2011

Improved Emission Data Collection in Air Cargo Processes using ADS-B

Hendrik Hilpert
University of Göttingen, hhilper@uni-goettingen.de

Stefan Friedemann
University of Göttingen, sfriede1@uni-goettingen.de

Matthias Schumann
University of Goettingen, mschuma1@uni-goettingen.de

Follow this and additional works at: http://aisel.aisnet.org/acis2011

Recommended Citation
Hilpert, Hendrik; Friedemann, Stefan; and Schumann, Matthias, "Improved Emission Data Collection in Air Cargo Processes using ADS-B" (2011). ACIS 2011 Proceedings. 16.
http://aisel.aisnet.org/acis2011/16

This material is brought to you by the Australasian (ACIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in ACIS 2011 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact elibrary@aisnet.org.
Improved Emission Data Collection in Air Cargo Processes using ADS-B

Hendrik Hilpert
Stefan Friedemann
Matthias Schumann
Chair of Application Systems and E-Business
University of Göttingen, Germany
Email: {hhilper|sfriede1|mschuma1}@uni-goettingen.de

Abstract

The increasing demand for sustainable development has led companies to report their GHG (greenhouse gas) emissions. The calculation of air cargo transport emissions and their environmental impact is currently based on average values and estimations, leading to highly uncertain results, which are not suitable for GHG accounting and decision support. We therefore propose a primary data collection middleware and a calculation model for environmental management information systems (EMIS). The system derives actual flight trajectory data from the upcoming secondary surveillance radar technique ADS-B (Advanced Dependence Surveillance Broadcast). Following a design science research approach, we present the system architecture, the calculation logic and evaluate our results against a common calculation standard, using a Product Carbon Footprint (PCF) case study. The result of this paper is a Green IS artifact for decision support, which enables to reduce GHG emissions and greener transports, based on more detailed GHG emission reports.

Keywords
GHG emissions, Air cargo, ADS-B, Scope three emissions, Product Carbon Footprint

INTRODUCTION

Between 1970 and 2004 the total global GHG emissions emitted by human activities increased by 70 % (IPCC 2007). Even though air transportation only accounts for a small part of the total global GHG emissions with 2 - 3 % (Owen et al. 2010; Forsyth 2011), it increases by around 5 % a year (ICAO 2009; Mason and Alamdari 2007). Furthermore, the impact of aircraft emissions on the environment is 2 - 4 times higher than that of other industrial processes due to the direct emission exposition in the upper tropo- and lower stratosphere (IPCC 2007; Lambert 2008). Air transports and resulting GHG emissions typically occur in up- and downstream processes of a focal supply chain company and are conducted by third party carriers (WBCSD 2010), resulting in scope three emissions (Finkenbeiner 2009). Accurate emission data could be obtained by FDRs (flight data recorders) of the air carrier, as they track complete flight trajectories. However, air carriers neither provide the public nor the focal company with these data, nor do they use FDRs as a data source because these data are difficult and very costly to read-out (ECAC 2005). Scope three emission calculations are therefore typically based on theoretical models and average data that are highly uncertain. Consider estimated distances using the great circle distance (GCD), which neither reflect real flight trajectories (ICAO 2006; WBCSD 2004) nor include variations like holding patterns near airports or bypasses through bad weather conditions.

Due to the demand for a more sustainable development, companies have started to measure and report their activities’ environmental impact in order to reduce it in the long term. Thus, ecological aspects are increasingly used as decision factors (Dada and Starke 2008; El Gayar and Fritz 2006; Solomon and Lewis 2002). Whereby average emission data are acceptable for initial GHG observations (WBCSD 2010), they are not for decision-making and environmental management accounting (EMA). This is especially true when significant variations occur in single instances of a process and average data therefore under- or overestimate real activities (Dada et al. 2009). Consider this aspect in decisions about routes or means of transport, e.g. air vs. sea transportation: Uncertain emission data could lead to false mean of transport decisions, and thus not to minimized environmental impacts. In addition, when regarding upcoming global legal constraints (e.g. GHG emission trading schemes) such false decisions have economic influences on companies. Companies will have to buy emission certificates for their GHG emissions, where a) the minimization of GHG ceteris paribus leads to economic benefits and b) miscalculations in annually GHG emissions reports could lead to financial penalties (Aakre and Hovi 2010; Hodgkinson et al. 2007). In order to counteract, companies seek economic ways of gathering detailed emission data of highly variable processes, such as air cargo, for reporting and decision support purposes (Dada et al. 2009; El-Gayar and Fritz 2006; Mason and Alamari 2007; Miyoshi and Mason 2009).
One way of gathering economic activity data in air transport processes is to use ADS-B, a worldwide emerging secondary surveillance radar technique (FAA 2010). ADS-B broadcasts complete flight trajectories (e.g. location, altitude and speed) via the internet. Using this system as a primary data source, we present the combination of a data collection middleware with an EMIS calculation model for (scope three) GHG emissions in air cargo transport processes. Moreover, with our system it is possible to analyze environmental impacts for specific timeframes, locations and altitudes in detail. In order to provide more accurate emission data for GHG accounting and decision-support processes we propose a system with which real activity data can be collected in detail.

