2</td>
<td>20</td>
<td>48</td>
</tr>
</tbody>
</table>

The following calculations were made based on the primary simple approach from ICAO which is explained in further detail in chapter 2:

Table 18 Emissions Ground Support Equipment Schiphol 2019

<table>
<thead>
<tr>
<th>Type</th>
<th>Narrow-Body (kg)</th>
<th>Wide-Body (kg)</th>
<th>Total (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>203.727 * 0.260 = 52.969,02</td>
<td>44.721 * 0.510 = 22.807,71</td>
<td>75.776,73</td>
</tr>
<tr>
<td>HC</td>
<td>203.727 * 0.020 = 4074,54</td>
<td>44.721 * 0.045 = 2012,45</td>
<td>6086,99</td>
</tr>
<tr>
<td>CO</td>
<td>203.727 * 0.100 = 20.372,70</td>
<td>44.721 * 0.225 = 10.062,23</td>
<td>30.434,93</td>
</tr>
<tr>
<td>PM</td>
<td>203.727 * 0.015 = 3055,91</td>
<td>44.721 * 0.030 = 1341,63</td>
<td>4397,54</td>
</tr>
<tr>
<td>CO2</td>
<td>203.727 * 20 = 4.074,540,00</td>
<td>44.721 * 48 = 2.146,608,00</td>
<td>6.221,148,00</td>
</tr>
</tbody>
</table>

The calculated emission values are a rough estimate, due to the lack of data for more thorough calculations. These emissions can be lowered with the implementation of electric ground support equipment, because:

- Electrical ground support equipment doesn’t emit emissions when the engine is running, because there is no internal combustion which produces emissions. An electric engine is powered by battery packs. These battery packs provide electricity to the electric engine which uses the electricity to make the vehicle move. (U.S. Department of Energy, n.d.)

- The battery packs itself don’t produce any emissions when they are connected to the vehicle’s engine, but the process of making these battery packs does produce emissions. There are two types of battery packs which are mostly used in electric ground support equipment, Lead-Acid battery packs and Lithium-Ion battery packs. Also, when a battery pack needs to be replaced the battery pack is recycled which also produces emissions, but the emissions from manufacturing and recycling these battery packs is much smaller than the emissions that are produced when fossil fueled ground support equipment is used. (The International Council On Clean Transportation, 2018)

- If a fossil fueled ground support equipment unit is empty it can be filled with diesel or gasoline and it is on its way again. For an electric ground support equipment unit this is different, this unit needs to be driven to an empty charging station where it is connected to a charging station. This charging station is connected to the electrical grid which is powered by an electricity plant somewhere in the country. This electricity plant produces its own electricity which also produces emissions. This means that when a ground support equipment unit is charging it is indirectly producing emissions. These emissions that are produced, when electricity is produced, can be decreased by connecting the electrical grid to solar panel fields. These panels turn sunlight into electricity which doesn’t produce any emissions. Amsterdam Airport Schiphol already connected its electrical grid to such a field in 2012 which contains an area of 3000 m² (Royal Schiphol Group, 2012).
4.2.2 Costs & Maintenance

Alternative-fuelled ground support equipment usually has a higher initial cost than conventional fuelled ground support equipment. This higher initial cost is due to the fact that the technology that is used in the ground support equipment is fairly new, which makes it more expensive to manufacture, implement and purchase. (National Academies of Sciences, Engineering, and Medicine, 2012)

One of the other factors that indirectly comes from using electric ground support equipment is the availability of charging stations. Charging stations are necessary around Amsterdam Airport Schiphol to charge the ground support equipment to full power, allowing the equipment to be used again for operations. Currently, 660 charging stations are available around Schiphol (Royal Schiphol Group, 2020) and in 2025 the goal is to have 900 charging stations available around the airport (2, 2020). These charging stations are necessary to help the growth of the electrical ground support equipment that will be used at Schiphol, but they also come with costs. Schiphol has to change its infrastructure in such a way that every time a piece of equipment needs to be recharged, a charging station is available to charge the piece of equipment. Schiphol is more than willing to accommodate the charging stations as it heavily stimulates ground handlers to use electric ground support equipment. (Royal Schiphol Group, 2020)

Currently, all driving conventional fuelled equipment at Amsterdam Airport Schiphol is filled at a large facility with the necessary fuel. The driver has to drive his vehicle to the facility, tank the vehicle and drive back to the workspace where he has to work. The stationary equipment is tanked by a large truck that drives around the airport to tank all this equipment when it is almost empty. (1, 2020)

Electrical ground support equipment would be charged in multiple ways. If it is driving equipment, for instance baggage tractors, they would drive to the charging station, connect the vehicle to the charging station and take another vehicle that is already charged. The stationary equipment, for instance a ground power unit, would need to be towed to the charging stations in order for them to be charged. This would require more equipment in order for the operation to continue, because the equipment would be not be available for several hours because it has to charge.

