Master Thesis

In

Requirements Engineering and Software Development
Process of an A-SMGCS Earth Magnetic Field Sensor
Data Playback and Basic Analysis Tool

For Fulfilment of the Academic Degree
M.Sc. in Automotive Software Engineering

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Place: Frankfurt

Rishi Ashwin Panditpautra

Date: February 28, 2017
Abstract

Advanced Surface Movement Guidance and Control Systems (A-SMGCS) help to further improve safety and efficiency of the traffic on the aerodrome surface. The current A-SMGCS sensor technologies have certain operational and functional limitations. A new and unprecedented sensor technology is being tested as a pilot project. This unique sensors is called MagSense®. It works based on the principle of detecting the influence of ferromagnetic materials on earth’s magnetic field. For applications in the aviation environment, learning processes are necessary which are generally based on the graphical depiction of stored sensor data and features to analyze the graphs. For this purpose a visualization and analysis tool is needed.

In order to create an adequate tool to allow for depicting stored sensor data and the peaks caused by ferromagnetic objects in aircraft and vehicles, a requirements engineering process will be conducted wherein the requirements of the various stakeholders will be identified and harmonized. In general, the appropriate RE approach will ensure mutual agreement among the stakeholders and a set of requirements for the first edition of the tool without contradictions. The harmonized package of requirements will then be used as the starting point for a software development process, after which the tool will be produced as specified and validated as a part of this Master’s Thesis.

This Master’s Thesis puts a special focus on the choice of a suitable method in Requirements Engineering and Requirements Management, adequately adapted to the project size and its quality. The selection of appropriate elements from the methodology as well as the outcomes from applying them on a specific software production project are at the core.

**Keywords:** Requirements, Requirements Engineering, Stakeholders, EMFS.
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<td>ACWP</td>
<td>Apron Controller Working Position</td>
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<tr>
<td>ADS-B</td>
<td>Automatic Dependent Surveillance - Broadcast</td>
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<td>AGL</td>
<td>Airfield Ground Lighting</td>
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<td>AIBT</td>
<td>Actual In-Blocks Time</td>
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<tr>
<td>ANSP</td>
<td>Air Navigation Service Provider</td>
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<tr>
<td>AO</td>
<td>Airport Operators</td>
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<tr>
<td>AOBT</td>
<td>Actual Off-Blocks Time</td>
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<td>AODB</td>
<td>Airport Operational Data Base</td>
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<td>A-SMGCS</td>
<td>Advanced Surface Movement Guidance and Control Systems</td>
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<tr>
<td>ASR</td>
<td>Airport Surveillance Radar</td>
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<td>ASSS</td>
<td>Airport Safety Support Service</td>
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<tr>
<td>ATC</td>
<td>Air Traffic Controller</td>
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<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
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<tr>
<td>A-VDGS</td>
<td>Advanced Visual Docking Guidance System</td>
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<tr>
<td>AVOL</td>
<td>Aerodrome Visibility Operational Level</td>
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<tr>
<td>CAN</td>
<td>Controller Area Network</td>
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<tr>
<td>CATC</td>
<td>Conflicting ATC Clearances</td>
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<td>CMAC</td>
<td>Conformance Monitoring Alerts to Controllers</td>
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<td>CR</td>
<td>Change Requests</td>
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<tr>
<td>CWP</td>
<td>Controller Working Position</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>DFS GmbH</td>
<td>Deutsche Flugsicherung GmbH</td>
</tr>
<tr>
<td>DGS</td>
<td>Docking Guidance System</td>
</tr>
<tr>
<td>DXB</td>
<td>Dubai Airport</td>
</tr>
<tr>
<td>EFB</td>
<td>Electronic Flight Bag</td>
</tr>
<tr>
<td>EFS</td>
<td>Electronic Flight Strip System</td>
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<td>EMF</td>
<td>Earth Magnetic Field</td>
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<td>EMFS</td>
<td>Earth Magnetic Field Sensor</td>
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<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FTG</td>
<td>Follow-the-Greens</td>
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<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<td>IREB-CPRE</td>
<td>International Requirements Engineering Board – Certified Professional Requirements Engineer</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
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<tr>
<td>IUK-AO11</td>
<td>Information and Communication Services - Airport Operators</td>
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<td>IUK-CI</td>
<td>Information and Communication Services - Corporate Information Management</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicators</td>
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<td>LVC</td>
<td>Low Visibility Conditions</td>
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<td>MASPS</td>
<td>Minimum Aviation System Performance Specification</td>
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<td>MFMS</td>
<td>Medium Field Magnetic Sensor</td>
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<td>MLAT</td>
<td>Multilateration System</td>
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<td>MSDF</td>
<td>Multi Sensor Data Fusion</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<td>RE</td>
<td>Requirements Engineering</td>
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<td>RETS</td>
<td>Radar Extraction and Tracking System</td>
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<td>RM</td>
<td>Requirements Management</td>
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<tr>
<td>RMCA</td>
<td>Runway Monitoring and Conflict Alerting</td>
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<td>RPA</td>
<td>Reported Position Accuracy</td>
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<tr>
<td>RWY</td>
<td>Runway</td>
</tr>
<tr>
<td>SMR</td>
<td>Surface Movement Radars</td>
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<tr>
<td>TC</td>
<td>Track Continuity</td>
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<tr>
<td>TCL</td>
<td>Taxiway Center Line Lights</td>
</tr>
<tr>
<td>TWY</td>
<td>Taxiway</td>
</tr>
<tr>
<td>UAV</td>
<td>Unmanned Air Vehicle</td>
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<td>WG-41</td>
<td>Working Group 41</td>
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1 Introduction

Fraport AG, owner and operator of Frankfurt Airport and around 30 more airports around the globe, has recently filed two applications for workers’ patents (PCT/EP2014/054095 and PCT/EP2016/058162) in the field of traffic management and sensor systems. The related technology is currently technically implemented as pilot projects, tested, evaluated, and turned into product solutions with the objective to market them globally. In general, Fraport AG focuses at optimizing its airport operations with new and improved safety technologies and procedures. The department IUK-AO11, the IT department responsible for developing airside systems, represents an innovative mindset, profound aviation expertise and also methodical expert knowledge including requirements engineering processes. The department is driven by the employees’ conviction on the operational impact of new and improved technical solutions in combination with the respective operational procedures. It aligns its strategy to the long-term forecasted development of the global aviation market and the forecast on Frankfurt Airport in particular. IUK-AO11 was the idea provider for the recently filed patents and is currently functioning as the project manager pursuing the communication between all partners involved.