This research in progress paper follows a design research paradigm according to Hevner et al. (2004) and Peffers et al. (2007). It provides a problem identification, a solution design and an evaluation. The paper is organized as follows: Section two gives a literature review on current emission calculation models in aviation transports, as well as on the ADS-B technology and its current applications. In section three the proposed data collection and calculation system design based on ADS-B is presented. The fourth section continues with the evaluation of the system. This is done with an air transportation case study, which compares the results of the proposed system with a standard calculation method. Section five provides a conclusion, limitations of the study and a short outlook on future research questions.

RELATED RESEARCH

The related research part is divided into two sections. First, we show the state of the art of current GHG emission calculation models for air transportation processes. The second section describes ADS-B technology and its applications in the field of air transportation.

GHG emission and air transportation

A typical aircraft mission consists of seven operational phases: taxi-out, take-off, climb-out, cruise, descent, approach and taxi-in (ICAO 2006; Miller et al. 2001; Sage 2005). The phases taxi-out and -in, take-off and approach are standardized as the LTO cycle (Landing and Take-off), which includes all phases below 3000 ft (ICAO 2006; Miyoshi and Mason 2009; Romano et al. 1999). Above 3000 ft, the aircraft proceeds with climbing until the Top of Climb (TOC) is reached. This is the beginning of the cruise altitude (about 35000 ft). The aircraft will try to stay on this altitude if no interims occur (e.g. bad weather conditions or flight path crossings) until the Top of Descent (TOD) is reached. This point typically lies 70 - 100 nautical miles (NM) pre-destination and is the starting point of the descent phase. The descent phase ends with dropping below 3000 ft by entering the approach phase. This phase’s end is defined by the aircraft’s touch-down. The taxi-in is complete when the aircraft has reached its parking position.

Aircraft emissions are produced when consumed fuel is combusted in the engines during the mission (ICAO 2006). The combustion depends on the thrust in a specific operational mode. As the impact on the climate depends on the altitude in which the emissions occur, it is very important to collect this data as accurately as possible. A differentiation between two sections (LTO-cycle; under and above 3000 ft) does not seem to provide sufficient accuracy. Figure 1 shows a typical aircraft flight profile including the LTO-cycle and the associated standardized thrust settings for LTO phases plus ICAO average time that is spend in that mode. There are no values given for the cruise phase in the ICAO LTO-cycle.

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Thrust setting (% of max. thrust)</th>
<th>Time-In-Mode (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>100 %</td>
<td>0.7</td>
</tr>
<tr>
<td>Climb-out</td>
<td>85 %</td>
<td>2.2</td>
</tr>
<tr>
<td>Approach</td>
<td>30 %</td>
<td>4.0</td>
</tr>
<tr>
<td>Taxi</td>
<td>7 %</td>
<td>26.0</td>
</tr>
</tbody>
</table>

Figure 1: Flight profile, LTO thrust settings and time-in-mode

In order to determine the environmental impact of air cargo transport processes and the long-term effects on global warming, activity data on the sum of consumed fuel are needed to calculate total GHG emissions using emissions factors. Several methods and models have therefore been evolved that try to account for the fuel consumption of an aircraft in increasing detail and information accuracy. The ICAO’s emission inventory guidebook provides basic methods for the calculation of aircraft emissions: The very simple, the simple and the detailed method (ICAO 2006). While the very simple and simple methods only aggregate average values and
have an uncertainty of 20 - 45 %, the detailed model is based on the LTO-cycle and uses average activity values for specific aircrafts and emission factors (ICAO 2006). Even the detailed model with more accurate data still has an uncertainty of 15 - 40 % (ICAO 2006).