The initial costs of the electric ground support equipment may be higher than the conventional fuelled ground support equipment, but the total costs after a certain period of time would be much lower. The fuel costs would be much lower, because electricity is cheaper to purchase than fossil fuels. Also, the maintenance costs are much lower with electric ground support equipment in contrast to fossil fuelled equipment.

As mentioned, electrical ground support equipment has lower maintenance costs compared to diesel equipment. The electric equipment doesn’t require oil changes or refilling, replacing or flushing of the cooling systems. It also doesn’t require changing belts, spark plugs, fuel injectors or emission testing. This means that the electric equipment also does not need a large inventory of spare parts that need to be kept in stock in case something breaks down. The brake pads on the equipment also require less changes, because electrical engines use regenerative braking. Regenerative braking converts kinetic energy that is induced when braking into electricity which is again stored into the battery packs of the equipment.
There is a downside to the maintenance of electric ground support equipment. The average work it takes to maintain the equipment, depending on the type of equipment, can be 65% to 70% higher than the maintenance that is performed on a fossil fuelled piece of equipment. But on the other hand, a fossil fuelled piece of equipment needs to be maintained 2.5 times more than an electric piece of equipment which makes the maintenance costs of electric ground support equipment less than fossil fuelled equipment. (National Academies of Sciences, Engineering, and Medicine, 2012)

The costs and benefits of implementing electric ground support equipment are presented below in table 19.

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher initial costs</td>
<td></td>
<td>Less emissions</td>
</tr>
<tr>
<td>Charging stations</td>
<td></td>
<td>Less maintenance required</td>
</tr>
<tr>
<td>Longer down time due to charging</td>
<td></td>
<td>Lower maintenance costs</td>
</tr>
<tr>
<td>Changed infrastructure</td>
<td></td>
<td>Lower fuel costs</td>
</tr>
<tr>
<td>Longer down time for maintenance</td>
<td></td>
<td>Less stock parts</td>
</tr>
</tbody>
</table>

4.3 Is the industry willing to use electric ground support equipment?

In order for electrical ground support equipment to be implemented at Amsterdam Airport Schiphol. There needs to be willingness and acceptance from the ground handlers who are going to use the electric ground support equipment. In the interviews that were conducted with KLM ground services, Worldwide Flight Services and Menzies, two main requirements were stated. These requirements are based on the answers they gave during the interviews. The requirements are:

- The electric ground support equipment needs to be operationally feasible. The equipment needs to have the same or better capabilities than the currently used equipment.
- The electric ground support equipment needs to be commercially viable. The initial costs of purchasing the equipment and the operational costs, such as purchased electricity and maintenance, combined needs to be lower than the currently used equipment.
Capabilities
Lower- and main deck loader
Lower- and main deck loaders are loaders that are used for loading and unloading cargo that is placed into pallets or containers, which are being stored in the cargo hold of an aircraft. The loaders consist out of two platforms which can be raised and lowered in order for the cargo to be lifted to the correct height of the cargo hold door. The cargo is placed on the back platform of the loader which is raised to the level of the front platform. This front platform is raised, depending on the aircraft, to the door of the cargo hold which can be on the lower deck or the main deck. The cargo is moved by a built-in roller system which moves the cargo across the platforms into the cargo hold of the aircraft.

The lower deck loaders can be used for loading and unloading the lower decks of narrow- and wide body aircraft. The lower deck loaders also have the capability to load and unload the main deck of narrow body aircraft such as the Boeing 737, if the loaders have the correct width and height specifications.

The main deck loaders can be used for loading and unloading the lower and main decks of both narrow- and wide body aircraft.

Currently, KLM ground services and Menzies are using 7 tons lower deck loaders for their operations. KLM ground services already uses electric lower deck loaders. The results from the tests, that were performed with these loaders, were good which is why KLM ground services chose to completely renew their lower deck loader fleet with electric versions. (2, 2020) Menzies is still using the 7 tons diesel versions for their operations. 35 tons main deck loaders are used by Menzies (1, 2020), but it is unknown which main deck loaders are being used by KLM ground services.

As researched in chapter 3.1.2, electrical lower- and main deck loaders are available for operations. All of the available electric loaders are diesel versions which are refitted and remodeled to be used with an electric engine and battery pack. This allows the electric versions to have the same lifting capacities as the fossil fueled versions.

All the manufacturers who produce lower deck loaders offer electric versions, but only JBT Aerotech and Laweco offer electric main deck loaders which are capable of handling the main deck of wide body aircraft. Both the JBT and Laweco version also offer the same lifting capacity as their diesel equivalent, but it is unknown what the operating time of these machines is on one charge.