In state-of-the-art airport operations, Advanced Surface Movement Guidance and Control Systems (A-SMGCS) help to further improve safety and efficiency of the traffic on the aerodrome surface. An adequate A-SMGCS is a vital system at any given time, but especially in Low Visibility Conditions (LVC) as it is based on the detection and identification of the mobiles1 which operate on the airport using established sensor technologies. Based on individual mobile’s positions, vectors, and identification, a holistic traffic situation is derived and enriched with flight plan data. The resulting synthetic surface situation is then depicted to the controllers as a map and on the screen of the Controller Working Position (CWP). It is used for improved situational awareness and as a basis for decision making processes. Furthermore, the availability of a reliable synthetic surface situation can prevent Air Traffic Management (ATM) from potential chains of events that may lead to negative operational impacts such as delays or dangerous traffic situations.

The current A-SMGCS sensor technologies have certain operational and functional limitations. These are well-known and represented in the current standards and regulations. Through R&D activities on national and European level, new A-SMGCS

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1 In aviation, the term ‘mobiles’ generally refers to all vehicles and aircraft operating on the aerodrome surface.
functions recently became available such as automated generation of surface routes and automated guidance, e.g. via Follow-the-Greens. Follow-the-Greens is a procedure to follow a forward moving chain of activated taxiway center line lights eliminating the task of ground navigation for the flight crews and vehicle drivers. Some of the new functions are soon to become mandatory for large and complex airports. These functions generally require a more precise and reliable surveillance compared to the currently established A-SMGCS components. In consequence, airports are hoping for sensor technologies to become available that adequately support the new A-SMGCS functions.

Fraport AG is among those Airport Operators (AO) looking for further improving the A-SMGCS precision and reliability. Based on the abovementioned patent applications and together with a partner company called MobiliSis GmbH from Heppenheim, Fraport wants to overcome the known inadequacies of Surface Movement Radars (SMR) and the Multilateration System (MLAT) with a new and unprecedented sensor technology. This unique sensors is called MagSense®. It works based on the principle of detecting the influence of ferromagnetic materials on earth’s magnetic field. It is currently being implemented and tested on taxiway N7 at Frankfurt and is already providing promising results exhibiting its outstanding capabilities. Based on the results from the evaluations performed to date, additional fields of application on the airside of airports have been identified. Originally, the sensors were used for landside applications mainly concerning road traffic and parking.

Since the sensors are from a different technological environment, the central components for analyzing the sensor data and for preparing the integration of the data into the existing system environment at airport level are not available by now. The sensors are integrated in Controller Area Network (CAN) bus cables\(^2\) with various length and number of sensors. In road traffic applications, the sensor data is used in close to real-time, e.g. for counting processes or for calculating speeds. Sensor data analyses or a visualization were not foreseen in this environment. In consequence, the sensor data can only be stored in simple but well-structured text files. For applications in the aviation environment, learning processes are necessary which are generally based on the graphical depiction of stored sensor data and features to analyze the graphs. For this purpose a visualization and analysis tool is needed.

The development of this analysis tool, now called ‘MagView’ was defined a part of the project to encompass this Master’s Thesis. To accomplish the development of the tool, an appropriate Requirements Engineering (RE) process had to be identified and conducted in order to collect and to coordinate the different requirements of the various

\(^2\) Standardized on international level as ISO11898 and originally developed by Bosch GmbH of Gerlingen.
stakeholders. The selection of appropriate elements from the portfolio-like RE methodology had to be documented and presented in the Master’s Thesis and together with the harmonized set of requirements. In general, the appropriate RE approach shall ensure mutual agreement among the stakeholders and a set of requirements for the first edition of the tool without contradictions. After this set of requirements for MagView was established, the production and testing of the tool began.

![Official MagView Starting Screen](image)

**Figure 1: Official MagView Starting Screen**

### 1.1 Motivation

As of now, there is no way to graphically analyze MagSense data, e.g. in order to identify individual ground movements in the sensor data stream. In general, a visualization of the data after the actual event is currently not possible.

The availability of such a visualization and analysis tool is prerequisite for in-depth evaluation of the sensor capabilities. This again is a basis for the definition of products and regulatory processes including the process leading to the permission to use the sensor data for operational purposes on the aerodrome surface by the responsible authorities.

In consequence, this Master’s Thesis contributes significantly to the introduction of a new and highly beneficial sensor for the aerodrome surface. It improves people’s
safety and the performance of the airport in all weather conditions, which I consider a very motivating objective.

1.2 Problem Statement

In order to improve the data quality and reliability of the A-SMGCS system at Frankfurt Airport and to develop further products, an innovative sensor called MagSense® is currently been evaluated on taxiway N7. MagSense is an Earth Magnetic Field Sensor (EMFS) manufactured by MobiliSis GmbH.

![Image of MagSense CAN-Bus Cables](MobiliSis GmbH)

The EMFS detects the influence of ferromagnetic substances of the mobiles on earth’s magnetic field. This information can then be used to precisely determine the positions and vectors\(^3\) of the mobiles.

The output of the sensor bus or multiple sensor bus systems can be viewed in real-time on a display in the field. When a sensor detects a significant change in the earth’s magnetic field caused by a vehicle or aircraft, the detection is displayed in form of peaks. So whenever there is an occurrence of a peak on the output screen at a particular time, this indicates that one or more sensor(s) have detected an aircraft or vehicle which has passed over them.

Currently, the output of the EMFS sensors is stored in text files. The output values of EMFS sensors are in format of three-dimensional axis values (x-axis, y-axis and z-}

\(^3\) For determining the vectors of the mobiles, more than one sensor bus is necessary.
axis), number of sensors, length of vector and time respectively (please see Figure 3: Example Screen Shot of MagSense Sensor Data).