Several authors, who were aware of the high uncertainties in these basic calculation methods, have developed emission models aimed at reducing these. Kalivoda and Feller (1995) introduced the ATEMIS (Air Traffic Emission Simulation), which is based on real aircraft data and uses the LTO-cycle as a model. The authors note that it is still inaccurate as a link is missing between aircraft engine data and corresponding flight activity data. Miller et al. (2001) used taxi and airborne times, reported by airlines for specific flights, combined with fuel flow and specific emission coefficients from the ICAO Engine Performance database. The Eurocontrol Experimental Centre (EEC) developed a collection of aircraft performance and operation parameters, called the “Base of Aircraft Data” (BADA), which is the most comprehensive set of aircraft performance and aerodynamics data (EEC 2004). Several other models use these datasets in their own models, e.g. the Sage model (Sage 2005). Vera-Morales and Hall (2010) propose PESO (Performance and Emission Simulation of Aircraft Operations), which is a complex model that simulates the performance of an aircraft, including the main aircraft aerodynamic characteristics. Nevertheless it does not use real activity data of a specific flight, but only simulated standard trajectories. The Federal Office of Civil Aviation (FOCA 2007) developed a model which can be used to calculate fuel consumption and emissions in the LTO-cycle. The „Advanced Aircraft Emission Calculation Method“ (ADACAM) uses the ICAO engine database and non-public available real flight activity data, obtained from airport operators. In order to evaluate the model, they compared it with FDR data, showing that the proposed model deviates from real FDR data, but provides a better model than the ICAO standard ones (FOCA 2007). Several other methods, models and analysis of uncertainties exist, all of which show that actual options do not provide accurate results for real flights. The fuel consumption in airplane models in the taxi phase differs up to 40% from the real data (Patterson et al. 2007). The BADA model, for example, differs from actual fuel consumption by about 22 % (Senzg et al. 2009). This is mainly due to delays, which are not included in the models (Kesgin 2006; Mueller and Chatterji 2002). With 11 %, the fuel consumption above 3000 ft significantly deviates from real data when using the GCD method (Miyoshi and Mason 2009). The real altitude of an aircraft is also uncertain in the models due to the usage of simulated standard flight paths (ICAO 2006). However, as mentioned above, the flight altitude is one of the main factors determining the emission impact on the climate.

**ADS-B Applications**

Automatic Dependent Surveillance Broadcast (ADS-B) “is a function on an aircraft or surface vehicle that periodically broadcast its state vector and other information” (RTCA 2002) to other users, e.g. Air Traffic Control or other aircrafts (Hicok and Lee 1998). The goals of ADS-B are the improved use of airspace, enhanced safety and to be a viable alternative to other surveillance radar technologies. The system is an automatically one-way broadcast system which uses GPS technique and consists of a transmitter, the propagation medium and a receiver (RTCA 2002). An aircraft equipped with a transmitter can broadcast its position, velocity, direction and altitude data, while other aircrafts or tracking stations, equipped with a receiver, can receive the signal (Hicok and Lee 1998). A 1090 megahertz extended squitter or the Universal Access Transceiver is used as the broadcast link. It is possible to send data repeatedly within a second, with a total latency lower than two seconds (FAA2010). Several papers about possible ADS-B applications have been published since this technique was established. Cieplak et al. (2000) propose a Cockpit Display of Traffic Information system, using ADS-B signals to display the traffic situation in the environment of an aircraft. Song et al. (2008) developed a secondary radar prototype system based on ADS-B, in order to derive air traffic data of the airport environment. Another approach is shown by de Miguel Vela et al. (2008), who integrated ADS-B aircraft trajectory data in a present airport multiradar tracking system. Gutierrez et al. (2008) present a 4D radar system with ADS-B data, using Google Earth and an application programming interface (API) to display current aircrafts around a signal receiver. By using Google Earth several embedded functions can be used to differently display the current traffic situation (e.g. zoom, angle, in-flight view). Vismari and Camargo (2008) compared different surveillance systems and found that ADS-B systems are more exact than older surveillance systems, thus enabling better traffic control. Williams et al. (2008) discuss the potentials of improved navigation and surveillance capabilities enabled through ADS-B. As ADS-B systems provide more precise data, separation requirements of aircrafts can be reduced, thus leading to an increased airport capacity. Jennigis et al. (2002) developed a 3D ADS-B aircraft instrument prototype, which can be used for closely spaced parallel approaches. The ADS-B enables this technique by providing additional real-time data about the environmental traffic situation, e.g. position, heading, and velocity or roll angle of other aircrafts.