According to TLD, their TXL-838-reGen is the only battery powered loader that represents a one for one replacement of a diesel loader (Airside International, 2018). It features a patented technology which was created by TLD. It uses energy that is claimed during the lowering of the platform which then is reused to supplement the battery during its next lift. This results in a two to three times longer battery life between charges which gives the vehicle the capability to handle a full day of heavy operations and a handling capacity of more than 250 containers before the vehicle needs to be recharged. No information could be retrieved regarding the battery life of the other manufacturers’ loaders.
Container Transporters

Container transporters are vehicles which are used for transporting Unit Load Devices (ULD). These ULD’s can be containers or pallets depending on the cargo it is carrying. There are two different functions these container transporters are used for (1, 2020) (2, 2020):
- Transporting ULD’s from the warehouse to the aircraft and back
- Transporting ULD’s from a dolly to the aircraft and back

ULD’s are loaded in the warehouse of the respective ground handler. A container transporter can be used to transport the ULD from the warehouse to the aircraft where a loader is loading the aircraft. The container transporter uses a built-in rolling system to move the ULD’s from the loader onto the back platform of the loader. It can also be used to retrieve a ULD from the loader and transport it back to the warehouse where it is unloaded. ULD’s can also be transported to a dolly which is placed somewhere at airside by a towing tractor or from a dolly to the aircraft. ULD’s all have different weights and measurements which specifications can be found in appendix V.

Currently, no electric container transporters are used at Amsterdam Airport Schiphol for transporting ULD’s from one point to another. This is because electric transporters are currently not available with side loading and unloading options. This is due to the fact that these sides are used to store the battery packs to power the transporter during their operations (2, 2020). This side loading is necessary, because the transporters can come alongside the dolly, retrieve the cargo with side loading and drive to the loader where the cargo is unloaded from the front of the transporter.

The maximum load capacity of a lower lobe ULD is 6033kg which is stated in chapter 4.1.2. The maximum load capacity of the currently available is 7 ton. The maximum load capacity of a main deck ULD is 11,340kg. The available electric transporters would be able to transporters the lower lobe ULD’s, but not the main deck ULD’s. This makes it dependable on the aircraft which needs to be loaded and with types of ULD need to be loaded into the aircraft.

Towing Tractors

Towing tractors are also known as cargo dollies or cargo tugs. These tractors are the vehicles that drive dolly trains (multiple dollies connected to each other) around airside which are loaded with cargo. These tractors have almost the same two functions as the transporters and they have a third function:
- The tractors are used to transport the dollies from the warehouse to the aircraft and back.
- The tractors are used to transport dollies from the warehouse to airside and back.
- The tractors are used to transport dollies from airside to the aircraft and back.

The tractors transport dollies from the warehouse to the aircraft where the dollies are lined up with the loader which loads the ULD’s from the dollies into the aircraft. It also works the other way around where the dollies are loaded with ULD’s from the aircraft. The dollies are then transported to the warehouse or a place on airside where the dolly train is disconnected and picked up by another tractor.

These dolly trains can weigh up to 58,500kg as stated in chapter 4.1.2. This would require the towing tractor to have a pulling capability of 58,500kg. Electric towing tractors are available that can pull this amount of weight, but this is depended on the speed they drive. The amount of pulling capacity the tractor would need is depended on the total weight of the dollies and their load. The exact models that are available can be found in chapter 4.1.2. Also, KLM has already replaced their fossil fueled MULAG tractors with electric powered VOLK tractors which have an approximate battery life of six hours (2, 2020).
Conclusion

In this thesis, an answer to the following main research question has been researched:

“What are the possibilities and (sustainability) effects of electrical ground support equipment at Amsterdam Airport Schiphol?”

The electrical ground support equipment is limited to the lower- and main deck cargo loaders, the container transporters and the towing tractors. These types of equipment all have different conclusions when it comes to their possibilities.

- The available electric lower deck loaders can be used for daily cargo loading and unloading operations, but this is depended on the company which manufactures them. TLD, currently, produces the only version that has the proven capability to be used daily for the heavy operations without having to recharge the battery. This version, the TXL-838-reGen, is already being used at Amsterdam Airport Schiphol. The other companies do provide electrical lower deck loaders, but these lower deck loaders don’t have the proven battery capacity needed to be used daily for heavy operations which means it is unknown if they need to be recharged during the operation. In regard to the lifting capacity, all the available loaders do have the same lifting capacity as the available diesel loaders.

The available electric main deck loaders can be used for daily cargo loading and unloading operations. The available main deck loaders batteries don’t have the proven capacity to be used all day for heavy operations which means they might need to be recharged during the day. The available main deck loaders do provide the same lifting height as a diesel version, but the maximum lifting capacity that can be reached with an electric main deck loader is 15 ton which would be enough to lift the maximum gross weight of a main deck ULD.

- The container transporters are available as electric versions, but it is unknown if they capability to perform heavy daily operation without having to recharge. The available electric versions are currently not being used due to the lack of side loading capabilities on the container transporters which is currently being used by the ground handlers. The sides currently provide storage for the battery packs. The available electric versions would have the loading capacity for all lower lobe ULD’s, but the main deck ULD’s could only be transported if they have maximum weight of 7 ton.

- The towing tractors are available as electric versions, but it is unknown if they provide the capability to perform a full day of heavy operations on one charge. The maximum towing capacity of an electric version is 80 ton which is a little bit less than the maximum towing capacity of the heaviest diesel versions which is 100 ton, but it would be able to pull the maximum weight of a dolly train which would be 58,500kg. This would require the towing tractor to drive at a slower speed then allowed, but it would be possible.