Figure 3: Example Screen Shot of MagSense Sensor Data

In order to create an adequate tool to allow for depicting stored sensor data and the peaks caused by ferromagnetic objects in aircraft and vehicles, a requirements engineering process will be conducted based on International Requirements Engineering Board – Certified Professional Requirements Engineer (IREB-CPRE) methodology wherein the requirements of the various stakeholders will be identified and harmonized.

Based on the initial priority, the requirements for the tool will be selected or deselected for the first release during the requirements engineering process. The harmonized package of requirements will then be used as the starting point for a software development process, after which the tool will be produced as specified and validated as a part of this Master’s Thesis. The further development, i.e. future releases beyond version 1.0, will be performed IUK-AO11 as future work. Nevertheless, all the requirements known to the stakeholders at this stage will be collected and reserved for the next releases.

1.3 Research Objectives

From the practical project management point of view of IUK-AO11, a clear tendency towards longer planned periods for RE in airside development projects on airports can be observed\(^4\). This underlines the importance of the phases before actual programming takes place in order to better identify the expectations of the user groups.

\(^4\) This corresponds to greater investments in this early stage of projects.
and their needs. In consequence, the overall objective of this Master’s Thesis is the depiction of the RE processes that create the basis for the software development of a visualization and playback tool for stored MagSense EMFS data with basic analysis features. The main scientific challenge of the work is the appropriate Requirements Management (RM) process.

Concretely speaking, the starting point of the RE process in this particular case were preliminary considerations in order to identify presumably appropriate building blocks of the RE methodology for the current project. Compared to other projects the production of MagView was a rather small undertaking with only a few stakeholders and with no critical conflicts to be expected. Hence, elements of the RE methodology best supporting small and medium projects in this environment needed to be identified. Generally, the RE and RM processes shall ensure that all stakeholder’s requirements are taken into account, are sensibly prioritized and finally assigned to either the first release of the software, or to subsequent versions. All decisions concerning requirements and the release planning need to be taken in consensus of all the stakeholders. This is expected to reduce the number of requests for changes and leads to a greater acceptance of the final product by the users.

Among the stakeholders that were invited to formulate requirements on MagView, the IUK-CI department of Fraport AG has a special role: IUK-CI will not use the final product, but holds responsibility for Corporate Information Management. In consequence, IUK-CI makes unambiguous specifications concerning the IT architecture, operational behavior, and programming languages of all products that are produced and used within Fraport AG. Other stakeholders proposing requirements were MobiliSis GmbH and IUK-AO11.

In all, this Master’s Thesis puts a special focus on the choice of a suitable method in RE and RM, adequately adapted to the project size and its quality. The selection of appropriate elements from the methodology as well as the outcomes from applying them on a specific software production project are at the core. Hence, the driving research question, the scientific challenge of the Thesis, is as follows: What is the most appropriate way of depicting the sensor data and how are the requirements of different stakeholders concerning basic analysis features best taken into account?

Some of the main tasks deriving from this question are (not exhaustive):

- Reasoned choice of methods in the field of requirements management
- Implementation of requirements workshops with relevant stakeholders
- Analyzing applications and selection of elements from the IREB-CPRE methodology
- Execution of RE process to establish harmonized set of requirements
• Producing a generally accepted requirement state for a first release
• Creating an appropriate request documentation
• Documentation and evaluation of approach.
• Production of software tool according to previously established agreement
• Initializing Technical implementation of the tools, testing and commissioning

The following figure (Figure 4: Main stages of the MagView project) depicts the main stages of the overall project, from the raw text files to the harmonized set of requirements.

Figure 4: Main stages of the MagView project

1.4 Structure of the Thesis

The structure of this Master Thesis report is based on the knowledge which was acquired in the course of literature review, also involvement of several attributes and is classified into eight sections:

Section 2 illustrates the fundamental concepts of the literature research findings in perspective to the scope of this master thesis in order to describe broader summary on
the state of the art of the present technologies at Frankfurt airport. It also focuses on the notion and the solution in the aviation field which could improve and ensure better results.

**Section 3** describes the requirements engineering approaches in order to implement the solution. It mainly focuses on the introductory part of how requirements engineering was carried out and the discovery techniques used to elicit the requirements of the stakeholder’s. The approach is divided into different stages which are explained in section 3 to section 6.

**Section 4** outlines the manner in which the requirements discovered from relevant stakeholders must be managed. The perspectives of and the quality criteria’s of a requirement document are outlined along with the goal model.

**Section 5** expresses the validation and negotiation techniques which needs to be carried out so that conflicts are identified at early stages before the implementation of the tool is completed and resolutions are proposed to the stakeholder’s in order to satisfy the requirements proposed. It also portrays the method in managing a requirements document. It highlights the importance and the necessity of defining the properties of the requirements and various prioritization techniques which used in practice to prioritize the requirements.

**Section 6** depicts the results which were delivered based on the requirements proposed by the stakeholders. It shows the working of tool on the two aspects which were visualization and basic playback functionalities.

**Section 7** encapsulates the conclusion to this work emphasizing the goal to be accomplished. Also, it suggests some significant developments to the present project, the possibilities for future expansions.
2 Technical Background – Fundamental Concepts

This section delivers the literature research findings that have been discussed in context to the scope of this Master’s Thesis in order to illustrate extensive outline on the state of the art of the technologies concerning EMFS in the aviation domain.

According to statistics from EUROCONTROL and the Federal Aviation Administration (FAA) from the year 2000, ground movements of mobiles are considered to be the highest risk factor at the airfield (Bloisi, Iocchi, Nardi, Fiorini, & Graziano, 2012). Several aspects are considered contributing factors to ground movement risks, e.g. Low Visibility Conditions (LVC) prevailing, unavailability of ground radars, ragged and obscured guidance signs, taxiway labels not present on the ATC map, etc. In consequence, a special focus on the safety of ground movements is absolutely mandatory.

2.1 Advanced Surface Movement Guidance and Control System

2.1.1 A-SMGCS Overview

The Advanced Surface Movement Guidance and Control System (A-SMGCS) is one of the cores of the evolutionary progress in research and development at present in Air Traffic Management (ATM). A-SMGCS imply the growing trends to enhance the ATM system by adopting, integrating and harmonizing sophisticated automation techniques.