**SYSTEM DESIGN**

None of the emission models shown above use detailed primary activity data in air transportation processes as a way of reducing the uncertainties and hence do not provide valid GHG accounting and reports. ADS-B data streams provide real activity data which are publicly available via the internet and can be used to model aircraft
emissions ex post. The FAA (Federal Aviation Administration) provides detailed events of flight status to gather, for example, the delay data mentioned above, which accounts for a great part of uncertainty in the LTO-cycle. In this paper, we intend to integrate this real activity data. In order to provide such a model, we propose a middleware which collects real-time ADS-B data, delay data from the FAA, aircraft performance and loads data to calculate scope three emissions for single flights in an EMIS. In the following section, the design of the data collection middleware will be explained in detail. Following this aim, we give explanations for the single components that are included in the system and use an UML (Unified Modeling Language) component model to show the design of the system. In the next step, we explain the calculation model for aircraft emissions in detail and demonstrate how the single components provide data for calculations in the EMIS.

System Components

The proposed middleware uses multiple web services and content repositories via HTTP in order to collect the necessary activity data. The first web service (web service A) is utilised to obtain flight event time frames, e.g. take-off or wheels-down, which are provided by the FAA for every flight in a standardized data stream. This data stream can be obtained from several web services, e.g. flightstatus.com or directly from faa.com. The second web service (web service B) is utilised to obtain ADS-B flight trajectory data (e.g. position and altitude). This ADS-B data also can be obtained from several web service providers, e.g. flightaware.com or flighttracker.com. Besides obtaining data from several web services, the middleware is also able to collect data from content repositories. Two repositories are needed, where the first one contains aircraft engine performance data, namely thrust settings and corresponding fuel flows for every engine. These data can be obtained from the ICAO aircraft engine emission database. The second repository contains airframe (type of aircraft) load volume data, including maximum load volumes and the amount as well as type of ULDs (unit load devices) that can be loaded on the different decks of an aircraft (there are several different ULDs that can be loaded in aircrafts). The repositories are typically located on the manufacturer’s webpage. The described system is displayed in a static component diagram, shown in Figure 2.

![Figure 2: Component diagram of proposed system](image)

The static components are subsequently briefly described under dynamic aspects in order to explain their workflow behaviour. The middleware starts the data collection process by an event trigger, periodically listening to web service A, waiting for start and end time of a specific carrier’s cargo flight (assumption: job data in the EIS database of the focal company contains the tail number of the carrier’s flight number). The proposed middleware starts the data collection from web service B when the wheels-down event is streamed by web service A, in order to transfer the complete flight trajectory tracking protocol, which is only available afterwards via the service. Having stored the events and tracking protocol of the flight in the EIS database as a new entry, linked to the job data, the middleware reads out technical airframe specifications and obtains corresponding engine performance data. In addition, the middleware extracts the specific maximum cargo load volume from the corresponding repository. These repository data are also stored in the new EIS database entry.

Calculation Model

The next step in our system design is the calculation of aircraft emissions in an EMIS, using the obtained activity data. In order to calculate the emissions of a complete flight we use a basic formula for the LTO-cycle (Miller et al. 2001), extended to non-LTO phases. These are the climb, cruise and descent operational phases, as displayed in Equation 1. Moreover we include basic relations from emission models, presented in section two, between engine performance, activity and phases in our model. The total emissions $E$ for every GHG $i$ for one flight of an aircraft $j$ consists of the emissions in the seven operational phases $k$. The emissions for one timeframe of $\text{TIM}_{jk}$, multiplied with the fuel consumption ($\text{FF}_{jk}$), the emission factor ($\text{EI}_{jk}$) and the number of engines ($\text{NE}_j$), can be
aggregated to single phase emissions and for one complete flight. Equation 1 shows the proposed calculation. Some components of this equation are variable and some constant. The activity data $TIM_{jk}$ and $FF_{jk}$, are variable in every phase, while $EI_{ijk}$ and $NE_{j}$ are constants for a specific flight, as the number of engines depends on the aircraft. For every operational phase (taxi-out, take-off, climb out, cruise, descent, approach and taxi-in) the variable components of the Equation 1 and the data, which will be used for the calculation, are explained successively:

$$E_{ij} = \sum_k (TIM_{jk}) \times (FF_{jk}/1000) \times (EI_{ijk}) \times (NE_{j})$$

- $E_{ij}$: GHG Emissions i per aircraft j
- $TIM_{jk}$: Time in operational phase k in minutes for aircraft j
- $FF_{jk}$: Fuel consumption in kg/minute in phase k for one engine j
- $EI_{ijk}$: Emission factor i in phase k for one engine of aircraft j
- $NE_{j}$: Number of engines of aircraft j

Equation 1: Basic calculation

Taxi-out: The LTO-cycle defines 26 minutes for standard taxi-out and -in, but several studies (see section two) show that this standard time does not reflect real airport situations. We therefore use more detailed ADS-B data from web service B, combined with FAA data from web service A, which provide events on pushback time from aircraft’s parking space ($t_{wheels-off}$) and exact departure time ($t_{wheels-off}$), indicating that an aircraft went over to airborne status. After take-off, the aircraft provides this information in order to recalculate new arriving times at the destination. The $TIM_{j(Taxi-out)}$ can therefore be calculated by the following term (note that the time for take-off $TIM_{j(Take-off)}$ has to be subtracted, see next phase): $TIM_{j(Taxi-out)} = t_{wheels-off} - t_{wheels-off} \cdot TIM_{j(Take-off)}$. The fuel flow $FF_{jk}$ for the taxi-out is defined by the LTO-cycle with idle-thrust (7 %). Using this setting, we obtain the $FF_{j(Taxi-out)}$ from ICAO engine database for the specific engine, converted to a kg/min value.

Take-off: The take-off time in the LTO-cycle is defined as the time which an aircraft needs from the point when the brakes are released on the runway until the aircraft looses ground contact. For this phase, the LTO-cycle defines an average time of 0.7 minutes and a thrust setting of 100 %. We will use both standard values, because the ADS-B system does not publish the first minutes of the flight due to security reasons. Therefore $TIM_{j(Take-off)}$ is set as constant with 0.7 and the $FF_{j(Take-off)}$ for the specific engine can be obtained by the ICAO engine database, converted to kg/min.

Climb: For the climb out time we use ADS-B data and FAA data. The FAA event $t_{wheels-off}$ is the start timeframe of the climb-out phase. The end timeframe of this phase can be obtained from web service B. The end timeframe is the last timeframe where the altitude is below the aircrafts cruise altitude, $t_{TOC}$. In summary, the time for climb out phase, $TIM_{j(Climb-out)}$, can be calculated as follows: $TIM_{j(Climb-out)} = t_{TOC} - t_{wheels-off}$. The climb out thrust is defined as 85 % (of maximal thrust) by ICAO. Using this setting, we derive $FF_{j(Climb-out)}$ from the ICAO engine database for the specific engine type, converted to kg/min.

Cruise: The time between the TOC and the TOD, which represents the time of the cruise phase, can be obtained from trajectory data from web service B. The time in cruise phase is thus defined as $TIM_{j(Cruise)} = t_{TOD} - t_{TOD}$. The thrust in the cruise phase is typically set to 22 % of the maximal thrust setting, when travelling at cruise altitude (Endres 1998). In order to calculate the fuel flow for this setting we have to use a curve-fitting model, as the cruise phase is not included in the ICAO data (see Figure 1). Using the four provided values for power setting (% of rated output) and fuel flow (kg/s) from the ICAO engine emission databank, we can calculate the fuel flow for a 22 % thrust (note: using a cubic model, due to engine characteristics, leads to a perfect fitted model in most cases). The fuel flow $FF_{j(Cruise)}$ for this phase can now be computed and has to be converted into kg/min.