The main effects of electrical ground support equipment are:

- A reduction in emissions, because the electrical ground support equipment itself doesn’t emit any emissions. The only emissions that are produced are indirect emissions which are produced during the production of the batteries and the generation of electricity which is needed to charge the equipment.

- A reduction in costs, because the total costs during the lifespan of the electrical equipment are lower than the costs of conventional powered equipment. The initial cost of electric equipment is higher than the conventional powered equipment, but the costs of maintenance and fuel is lower. Maintenance is less and less spare parts need to be kept in stock and the price of diesel is currently higher than the price of electricity.

The stated hypothesis, “The implementation of electric ground support equipment decreases emissions and lowers the total costs in comparison with the currently used fossil fuelled ground support equipment.” in chapter 3.2 is in line with the conclusion above and results in an accepted hypothesis.
Discussion

The conducted research of in this thesis provides insight in the possibilities and (sustainability) effects of electric ground support equipment. For this research, literature was reviewed and interviews were conducted. The literature was based on official documents from, for instance, ICAO (ICAO, 2015) and the National Academies of Sciences, Engineering and Medicine (National Academies of Sciences, Engineering, and Medicine, 2015). These are accredited sources which are valid sources for this research. Also, the interviews that were conducted are with people who work in the air cargo industry who can provide valid information about this research.

The result of the first sub research question was that some of the researched equipment can be replaced by an electric version. The goal was to first access the current situation and analyse the currently used types and brands. Based on this information, the needed capabilities could be stated. Then research would be conducted into which electric ground support equipment is available and what its capabilities are. These electric capabilities would then be compared to the needed capabilities that were stated earlier and the research question could have been answered. Due to COVID-19, very little information could be retrieved about the currently used vehicles and its capabilities. No observations could be made on which equipment was used and its capabilities. Also, no information about the operating hours on one battery charge during a full day of heavy operations could be retrieved which is needed to compare to the operating time of the current equipment.

The results of the second sub research question are stated in the literature review and provide insight in the results of implementation of electric ground support equipment at other airports. The other airports are used to provide insight in the results of implementing electric ground support equipment and the effects of implementing this equipment.

The results of the third sub research questions are less emissions also, the total costs of the equipment are lower, and the electric equipment needs less maintenance. The initial costs of the equipment is higher with electric equipment, but the maintenance costs and operating costs of the electric equipment is lower which results in a total costs. The amount of costs that are saved with implementing equipment couldn’t be calculated, because no information was available online about the pricing and maintenance costs of the electric equipment. Multiple attempts were made to contact the equipment manufacturers, but no response was received.

The emissions are less when operating electric powered ground support equipment in comparison with fossil fuelled equipment. Formulas were explained in the literature review in chapter 2. These formulas were going to be used to calculate the current emissions of the current equipment and to calculate the emissions when the equipment was replaced with electric equipment. These formulas are stated in ICAO documents (ICAO, 2015) which validates them and makes them usable in this research. Because very little to no data from 2019 or earlier could be retrieved from the interviewed companies or other sources, these calculations could not be performed. The only calculation that is made is based on the movements of 2019 at Amsterdam Airport Schiphol, but the result of this calculation is a very rough estimate of the emissions.

The result of the fourth sub research question is that the equipment is commercially viable in comparison with the current equipment. The equipment has lower costs and less maintenance which makes it commercially attractive for companies to implement this equipment.
The result of the fifth sub research question is that the industry is willing to use the electric ground support equipment. Based on the interviews that were conducted two specific requirements were stated. The equipment needs to have the same or better capabilities as the current equipment, and it needs to be commercially viable in comparison to the current equipment.

Further research into this subject should include a further analysis of the currently used equipment and why this equipment was chosen. This would enable the researcher to create a more thorough list of the needed requirements for the new electric ground support equipment. Also, a costs analysis should be made with the purchase and lease prices of the equipment, the maintenance costs and an analysis of the current fuel costs against the costs of the required electricity. This enable the purchaser to have an immediate cost comparison between the current fossil fuelled equipment and the new electric ground support equipment. Further, a more thorough emission analysis should be made to create an overview of the current emissions of the ground handlers’ equipment and the emissions which would be produced when electric ground support equipment would be used. The formulas and information to perform this analysis can be found in this research.

Finally, further research should be conducted into the operating hours of one battery charge during a full day of heavy operations for the electric ground support equipment. This would enable the ground handler to compare the operating time of the electric ground support equipment with the current equipment.
7 Recommendations

After conducting this research, the following recommendation can be given based on the results.

The lower deck loaders
The electric lower deck loaders can be implemented, for where they are not already implemented, at Amsterdam Airport Schiphol. Depending on the brand and type that is implemented, there are versions available that provide the same lifting capacity and a full day of heavy operations which makes them operationally attractive. The available electric lower deck loaders also emit less emissions, are more cost-effective and require less maintenance.