As explained in section 1.1, the A-SMGCS delivers a synthetic surface traffic situation to the working position of the controllers. Consequently, the role of this Controller Working Position, independent from whether it is for a controller of the Air Navigation Service Provider (ANSP) Deutsche Flugsicherung GmbH (DFS GmbH) or an Apron Controller Working Position (ACWP) used by controllers working for the AO, improves the actors’ capability to safely and efficiently perform traffic management on the airside of the airport.5

5 This depiction reflects a shared responsibility situation which is only prevailing on large airports in Austria, Germany, and Switzerland. In these countries, Airport Operators (AO) are in the position to perform a limited set of ATC Services themselves. In consequence, they own and operate control towers and employ controllers responsible for managing apron areas and the taxiway system. These are generally referred to as ‘Apron Controllers’ or ‘Apron Managers’. In most other countries, all ATC Services are provided by the ANSP, while in the US, some apron areas are controlled by the airlines.
In this section the theoretical concept behind A-SMGCS and its fundamental building blocks will be presented with the purpose to establish broader understanding of the technical and operational situation implemented at medium and large airports in general and at Frankfurt Airport in particular.

ICAO defines A-SMGCS as follows: “It is an ideology to support guided direction, routing service and surveillance system to manage airplane and vehicles to sustain determined movement rate of the outside under every single weather condition stretch the providing routing, guidance and for the control of aircraft and vehicles in order to maintain the declared surface movement rate under all weather conditions within the scope of Aerodrome Visibility Operational Level (AVOL) and at the same time maintaining the obligatory safety level.” (EUROCAE, 2015)

A-SMGCS is based on advanced technologies and a high-level of integration. It is expected to support adequate capacity and safety in all visibility conditions, traffic densities and complexities of airfield layouts. As a standardized unit with integral procedures, it comprises four elementary functions:

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6 This reflects the situation and phraseology as represented in the still globally valid ICAO Doc9830 (2004). Through R&D results and new functionalities, the names of the building blocks of A-SMGCS have changed in the meantime: While the initial concept descriptions talked about ‘levels’, current documents use ‘functions’ or ‘services’. In addition, the functionalities within the ‘functions’ and ‘services’ have been in the process of expanding and upgrading for the last about three years and mainly thanks to research work and standardization work performed in and around the SESAR Programme in Europe. This will be reflected on the ICAO level fairly soon, as work on a successor for 9830 has already begun.
Lower level operations\(^7\) contribute to improved identification and detection procedures and help controllers create an enhanced circumstantial awareness, e.g. by detecting runway incursions (Eurocontrol, 2016). The air traffic is growing day-by-day and this leads to an increase in the number of movements at the airports. This rise will further escalate the complexity of traffic flows on the airports and it is therefore necessary to minimize the risk of misbehavior and misunderstanding leading to unexpected behavior and ultimately to incidents and accidents.

Currently, the mobility area at Frankfurt Airport, i.e. “that part of an airfield utilized for the takeoff, landing and taxiing of aircraft” (Fraport, 2016) is controlled and monitored with the help of two sensor technologies. Fraport AG own and operate one of the largest MLAT systems worldwide, which detects aircraft by using a methodology recognized as time difference of arrival (Wilco, 2010). The data coming from the MLAT System is then fused in a Multi Sensor Data Fusion (MSDF) with tracks derived from two Surface Movement Radars (SMR) provided by the ANSP DFS GmbH and one Airport Surveillance Radar (ASR), which operates to identify and track aircraft altitude and speed vector in the approach phase of flight and during climbout (Fraport, 2016).

In Frankfurt, the special situation prevails that MLAT, SMR and ASR data are exchanged between ANSP and AO, while the two organizations have independent MSDF systems. In consequence, this may lead to potential differences in the surface traffic situation depicted to their respective controllers. As the responsibilities are shared along clearly defined geographical border lines with fixed areas for transferring responsibilities over flights and vehicles between ANSP and AO, these differences surface only in individual cases (Fraport, 2016).

### 2.1.2 A-SMGCS Services (Functions)

In this section the operational and technical building blocks of A-SMGCS will be discussed from a theoretical point of view. The objective is to present the services of A-SMGCS and give a brief overview on A-SMGCS requirements.

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7 This function is now called ‘Airport Safety Support Service’ and it features additional alerts and warnings for traffic situations also away from the runway(s).

8 i.e. Surveillance-only operations.
On a European level, the A-SMGCS Services are now named and described as follows (please see Figure 6: A-SMGCS Overview (EUROCONTROL A-SMGCS Specification))\(^9\): (Eurocontrol, 2016)

- Surveillance Service
- Airport Safety Support Service
- Routing Service
- Guidance Services

![A-SMGCS Overview](image)

**Figure 6: A-SMGCS Overview (EUROCONTROL A-SMGCS Specification)**

This section will use two main documents from the previous organizations to explain the operational and technical requirements of A-SMGCS: EUROCONTROL Specification for A-SMGCS version 0.5 (Eurocontrol, 2016) and EUROCAE ED-87C Minimum Aviation System Performance Specification for Advanced Surface Movement Guidance and Control Systems (EUROCAE, 2015). While the EUROCONTROL document will serve as a guideline for implementing or upgrading an A-SMGCS at an airport when published by the end of 2017, the ED-87C constitutes a regulatory document that defines the minimum performance necessary to call a system an A-SMGCS, e.g. in terms of Reported Position Accuracy (RPA) or Track Continuity (TC) key performance indicators.

\(^9\) As described in FN7, work on a new document on ICAO level has just begun. As of now, European documents such as the EUROCONTROL Specification for A-SMGCS are the first to feature the new phraseology and content of the services. Nevertheless, it is expected that ICAO will take these concepts on board.
The minimum configuration for any A-SMGCS is the combination of a non-cooperative sensor system, e.g. a SMR, and a cooperative sensor, e.g. a MLAT System (Casaca et al., 2007). The difference between cooperative and non-cooperative is as follows: A cooperative sensor actively delivers information to the sensor, e.g. identification information such as aircraft type, callsign, or registration. A non-cooperative sensor is passive and does not interact actively with the sensor (Casaca et al., 2007).

- **Surveillance Service**

  The Surveillance Service represents the foundation layer of an A-SMGCS. It is essential for the system to deliver the desired results as all other A-SMGCS services depend on the input data provided by the Surveillance Service.