Descent: In order to determine the start- and endpoint of this phase, we use the $t_{TOD}$ from the end of the cruise phase and set up a new timeframe $t_{enterLTO}$, which is defined as the first gathered dataset with an altitude below 3000 ft. The time of descent phase can therefore be calculated as follows: $TIM_{j(Descend)} = t_{enterLTO} - t_{TOD}$. With the beginning of this phase the aircraft reduces its thrust to descent idle thrust (Stell 2010), which is equivalent to ICAO idle thrust (7 %). The fuel flow $FF_{j(Descend)}$ is the ICAO idle value, converted to kg/min.

Approach: The approach phase is defined in the LTO-cycle as the final landing section below 3000 ft until the full stop after wheels are let down on the runway. We use ADS-B data combined with FAA data to calculate the overall time $TIM_{j(Approach)}$ in which the aircraft is in this phase. The start timeframe of
this phase is \( t_{\text{enterLTO}} \). The endpoint of that phase is the time where \( wheels-down \) on the runway is signalled, gathered from web service A, denoted as \( t_{\text{wheels-down}} \). The complete time \( TIM_{j(Airport)} \) is thus calculated by \( TIM_{j(Airport)} = \left| t_{\text{wheels-down}} - t_{\text{enterLTO}} \right| \). In this phase, the standard thrust is set to 30 % (of max. thrust). The fuel flow for one engine, \( FF_{j(Airport)} \), is calculated by using the LTO thrust setting from ICAO engine database for the specific engine, converted to an kg/min value.

**Taxi-in:** With regard to the taxi-out time, the LTO standard times for taxi-in are not suitable (see section 2). We therefore also use ADS-B and FAA data in order to determine the real taxi-in time from touch-down to final parking position. The FAA data provide events on arrival, e.g. \( wheels-down \) and the final parking time (\( t_{\text{Landed}} \)). We use these events to calculate the minutes used for the taxi-in process. Therefore, the taxi-in times \( TIM_{j(Taxi-in)} \) can be calculated by the following term: \( TIM_{j(Taxi-in)} = \left| t_{\text{Landed}} - t_{\text{wheels-down}} \right| \). The fuel flow of an engine during the taxi-in \( FF_{j(Taxi-in)} \) is equal to the taxi-out fuel flow, converting the ICAO engine data from kg/s into kg/min for a specific engine.

Using the defined variables and equation for every phase, we provide the needed data for air cargo transports in emission calculations in the EMIS for one flight.

**DEMONSTRATION & EVALUATION**

The last step for a design science research paradigm is to evaluate the artifact. Depending on the artifact, evaluation can take many forms (Peffers et al. 2007), such as case studies, static/dynamic analysis, experiments, tests or descriptive scenarios or a combination of these (Hevner et al. 2004). In the evaluation we analyse and compare our artifact and calculation model to the well known detailed calculation model from the ICAO in a PCF calculation case study. A PCF is the “total absolute value of life-cycle carbon dioxide-equivalent (\( CO_2 \)) emissions measured in kilograms or metric tonnes” (Kral 2009). Its accounting process is described in several guidelines, e.g. the “GHG protocol” from the World Business Council for Sustainable Development (WBCSD 2004). They define several steps for calculating a PCF. Typically the product life-cycle needs to be defined, boundaries and prioritisations have to be set up and activity data/emission factors need to be collected (WBCSD 2004). We will briefly follow these steps, but for the sake of simplification, we only show the calculation for \( CO_2 \) emission (other GHG can be calculated similarly, thus overall resulting in a \( CO_2 \) PCF).

The envisaged PCF calculation case is as follows: Due to an increased demand for the new Chevrolet Volt (Green Car of the Year 2011), the General Motors (GM) facility in Detroit plans extra duties on the weekend with the production goal of 1000 additional cars in this month. The supplier parts therefore need to be delivered to the facility on short notice. While most suppliers have warehouses nearby the GM facility, some suppliers do not, and are thus not able to deliver parts by truck overnight. In this case, we focus on rear lights, which are produced by Automotive Lighting in Juarez, Mexico. In order to bridge the distance of 1455 miles as fast as possible, the shipment will be carried out by FedEx, which uses a typical air cargo hub and spoke system. FedEx has an international main hub in Memphis, TN, and several collection and delivery stations (CDS) in the US. The next CDS from Juarez is El Paso at the Mexican border. Thus, the air cargo transport will consist of two single flights via the main hub in Memphis (the following parentheses show the airport codes). The first flight is from El Paso (KELP) to Memphis (KMEM) and the second flight from Memphis to Detroit (KDTW). Due to an overnight service, the first flight has to arrive in Memphis before midnight in order to allocate it to the next flight to Detroit in the early morning.