The main deck loaders
The electric main deck loaders can be implemented at Amsterdam Airport Schiphol, but it is unknown if they provide enough battery capacity which is required for a full day of heavy operations. The available versions also have a maximum lifting capacity of 15 ton which is less than the average 35 ton main deck loaders which are currently used, but is enough to lift the maximum weight of a main deck ULD. The available electric main deck loaders also emit less emissions, are more cost-effective and require less maintenance.

The container transporters
The electric container transporters cannot be implemented at Amsterdam Airport Schiphol with the current working method. The current available electric versions do not provide the possibility to load cargo from the side of the vehicle which is currently used. For the ground handlers, who do not use side loading, electric versions can be implemented depending on the ULD it needs to carry as the current version can carry up to 7 ton. Available electric container transporters also emit less emissions, are more cost-effective and require less maintenance.

The towing tractors
The electric towing tractors can be implemented at Amsterdam Airport Schiphol. Electric towing tractors have already partly been implemented at the airport. The available versions have the capabilities to tow the maximum weight of a dolly train at a reduced speed, but it is unknown if the batteries have the capability for a full day of heavy operations. The available electric towing tractors also emit less emissions, are more cost-effective and require less maintenance.
8 Implementation plan

This implementation plan provides the activities and stakeholders involved in implementing electric ground support equipment at Amsterdam Airport Schiphol. The goal of this implementation plan can be found in chapter 8.1. Chapter 8.2 creates an overview of the activities involved to reach the set goal. Chapter 8.3 elaborates on the involved stakeholders required.

8.1 Goal

The goal of the implementation plan is to provide the ground handlers with a plan for them to follow on how to purchase electric ground support equipment and decrease their emissions. The goal can be found as a SMART goal in table 20 below.

<table>
<thead>
<tr>
<th>Specific</th>
<th>Measurable</th>
<th>Achievable</th>
<th>Relevant</th>
<th>Timebound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide a guide on how to implement electric</td>
<td>The decrease of emissions by ground support</td>
<td>Achievable, because electric ground support</td>
<td>Relevant, because the emissions need to be</td>
<td>From 2020 to 2030</td>
</tr>
<tr>
<td>ground support equipment which decreases the</td>
<td>equipment</td>
<td>equipment is available and already being used</td>
<td>decreased in order for the 35% CO₂</td>
<td></td>
</tr>
<tr>
<td>emissions from ground support equipment</td>
<td></td>
<td></td>
<td>reduction goal to be achieved as mentioned</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in the 'Slim én Duurzaam' plan.</td>
<td></td>
</tr>
</tbody>
</table>

The goal will result in:
- A different type of equipment for the employees to use
- Different working methods for the new equipment
- Charging instead of refuelling
- Different type of equipment planning due to the charging times of the electric equipment

For this goal to be reached some prerequisites are required:
- Electric ground support equipment needs to be available which has the same or better capabilities as the conventional powered ground support equipment
- The airport infrastructure needs to be able to provide electric ground support equipment with the necessary charging points
- Employees need to be willing to change their working methods
8.2 Activities

This implementation plan can be used for multiple reasons. The currently used equipment might be broken beyond repair which requires the ground handlers to start researching new equipment and purchase or lease it. Another reason could be, if the currently used equipment is nearing the end of its lifespan which also requires the ground handler to start the research in new equipment. Or it could be because the equipment needs to be replaced with greener equipment which is necessary to reach the companies’ sustainability goals.

The steps for researching and purchasing/leasing this equipment are elaborated in this subchapter.

Preparation

Before the equipment can be purchased or leased, research and tests need to be performed by the company to find the best match for their company.

This process starts by researching if all the prerequisites are in place or are worked on, because if these are requirements are not met electric ground support equipment can’t be implemented at the company.

First, the airport needs to be contacted to discuss the current layout of their infrastructure and their plans for the charging points for the electric ground support equipment. If there are enough charging points available by the time the equipment is implemented the first prerequisite is checked. Then, the employees need to be interviewed to get their input on the implementation of the electric equipment and their requirements for the new equipment. According to Forbes (Kappel, 2018), it can be beneficial for your business and employees if you involve them in decision making. When the employees are interviewed, the research into the new equipment can be started.

This research can use the overview of the available equipment, that is researched in chapter 4.1.2. This provides a list of all the researched electric ground support equipment (high and lower deck loaders, container transporters and towing tractors), but does not include pricing details which couldn’t be obtained in this research. The company should create a list of requirements containing the power, the battery capacity, etc. and cross check these requirements with the specifications of the listed equipment. If a piece of equipment matches the requirements further research should be provided into this type of equipment.

This further research starts by contacting the manufacturer to get further information and pricing details of the equipment. This can be done at multiple manufacturers to get a list of equipment to choose from. When further into the research, options can be eliminated until one piece of equipment proves to be feasible for the company’s operation. After this further research, a deal could be made with the manufacturer to test a piece or multiple pieces of equipment in their operation and/or get test results from the manufacturer to analyse. During these tests the DMAIC cycle could be used to analyse and improve the performance. This DMAIC cycle is provided in table 21. This cycle could be repeated multiple times until the best process and planning is found.