  Surveillance provides information on position and vector of all mobiles operating on the aerodrome surface. By enriching this information with flight plan data and by also integrating aircraft on approach and in the initial phase of flight after the take-off, a holistic synthetic and map-based overview of the airport traffic situation can be generated and presented to the controllers (Eurocontrol, 2016). This synthetic traffic situation constitutes the basis for managing the traffic on the airport. This management process includes surface traffic such as crossings of active runways and sequencing at intersections, as well as take-offs and landings (Eurocontrol, 2016).

  The Surveillance Service and the therewith derived synthetic surface situation, e.g. on an ACWP, will help the controllers in various aspects:

  **Traffic display:** Helps avoid collisions between mobiles, especially in LVC and allows for planning ahead in managing the traffic based on sensibly consolidated information.

  **Mobile identification:** Confirms the identity of all cooperative mobiles. This is usually achieved by attaching a label to the symbol or shape representing the mobile on the Human Machine Interface (HMI).

  **Mobile position:** Detects and indicates the position of potential intruders. The quality and reliability of the position information is crucial in this case as intrusion will trigger immediate controller action, e.g. the instruction to abort landing for aircraft on approach.

  Additionally, the controller also needs unambiguous depiction of the airport environment including the building structures and the runway and taxiway layout, current constraints (closed TWYs/RWYs, one-way TWYs, etc.) and reference points (RWY thresholds, holding points, etc.). This has to be ensured via adequate system maintenance routines and in coordination with partnering systems.
• **Airport Safety Support Service**

The Airport Safety Support Service (ASSS) aims at further improving the safety situation on the aerodrome surface. In general, violations against rules and instructions can be caused by aircraft, vehicles or ATC\(^{10}\). ASSS provides ATC with a variety of advantages (EUROCAE, 2015):

- Anticipation of potential collisions (aircraft vs. aircraft and aircraft vs. vehicle)
- Detection of intrusions and conflicts
- Detection of mobiles not acting in conformance to rules and instructions
- Provision of clear and unambiguous information and alarms to controllers (EUROCAE, 2015).

Not all alerts involve the same risk and potential impact. Hence, they shall be presented differently to the controller according to how dangerous they are. In general, two stages of alerts are recommended:

- Stage 1: A stage 1 alert is an *Information* alert. It indicates possible hazardous situations to controllers. On many CWPs, this type of alert is depicted in yellow (Eurocontrol, 2016).
- Stage 2: A stage 2 alert is an *Alarm*. It indicates the emergence of a dangerous situation to controllers that requires immediate controller attention and action. On many CWPs, this type of alert is depicted in red (Eurocontrol, 2016).

The sources for potential danger on the aerodrome surface are manifold. In consequence, the traditional RMCA alerts\(^{11}\) (please see below) did not suffice any longer and new alerts were introduced and categorized with respect to the actor who causes the risk. Hence, the Airport Safety Support Service consists of three sub-services (Eurocontrol, 2016). These are:

- Runway Monitoring and Conflict Alerting (RMCA)
- Conflicting ATC Clearances (CATC)
- Conformance Monitoring Alerts to Controllers (CMAC)

**RMCA Sub-Service**

RMCA was previously the so called ‘Level 2’ in the old definition of A-SMGCS. Not all airports have RMCA and the ones that have it still experience incidents. RMCA

\(^{10}\) Rarely, other intruders occur. This may include rotorcraft, animals and people.

\(^{11}\) This set of alerts comes from older definitions of A-SMGCS and represents what ICAO originally defined as ‘Aerodrome Safety’ in 2004.
Technical Background – Fundamental Concepts

is based on surveillance only (positions of the mobiles) and triggered at the last moment, i.e. when the incident is detected. RMCA is very hard to tune in order to avoid false alerts while still providing adequate safety (Eurocontrol, 2016).

Figure 7: Typical RMCA Alert on a CWP. Is AUA411U really beyond the holding position? (EUROCONTROL)

In general, RMCA is still used at several European airports and is considered to be overcome by the CATC and CMAC sub-services in the coming years.

Figure 8: Incidents that happened despite RMCA available (EUROCONTROL)

2.1.2.1.1 CATC Sub-Service

The CATC types of alerts cover the situation where a controller forgets a previously issued clearance to a mobile and then try to give another clearance which could lead to an incident or accident (Eurocontrol, 2016). A rather well known example for a CATC situation occurred on 15/03/2011 at Zurich, where two Airbus A320 of Swiss nearly collided on take-off. Post-analysis revealed that both aircraft had been cleared for take-off on runway 16 and runway 28, respectively, and by the same controller after he had forgotten about the original clearance he had issued before (Hradecky, 2011) (please see Figure 9: Close call on 15/03/2011 at ZRH (EUROCONTROL)).
While the situation at Zurich fortunately ended without a crash, comparable incidents led to tragic accidents like the 1991 crash of a USAir Boeing 737-3B7 (N388US) and a SkyWest Fairchild Swearingen SA 227AC Metro III (N683AV) at Los Angeles International Airport, killing 39 people (National Transportation Safety Board, 1991). This is just one example for a situation that clearly depicts the demand for technical support in this area and many others are well-known too, such as the terrible collision at Milan Linate on 8/10/2001, where 118 people lost their lives in a tragic crash in the morning fog (“Linate Airport disaster,” 2001).

2.1.2.1.2 CMAC Sub-Service

The Conformance Monitoring Alerts for Controllers cover situations of non-conformance to procedures or instructions. Examples are Flight Crew not doing what they
have been instructed to, like lining up or taking off without a clearance, taxiing the wrong way or entering a closed runway or taxiway. CMAC also covers route deviations, entering of closed areas, runway incursions, and many situations of non-conformance to instructions (Eurocontrol, 2016).

Figure 10: No Take-Off Clearance Alarm (CMAC) on the Controller Working Position at Riga Airport (Eurocontrol, 2016)

- **Routing Service**

  The objective of the Routing Service is to automatically generate and propose routes for mobiles operating on the taxiway center line\(^\text{12}\). The Service takes prevailing and planned constraints into account and is aware of all restrictions and limitations, e.g. wing span limitations.