The flight numbers are FDX1255 (El Paso Intl. - Memphis) and FDX1418 (Memphis - Detroit). Both flights are conducted every business day and are performed by the equal airplane (Mc Donnell Douglas DC10-10F), which is a dedicated air cargo transporter. Our proposed middleware delivers the following data from the content repositories: The DC10-10F have a load volume of 402.1 cubic meters (Boeing 2004). For the sake of simplification we assume that packaged rear lights for a thousand Chevrolet Volts have a volume of 45 m³ (one packaged rear light has a volume of approx. 0.0225 cube meters), which means that they can be loaded on to five LD3 containers (9.06 m³) with a total load volume of 45.3m³. The average cargo load factor in 2010 was 53.8 % (IATA 2011). We therefore assume the same load factor for both flights, resulting in a load share of 20.94 % (Loadshare,) for the supplier parts. The ICAO engine database reveals that the charged aircrafts have three CF6-6D1 engines from General Electric (Endres 1998), providing thrust settings for take-off, climb-out, approach and taxi mission phases (CAA 2011). Using the thrust settings from the database and transferring them into a curve-fitted function, we are able to calculate fuel flows in a cruise operational phase with 22 % thrust (adjusted fuel flow function is \( FF_{j(Cruise)} = 0.3800 \text{ kg/s} \). Beside the repository data, the proposed middleware also collects flight activity data from web service A and B (web service track protocols for both flights on the 22nd and 23rd of June 2011 can be inspected at flightaware.com, using provided date, flight number and airport codes).
Using the proposed system, a company can calculate the PCF for transported goods in the specific life-cycle phase. Aggregated results of the data collection are presented in Figure 3, providing the sum of fuel which was used in every flight and showing the allocation of fuel to the single phases of the flight (note: we therefore set $E_{ijk}$ to value 1, in order to compare calculations independently from emission factors, which can vary. For demonstration purposes, we will multiply fuel with an exemplary emission factor later). In order to compare our proposed model, we also provide a standard calculation for fuel, using the detailed model by the ICAO (ICAO 2006). The ICAO calculation model only provides one value for the cruise phase (flight above 3000 ft) and an average value for the LTO-cycle (under 3000 ft). The first flight took place as scheduled (departure 08:40 pm), covering a distance of 865.01 NM (GCD = 843.95 NM), whereas the second flight was delayed by 42 minutes in departure (take-off 03:58 am) but also flew the planned distance of 576.67 NM (GCD = 530.77 NM).

As shown in the results fuel consumption is lower than the calculation with the ICAO detailed calculation model for both flights. These values are in line with previous findings (FOCA 2007) that ICAO models systematically overestimate fuel consumption and the emissions. While the data presented in Figure 3 are aggregated to single phases and complete missions, in order to present it in a more concise manner, this aggregation has actually an underlying timeframe by timeframe granularity (due to the usage of ADS-B data), which allows us to provide detailed data for the analysis of the climate effect at different altitudes. Consider $NO_x$ emissions in the stratosphere caused by aircraft traffic. Using a $NO_x$ emission factor, we are able to determine the exact amount of $NO_x$ and resulting ozone/methane (Lambert 2008) at a specific location and altitude. An exemplary single dataset {Time; Latitude; Longitude; Speed (Kn); Altitude (ft.); Thrust, 04:17; 37.33; -89.16; 560; 33200, 22 %}, using a $NO_x$ emission factor, leads to specific $NO_x$ emissions for this location and altitude. These emissions then have to be transformed into $CO_2$ emissions and should also be included in the PCF (Sausen et al. 2005).