<table>
<thead>
<tr>
<th>Table 21 DMAIC cycle for testing new electric ground support equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
</tr>
<tr>
<td>Measure</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Analyse</td>
</tr>
<tr>
<td>Improve</td>
</tr>
<tr>
<td>Control</td>
</tr>
</tbody>
</table>
When the testing cycle is completed and the results from the test are satisfying for the company. The negotiation phase with the manufacturer can start on the pricing details, number of equipment that will be purchased or leased, etc. which will eventually lead to a deal with the manufacturer which will be the start of the realization phase.

Realization
When the company has reached a deal with the manufacturer the realization phase starts. Before the newly purchased or leased equipment arrives, new working methods need to be written for the employees to use. The employees need to be trained to work with the new equipment and learn how to safely operate the electric equipment. Besides the employees that need to be trained to work with the new equipment, a new type of planning method needs to be created. This new planning method is necessary, because the equipment requires a longer down time due to charging of the batteries.

When the above mentioned changes are in place and when all the prerequisites are checked, the equipment can be delivered and used in daily operation. During this phase of the realization, interim evaluations should be conducted to check the performance, the processes and the planning and adjust the procedures where needed. This can be done by using the DMAIC cycle which can be found in table 22.

Table 22 DMAIC cycle for adjusting the working methods

<table>
<thead>
<tr>
<th>Define</th>
<th>The performance of the newly used equipment</th>
</tr>
</thead>
</table>
| Measure | -The operational performance of the new equipment compared to the old equipment  
- The reduction of emissions  
- The operational hours of the new equipment  
- The down time of the new equipment |
| Analyse | Analyse the data obtained from these measurement |
| Improve | Adjust the working methods and planning procedures where needed to improve the performance |
| Control | Control the new working methods and planning procedures |

Evaluation
When the realization phase is finished and the equipment is fully integrated, the evaluation phase can start. During this phase, evaluations should be conducted on how the preparation phase and realization phase went, what could be improved on and what went well. This evaluation should result in a list of improvements which can be implemented in the implementation plan which improves the implementation plan. This makes sure the implementation plan can be used again when new equipment needs to be bought.

During the evaluation phase and after it is finished, the DMAIC cycle in table 22 should be used regularly to keep improving the processes and working methods to maintain a high working standard.
8.3 Stakeholders
The following stakeholders need to be included during the implementation of the new electric ground support equipment:

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Why?</th>
<th>Interest</th>
<th>Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Handlers</td>
<td>The ground handlers will use the new electric ground support equipment</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Airport</td>
<td>The airport needs to implement charging points for the new electric ground support equipment</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Energy Provider</td>
<td>The energy provider is responsible for the delivery of green electricity to the company</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Equipment manufacturers</td>
<td>The equipment manufacturers are responsible for the production of new electric ground support equipment</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Airlines</td>
<td>The new ground support equipment is based on the</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

A stakeholder map can be found below. This map provides an overview of the interests and influences of the different stakeholders.

![Stakeholder Map](image-url)

- The ground handler
The ground handler has a high interest in the implementation of the electric ground support equipment as it will lower their emissions and costs. They also have a high influence, because they are going to be the company who is going to use the new electric ground support equipment.

- The airport
  The airport is included has a high interest, because it will decrease the airports emissions. They also have a high influence, because if the airport does not implement enough charging points at the airport, the electric ground support equipment can’t be charged and used.

- The energy provider
  The energy provider has a medium interest, because electric ground support equipment requires more electricity from the energy provider which means more income for the energy provider. They have a low influence on the implementation of the electric ground support equipment, because they only need to deliver more electricity to the airport for charging the equipment. But they have no influence on which equipment is going to be implemented.

- The equipment manufacturers
  The equipment manufacturers have a high interest, because they provide the ground handlers with the needed electric ground support equipment. They also have a high influence, because the ground handler can only choose from the available electric ground support equipment.

- The airlines
  The airlines have a medium interest, because it decreases the emissions which are produced during the turn around of their aircraft, which decreases the airlines’ emissions. They have a high influence on the implementation, because the aircraft of the airlines determine the requirements of the equipment which is going to be implemented.
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Appendix I  Reflection
## Appendix II  Emissions Table Zurich Airport

Table 24 Emissions Table Zurich Airport (Fleuti, 2014)