  The idea behind this Service is pretty much comparable to a car navigation system: The system is fed with starting point and destination point of a movement via an interface to the Airport Operational Data Base (AODB) that contains all flight plan data and calculates the currently best possible route taking into account all known influencing factors such as traffic situation, constraints, aircraft type, etc. (Antonov et al., 2016). This route is then proposed to the controller via the HMI. Depending on the CWP and HMI in use, the controller can then use an input device such as mouse or finger touch to accept the proposed route or to make alterations before accepting (Eurocontrol, 2016).

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\(^\text{12}\) In general, these are aircraft, tow tugs, tow movements (tug + aircraft) and some vehicles.
The Routing Service will play a key role for enabling certain functionalities of the Airport Safety Support Service and also some for the Guidance Service as Guidance will generally be provided along the cleared route.

2.1.2.2 Guidance Service

The Guidance Service contributes to airport operations and A-SMGCS in particular by providing visual or audible representation of the cleared route to the actors on the aerodrome surface (Eurocontrol, 2016). The traditional voice instructions delivered via radio from controllers to flight crews and vehicle drivers are not considered part of the standard procedures of the Guidance Service, but may function as a fallback. Nevertheless, an audible way of providing Guidance to flight crews and vehicle drivers is subject to PCT/EP2014/054095 and hence protected Intellectual Property of Fraport AG. This technology is still under development and delivers synthetic voice instructions via the 75MHz Marker Beacon Receiver available in all aircraft to flight crews and to dedicated receivers in vehicles. This way of providing Guidance, as well as a number of other technologies, has not yet reached full maturity and will hence not be described in further detail in this document. Another example for such a technology is the depiction of the synthetic surface situation on handheld Electronic Flight Bag (EFB) devices in the cockpit. Fraport is currently preparing field trials with this technology.

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13 E.g. when it comes to compliance or non-compliance to an instructed/cleared route.
In consequence, at this stage the only fully mature technology considered ready for implementation is Guidance via Airfield Ground Lighting (AGL), commonly referred to as Follow-the-Greens.

**Follow-the-Greens**

As described in further up in the document, Follow-the-Greens is the procedure to follow a forward moving chain of activated Taxiway Center Line Lights (TCL) (Eurocontrol, 2016). This procedure eliminates the task of ground navigation for the flight crews and vehicle drivers as they can concentrate on following the light instructions.

The work principle of Follow-the-Greens is based on the correlation of the cleared route of a mobile with taxi instructions issued by the controller. Follow-the-Greens illuminates the TCL to a specified distance ahead of the mobile in question, switching them on and off automatically (Eurocontrol, 2016). The necessary distances between mobiles are the responsibility of the flight crew or vehicle driver in good weather situations only. In LVC, the controller has to provide safe separations. In consequence, Follow-the-Greens does not need to provide safeguarded distances in good weather, while in LVC the provision of safe ‘gaps’ between the mobiles moving on the aerodrome surface need to be established. This is usually achieved by making sure that the TCL behind a mobile are always switched off over a configurable distance.

The length of the route indication (please see Figure 12: HMI depicting the activated greens in front of the mobiles (left) and the route indication in the field (right)) and separation from other mobiles may vary with external factors such as visibility conditions (e.g. non-LVC or LVC), kind of mobile, type of aircraft, topographical influences, airport layout, desired velocity of the mobile, and others. The final decision on the length of the indication for a specific movement shall be taken according to local conditions.

The lighting situation in the field will also be presented to the controllers (please see Figure 12: HMI depicting the activated greens in front of the mobiles (left) and the route indication in the field (right)). It is important for them to remain in the loop on guidance information being provided to actors in the field. Hence, the TCL status for each movement must be presented to the controller in charge.

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14 Depending on the Use Case, this can also be done with apron taxilane lights and lead in and lead out lights on a stand
Figure 12: HMI depicting the activated greens in front of the mobiles (left) and the route indication in the field (right) (Fraport, 2016)

Follow-the-Greens is not a new concept. It was already discussed in the 1980s and first implementations were made in the early 1990s, e.g. at Munich Airport. In consequence, the ICAO Doc9830 has established a set of basic rules on Follow-the-Greens already in 2004 (International Civil Aviation Organization, 2004). These are as follows:

- Green lights in front of the mobile represent the instruction to follow
- No activated green lights (or activated red lights) in front of the mobile indicate a stop instruction to the mobiles
- Yellow lights (activated or flashing) represent the instruction to be cautious

The essential difference between the systems implemented some years ago and today’s concept of Follow-the-Greens is mainly the level of automation: While the longer established systems in London Heathrow and Munich are either manually controlled, a modern Follow-the-Greens can be considered a highly automated system that translates system status and controller inputs in corresponding switching commands for the TCL. A system with very modern features is for example implemented at Dubai Airport (DXB).

2.1.3 A-SMGCS Technical Requirements

On the regulatory side, the EUROCAE Working Group 41 (WG-41) constantly updates the Minimum Aviation System Performance Specification (MASPS) for A-SMGCS, the document ED-87 (EUROCAE, 2015). The currently valid version is ED-87C and it has full legal status in Europe. It features detailed technical descriptions and requirements on the technical behavior of an A-SMGCS. The latter are minimum requirements which have to be accomplished by all manufacturers. Nevertheless, based on individual AO or ANSP decisions, stricter requirements can be put in place for an A-SMGCS at any time.
Typical areas in which A-SMGCS have problems to comply with the requirements of the ED-87C are within the Surveillance Service and the Key Performance Indicators (KPI) Reported Position Accuracy (RPA) and Track Continuity (TC) in particular (EUROCAE, 2015). While the first regulates the maximum spatial deviation between actual position in the field and reported position in the system, the second limits number and duration of track loss. A full list of the Surveillance requirements in ED-87C can be found in the Appendix A2 (EUROCAE, 2015).

2.2 A-SMGCS at Frankfurt Airport

This section has its main focus on the Surveillance Service, as the EMFS will become a part of this Service depending on the actual sensor application and Use Case. Furthermore, this section is written from an AO’s point of view. Consequently, the A-SMGCS of the ANSP is not taken into account.