In order to calculate the PCF for the proposed case, we continue by exemplary calculating the carbon dioxide emissions for both flights, using the standard emission factor for jet fuel ($E_{ijk} = 3.157$), stated by the ICAO (2006). As a result we are able to allocate the emissions from single flights to products via the suggested load factor and divide the total share through the amount of products of that share ($Amount of Products$). The outcome is the $CO_2$-PCF in kilograms for one rear light package. In the last step we summarize both results in one PCF share for the transportation process via aircraft from El Paso to Detroit. The results are shown in Table 1.

\[ \text{PCF} = \frac{\sum \text{Fuel}(t) \times E_{CO_2} \times \text{Loadshare}}{\text{Amount of Products}} \]

Therefore one rear light accounts for 14.10 kg $CO_2$ in the air cargo transportation process from El Paso to Detroit. As mentioned before, this calculation also has to be done for the other Kyoto-protocol greenhouse gases in order to provide a complete $CO_2$-eq-PCF.

**CONCLUSION & LIMITATIONS**

In this paper we proposed a system that provides the data basis for the emission calculation in air cargo transportation stages that are realized by third party carriers, using ADS-B real-time flight trajectory data. We therefore followed a design science research approach, finally providing an evaluated initial system artifact. The
result of this paper is a more detailed GHG emission data collection and calculation Green IS artifact, which has been initially evaluated in a single case study. Compared to the common average ICAO calculation model, our results are 20 % lower for the observed air cargo items.

As this paper is research in progress, we are currently improving the model, using several additional data sources and well known aircraft/aerodynamic models (e.g. PESO, ADACAM or BADA). Considering aerodynamic characteristics and external influences, which are actually limitations of the system, will be a further improvement. For example, wind is excluded in our model but influences the thrust and specific speed. Consider head or back winds, for example, which would lead to different thrust levels for a constant cruise speed. In order to include wind effects in the model, real time weather data could be gathered via another web service to accommodate this effect. Another aspect is the aircraft's start weight that should be considered, as it also influences the thrust that is needed to keep the aircraft airborne. A significant part of the start weight is fuel, which decreases over the flight time due to combustion. This effect has to be included as a function of thrust that reduces the weight by the amount of fuel that was combusted over time. Moreover, as a next step, the improved model should be evaluated against other models and FDR data. The initial evaluation case against the ICAO detailed model shows that our model underestimates the GHG emissions in comparison to ICAO. While these results are equal to the ADACAM evaluation, our proposed system needs to be evaluated against FDR data, because these reflect flight situations exactly. Finally, the proposed Green IS is located at the focal companies EIS. Carriers could also implement such a system as a service, offering it to other companies in the supply chain. If air carriers do so, cargo load volume and engine performance repositories could be replaced by data that are included in the fleet management system of a carrier, thus making the implementation easier. Alternatively governmental or non government organizations could offer such a system as a service and make data sets publicly available for informational or further research purposes.

The proposed system contributes to practice and theory. Focal companies can benefit from the artifact, having a better data basis for decision support and reporting of scope three air transportation emissions, conducted by external carriers. Consider the above mentioned mean of transport decision under ecological and economic aspects or comparisons of different air carriers, regions or traffic settings. Furthermore the system can be used to analyse the environmental impact in detail. One possibility would be to show the impacts of high aircraft traffic densities around airports due to overloads, proving airport expansion legitimations in order to reduce traffic and delay loops, thus reducing the environmental impact. Moreover the system enables the provision of detailed fuel consumptions for every timeframe in every phase and altitude of an aircrafts flight. With this data it is not only possible to calculate the GHG emissions but rather the environmental impact of GHG (e.g. NOx and resulting ozone/methane in troposphere). If climate researchers develop models that can accurately quantify the effects of these gases related to the altitude, the model can easily be used to calculate and evaluate the climate effects exactly, even for specific flights.

REFERENCES


COPYRIGHT

Hilpert, Friedemann, Schumann © 2011. The authors assign to ACIS and educational and non-profit institutions a non-exclusive licence to use this document for personal use and in courses of instruction provided that the article is used in full and this copyright statement is reproduced. The authors also grant a non-exclusive licence to ACIS to publish this document in full in the Conference Papers and Proceedings. Those documents may be published on the World Wide Web, CD-ROM, in printed form, and on mirror sites on the World Wide Web. Any other usage is prohibited without the express permission of the authors.