<table>
<thead>
<tr>
<th>Pier Stands</th>
<th>Aircraft group</th>
<th>Unit</th>
<th>NOx</th>
<th>HC</th>
<th>CO</th>
<th>PM</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Aircraft</td>
<td>kg/ac</td>
<td>0.463</td>
<td>0.041</td>
<td>0.197</td>
<td>0.029</td>
<td>43.760</td>
</tr>
<tr>
<td></td>
<td>Medium Aircraft</td>
<td>kg/ac</td>
<td>0.452</td>
<td>0.040</td>
<td>0.191</td>
<td>0.029</td>
<td>42.579</td>
</tr>
<tr>
<td></td>
<td>Small Aircraft</td>
<td>kg/ac</td>
<td>0.331</td>
<td>0.028</td>
<td>0.125</td>
<td>0.019</td>
<td>27.487</td>
</tr>
<tr>
<td></td>
<td>Commuterl Aircraft</td>
<td>kg/ac</td>
<td>0.234</td>
<td>0.020</td>
<td>0.086</td>
<td>0.012</td>
<td>19.819</td>
</tr>
<tr>
<td></td>
<td>Turboprops</td>
<td>kg/ac</td>
<td>0.194</td>
<td>0.016</td>
<td>0.070</td>
<td>0.009</td>
<td>17.026</td>
</tr>
<tr>
<td></td>
<td>Business Jets</td>
<td>kg/ac</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>GA Propeller Aircraft</td>
<td>kg/ac</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Helicopters</td>
<td>kg/ac</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Open Stands</th>
<th>Aircraft group</th>
<th>Unit</th>
<th>NOx</th>
<th>HC</th>
<th>CO</th>
<th>PM</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Aircraft</td>
<td>kg/ac</td>
<td>0.535</td>
<td>0.046</td>
<td>0.241</td>
<td>0.032</td>
<td>51.272</td>
</tr>
<tr>
<td></td>
<td>Medium Aircraft</td>
<td>kg/ac</td>
<td>0.533</td>
<td>0.046</td>
<td>0.240</td>
<td>0.032</td>
<td>50.959</td>
</tr>
<tr>
<td></td>
<td>Small Aircraft</td>
<td>kg/ac</td>
<td>0.355</td>
<td>0.029</td>
<td>0.158</td>
<td>0.019</td>
<td>27.044</td>
</tr>
<tr>
<td></td>
<td>Commuterl Aircraft</td>
<td>kg/ac</td>
<td>0.130</td>
<td>0.011</td>
<td>0.047</td>
<td>0.007</td>
<td>9.396</td>
</tr>
<tr>
<td></td>
<td>Turboprops</td>
<td>kg/ac</td>
<td>0.118</td>
<td>0.010</td>
<td>0.037</td>
<td>0.006</td>
<td>21.807</td>
</tr>
<tr>
<td></td>
<td>Business Jets</td>
<td>kg/ac</td>
<td>0.052</td>
<td>0.004</td>
<td>0.016</td>
<td>0.003</td>
<td>17.001</td>
</tr>
<tr>
<td></td>
<td>GA Propeller Aircraft</td>
<td>kg/ac</td>
<td>0.052</td>
<td>0.004</td>
<td>0.016</td>
<td>0.003</td>
<td>17.001</td>
</tr>
<tr>
<td></td>
<td>Helicopters</td>
<td>kg/ac</td>
<td>0.052</td>
<td>0.004</td>
<td>0.016</td>
<td>0.003</td>
<td>17.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GPU</th>
<th>Unit</th>
<th>NOx</th>
<th>HC</th>
<th>CO</th>
<th>PM</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>All aircraft groups</td>
<td>kg/h</td>
<td>0.060</td>
<td>0.006</td>
<td>0.025</td>
<td>0.003</td>
<td>19.51</td>
</tr>
</tbody>
</table>
# Appendix III  Default emission factors Zurich Airport

Table 25 Default emission factors representative of Zurich Airport for aircraft handling (ICAO, 2015)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Unit</th>
<th>GSE Technology 1990-2005</th>
<th>GSE Technology 2000-2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Narrow-body aircraft</td>
<td>Wide-body aircraft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(single-aisle fixed-wing jet)</td>
<td>(double-aisle fixed-wing jet)</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>kg/cycle</td>
<td>0.400</td>
<td>0.900</td>
</tr>
<tr>
<td>HC</td>
<td>kg/cycle</td>
<td>0.040</td>
<td>0.070</td>
</tr>
<tr>
<td>CO</td>
<td>kg/cycle</td>
<td>0.150</td>
<td>0.300</td>
</tr>
<tr>
<td>PM(_{10})</td>
<td>kg/cycle</td>
<td>0.025</td>
<td>0.055</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>kg/cycle</td>
<td>18</td>
<td>58</td>
</tr>
</tbody>
</table>
## European emission factors for aircraft handling

Table 26 European emission factors for aircraft handling (ICAO, 2015)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Diesel (g/kg)</th>
<th>Gasoline (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{x}</td>
<td>32.8</td>
<td>7.1</td>
</tr>
<tr>
<td>HC</td>
<td>3.4</td>
<td>17.6</td>
</tr>
<tr>
<td>CO</td>
<td>10.7</td>
<td>770.4</td>
</tr>
<tr>
<td>PM</td>
<td>2.1</td>
<td>0.1</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>3160</td>
<td>3 197</td>
</tr>
</tbody>
</table>
Appendix V  ULD Specifications