2.2.1 Status Quo

At Frankfurt Airport, a rather complex and sophisticated Surveillance Service is currently in use. It features the following surveillance components (please see Figure 12: HMI depicting the activated greens in front of the mobiles (left) and the route indication in the field (right)):

- 1 ASR
- SMR
- 49 MLAT Remote Units
- 1 ADS-B Receiver
- 1 Multi Sensor Data Fusion for AO
- 1 Multi Sensor Data Fusion for ANSP

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15 A Remote Unit is basically a receiving MLAT antenna with an extremely precise clock.
The 49 Remote Units of the MLAT System are a very large number compared to other airports. Each RU is capable to also interpret ADS-B signals. As of now, the ADS-B is only used for vehicles, however in 2020 it has to be reliable enough for use with aircraft also. The MLAT antennas geographical distribution on the airport is depicted in Figure 14: Geographical distribution of MLAT antennas at Frankfurt.

As shown in Figure 13: Depiction of the current A-SMGCS (AO view) at Frankfurt and the planned EMFS additions (red), the data obtained from the several sensor systems is algorithmically fused in the MSDF. The MSDF is a highly capable server that collects all data inputs. These are precisely time stamped and can therefore be fused into
coordinated outputs at a frequency of 1Hz, e.g. as a synthetic surface situation depicted on a CWP or ACWP.

The individual sensor systems all have their intermediate level logics that prepare the raw data for the integration process in the MSDF. In case of the SMR, a Radar Extraction and Tracking System (RETS) analyses the radar reflections. It identifies moving objects and reports their position to the MSDF in a standardized data format (Bloisi et al., 2012). The actual integration process of the data from the various sensors is then performed based on individual targets, i.e. based on each individual mobile detected on the aerodrome surface. Since the data received by the MSDF are provided by different sensors with various technical limitations and data quality varying by geographical region of the airport, a powerful prioritization algorithm needs to be part of the data fusion process. It makes sure that the best available data is taken into account with higher priority compared to less reliable sources. The prioritization algorithms are self-learning in sophisticated MSDF and in general a constant subject to optimization by engineers. The fused position information is then enriched with additional information from the mobiles sent via the Mode-S antenna of aircraft and vehicles (Wilco, 2010). The information sent can then be correlated by the MSDF to flight plan data obtainable from the AODB (International Civil Aviation Organization, 2004). This process attaches the required additional information to the target in the system, e.g. aircraft type and callsign.

At Frankfurt Airport, the synthetic surface situation established by the MSDF is then displayed on a dedicated screen of the current ACWP. The overall system, in this particular case consisting of MSDF and HMI, is called Frankfurt Airport Surface Traffic Management System (FAST-MS). As depicted in Figure 15: FAST-MS Screenshot, FAST-MS depicts arrival traffic in orange, departing traffic in magenta, and tow movements in blue.
From a technical point of view, FAST-MS does only provide a Surveillance Service and a limited RMCA-Sub Service of the Airport Safety Support Service. Routing and Guidance Services are currently not implemented. In addition, the RMCA is deactivated ever since implementation of FAST-MS, as despite enormous efforts invested, no reliable alerting with an acceptable number of false alerts was deemed achievable. Hence, FAST-MS provides a synthetic surface situation to the controllers, but no further functions.

Nevertheless, FAST-MS is an important system for the controllers at Frankfurt Airport. This is especially true in LVC (EUROCAE, 2015). In any case, further systems are needed to provide all the information needed and to enable the controller to perform all necessary tasks. Figure 16: Current ACWP at Frankfurt Airport depicts the current ACWP, with the FAST-MS screen on the right and the Electronic Flight Strip System (EFS) on the left screen. Also visible are communication and lighting control tools as well as the multiple input devices needed to interact with the systems.
The tools available in the current ACWP are in general very supportive to the controllers. Nevertheless, the job remains physically and mentally demanding: A lot of training and experience is needed and a numerous controllers have to work in parallel due to the high traffic levels. This leads to a lot of coordination between the individual controllers and also to high costs. In addition, the current setup of the ACWP provides the information on various screens. This leads to additional mental and physical stress, which may ultimately lead to mistakes. In consequence, the upcoming generation of CWP s and ACWPs features integration of all relevant information to one single screen, as depicted in the upcoming section.

2.2.2 Further Development and Future Situation

The A-SMGCS at Frankfurt Airport is on the eve of a dramatic change. For more than two years, a large team of experts including IUK-AO11 members have been working on the definition of a new ACWP for the Apron Controllers working at Frankfurt Airport. The main technical phases that are completed by early 2017 are (Fraport, 2016):

- Creation of ‘big picture’ visionary objective for the 2020 to 2030 timeframe\(^{16}\)
- Definition of scope for the first release planned for 2019 and future releases

\(^{16}\) This ‘big picture’ mainly describes the principal working methods and tools in the 2020 to 2030 timeframe, i.e. how do we want to perform Apron Control in five, ten, or fifteen years?
• Coordination of target system architecture
• Harmonization of thousands of requirements in various individual tenders17
• Execution of a tendering procedure and procurement process according to international standards

In general, the future ACWP at Frankfurt Airport is defined by two words: Integration and Automation. It will have the following features (among others) (Fraport, 2016):

• Implementation of all A-SMGCS Services in the ACWP18
• Integration of all functionalities in one single screen
• Automation can be configured in very fine steps
• User interaction is possible via finger touch or pen touch

Modern systems like the ACWP recently procured by Fraport AG are significant investments and represent a dramatic change in controller working procedures and in the way controllers define themselves (Fraport, 2016). This leads to the question, why a decision-making process leads to the insight that a new ACWP is necessary despite the side-effects. Contributing factors to a decision in support of a new working position were (not exhaustive):

• Legacy systems:
The existing airside systems such as FAST-MS are ending their useful service life and need to be replaced. They are costly to maintain and in a rising number of cases necessary changes are complicated or impossible.

• Regulatory requirements:
As a result of the SESAR Programme, the Single European Sky ATM Research Programme, some A-SMGCS Services became mandatory for a number of airports, including Frankfurt (Fraport, 2016). These are not available in the current system.

• Airport expansion:
The new terminal (T3) is under construction in the South of the airport and a number of systems has to be certified to allow for remotely controlling the area from the North. This is currently impossible.