Figure 5 ULD Specifications (Thompson, 2019)
<table>
<thead>
<tr>
<th>Container</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LD-7</strong></td>
<td>- Pallet code: 17P7</td>
</tr>
<tr>
<td></td>
<td>- Description: Universal-purpose pallet for lower holds and main decks.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, 77C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 4,400 kg (9,726 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 650 kg (1,433 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.30 m³ (10.54 ft³).</td>
</tr>
<tr>
<td><strong>LD-7 with Folding Wings</strong></td>
<td>- Pallet code: 17P7-5P</td>
</tr>
<tr>
<td></td>
<td>- Description: Pallet with folding wings for stowage.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 4,400 kg (9,726 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 650 kg (1,433 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.30 m³ (10.54 ft³).</td>
</tr>
<tr>
<td><strong>LD-7 with Angled Wings</strong></td>
<td>- Pallet code: 17P7-5P+</td>
</tr>
<tr>
<td></td>
<td>- Description: Pallet with fixed wings for stowage.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 4,400 kg (9,726 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 650 kg (1,433 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.30 m³ (10.54 ft³).</td>
</tr>
<tr>
<td><strong>LD-9</strong></td>
<td>- Pallet code: 17P7-5P+</td>
</tr>
<tr>
<td></td>
<td>- Description: Universal-purpose pallet for lower holds and main decks.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 4,400 kg (9,726 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 650 kg (1,433 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.30 m³ (10.54 ft³).</td>
</tr>
<tr>
<td><strong>LD-9 Reefer</strong></td>
<td>- Pallet code: 17P7-5P</td>
</tr>
<tr>
<td></td>
<td>- Description: Containerized container with sliding door.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Door openings: 15 in. (381 mm) x 30 in. (762 mm).</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 7,000 kg (15,432 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 750 kg (1,653 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.60 m³ (21.13 ft³).</td>
</tr>
<tr>
<td><strong>LD-11</strong></td>
<td>- Pallet code: 17P7-5P+</td>
</tr>
<tr>
<td></td>
<td>- Description: Universal-purpose pallet for lower holds and main decks.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 4,400 kg (9,726 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 650 kg (1,433 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.30 m³ (10.54 ft³).</td>
</tr>
<tr>
<td><strong>LD-26</strong></td>
<td>- Pallet code: 17P7-5P</td>
</tr>
<tr>
<td></td>
<td>- Description: Universal-purpose pallet for lower holds and main decks.</td>
</tr>
<tr>
<td></td>
<td>- Suitable for: 3C, 7C, 17C, DC, 15C, MD, 8C, MD-C, and MD-19.</td>
</tr>
<tr>
<td></td>
<td>- Maximum gross weight: 4,400 kg (9,726 lb).</td>
</tr>
<tr>
<td></td>
<td>- Tare weight: 650 kg (1,433 lb).</td>
</tr>
<tr>
<td></td>
<td>- ASIS/2000 volume: 0.30 m³ (10.54 ft³).</td>
</tr>
</tbody>
</table>

Figure 6 ULD Specifications (Thompson, 2019)
Figure 7 ULD Specifications (Thompson, 2019)
Figure 8 ULD Specifications (Thompson, 2019)
Appendix VII  Interview interviewee 2
Appendix VIII  Interview interviewee 3
Appendix IX  Interview Questions

1. Could you please give a short introduction about yourself?

2. Which container transporters does your company use?
   a. What are the specific types?
   b. What kind of fuel does this type/these types use?
   c. How many transporters does your company use?
   d. How many times per day is a transporter tanked?
   e. Where are these transporters tanked?
   f. How many liters of fuel does the transporter use on an average day?
   g. How many times per day is a transporter used?
   h. What is the average distance a transporter travels per day?
   i. How many transporters are used per turn around?
   j. How many turn arounds does your company have on an average day?
   k. Do you have fuel data and/or travel data of the transporters that you could share?

3. Which loaders does your company use?
   a. What are the specific types?
   b. What kind of fuel does this type/these types use?
   c. How many loaders does your company use?
   d. How many times per day is a loader tanked?
   e. Where are these loaders tanked?
   f. How many liters of fuel does the loader use on an average day?
   g. How many times per day is a loader used?
   h. What is the average distance a loader travels per day?
   i. How many loaders are used per turn around?
   j. How many turn arounds does your company have on an average day?
   k. Do you have fuel data and/or travel data of the loaders that you could share?

4. Which towing tractors does your company use?
   a. What are the specific types?
   b. What kind of fuel does this type/these types use?
   c. How many towing tractors does your company use?
   d. How many times per day is a towing tractor tanked?
   e. Where are these towing tractors tanked?
   f. How many liters of fuel does the towing tractor use on an average day?
   g. How many times per day is a towing tractor used?
   h. What is the average distance a towing tractor travels per day?
   i. How many towing tractors are used per turn around?
   j. How many turn arounds does your company have on an average day?
   k. Do you have fuel data and/or travel data of the towing tractors that you could share?

5. Would you use electric ground support equipment?
   a. Are you already using electric ground support equipment?
   b. Are you already testing electric ground support equipment?
   c. What would be your requirements?