• Increasing traffic:

17 Literally thousands of expert’s working hours were necessary to complete the tender documents and it took more than one year.
18 This does not necessarily mean that they will all be used from the beginning and especially in terms of Follow-the-Greens, additional work in the field would be required to allow for the use of the new procedure.
Even the most conservative traffic forecasts available assume a constant further increase in air traffic. This is directly linked to the traffic on airports and further increases of traffic complexity at Frankfurt Airport.

- **Lack of controller productivity:**
  The level of automation has to be increased in order to achieve the objective of being able to handle more traffic with the current number of controllers.

As stated above, the new ACWP provides additional A-SMGCS Services compared to FAST-MS and this has a direct influence on the data quality that is needed from the Surveillance Service. For the current functionalities of FAST-MS, the data quality and reliability of the surveillance data is sufficient in most areas and cases, with minor exceptions known to engineers and controllers. There are gaps and issues today, but the controllers and the systems can accept them under the current procedure and system environment.

The new ACWP will be a complete ‘game changer’ in this area, as the new functionalities, especially concerning ASSS (CATC and CMAC) and Guidance, will not work properly or cause unacceptable numbers of false alerts if the gaps and issues are not sufficiently treated and rectified (Eurocontrol, 2016). A whole team of experts constantly works on improving the performance of the current surveillance system environment and on all levels, i.e. at individual sensor level as well as on the MSDF level. The performance increases in recent years were minor and the experts assume they are nearing the economically achievable optimum with the limitations inherent in the technologies in use.

Consequently, a new sensor is needed, a sensor capable of ‘filling the gaps’ in the current system. This is where MagSense, the EMFS, were brought in to solve the issues (MobiliSis GmbH, 2016).

### 2.3 Earth Magnetic Field Sensors

This section will introduce the Earth Magnetic Field Sensors (EMFS) or MagSense® in several stages. Initially, the fundamentals of the earth magnetic field will be presented to provide the basic concept that helps to understand the idea behind the sensors. After that, the actual make of the sensors and the initial field trials will be discussed and some of the aspired use-cases will be pointed out. Finally, a short description of the construction work needed to implement the sensors in a taxiway at Frankfurt Airport will be depicted.
2.3.1 EMFS Principles and Functionality

The primary commercial application of the EMFS technology has been in the field of vehicle detection in road traffic and parking space management ever since it was invented (Caruso & Withanawasam, 1999). Sensors like MagSense are capable of reliably detecting whether or not a specific parking stand in a multi-storey car park or in a parking area is vacant or occupied (MobiliSis GmbH, 2016). Connected to a system environment capable of counting and guiding vehicles, people searching for a vacant parking stand can be guided from the entrance to the next available place to park. MagSense can be installed either underground or above ground as depicted in Figure 17. Also visible in this figure are sensor chains that detect vehicles going up a drive-up, or entering or exiting a car park (MobiliSis GmbH, 2016).

![Figure 17: MagSense® actual applications (MobiliSis GmbH, 2016)](image)

The idea behind the EMFS seems quite simple in the first place and is based the influence of ferromagnetic objects on our planet’s magnetic field. They influence the field lines of the Earth Magnetic Field (EMF) comparable to the influence of differently shaped lenses on the light passing through them: They can concentrate the field lines or widen the distance between them as visible in Figure 18, where the effect of a car on the EMF is depicted sketchily (MobiliSis GmbH, 2016).
Figure 18: EMF behaviour when passing through a ferromagnetic object (Honeywell International Inc., 2005) (Daubaras & Zilys, 2012)

Physically, the Earth Magnetic Field (EMF) has a flux density of around 0.5 gauss (Honeywell International Inc., 2005). In order to detect this magnetic field, a Medium Field Magnetic Sensor (MFMS) can be used (Daubaras & Zilys, 2012). MagSense is a MFMS and it can detect magnetic fields with densities between 1 micro gauss and 10 gauss. If a ferromagnetic object like a car passes over the sensor, MagSense detects the change of the EMF in terms of field strength and direction. This change, usually calculated as the sum of the absolute offset vectors in x-, y-, and z-direction, may then be used to trigger a counter, e.g. the number of vacant parking stands is reduced by one, or for other purposes. Those purposes may require more than one sensor in the field and algorithms (signal processing) that analyze the raw sensor data in order to extract further information such as speed, heading and type of mobile (please see Figure 19) (Caruso & Withanawasam, 1999). This differentiates the magnetic sensors from other types of sensors such as temperature, pressure and light sensors, as those directly convert the real-life parameters into proportional voltage.

Figure 19: Difference between traditional (above) sensors and magnetic sensors (below) (Caruso & Withanawasam, 1999)
From a technical point of view, the EMFS have the capability to determine variations in the EMF by means of nickel-iron thin film resistive strips. They generate resistance variations between two and three percent when a magnetic field exists. The resistors are connected in a Wheatstone Bridge with the objective to assess magnitude and direction of the magnetic field along an axis (Caruso & Withanawasam, 1999; NASA, 2017).

![Wheatstone Bridge Circuit](https://www.grc.nasa.gov/www/k-12/airplane/tunwheat.html)

**Figure 20: Wheatstone Bridge Circuit (NASA)** (NASA, 2017)

In addition, MagSense features a Bluetooth Module capable of receiving Bluetooth signals from mobiles passing over the sensors (MobiliSis GmbH, 2016). This concept may be used to identify mobiles and to register or unregister mobiles in defined geographical areas of the aerodrome surface or any other location.

### 2.3.2 Use Cases of EMFS

Based on the physical principle behind the EMFS, the sensors can be used for many different Use Cases. This includes applications in road traffic, vehicle parking, rail transport, harbors and also on the airside of airports. This section depicts a number of Use Cases on the airside of airports (Fraport, 2016).

As depicted in section 2.2.2 the current surveillance coverage has some gaps. EMFS can be used to close these gaps by generating precise position information of mobiles and providing them in standardized surveillance data format, i.e. in EUROCONTROL ASTERIX language, to the A-SMGCS and the MSDF in particular.

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19 [https://www.grc.nasa.gov/www/k-12/airplane/tunwheat.html](https://www.grc.nasa.gov/www/k-12/airplane/tunwheat.html) (2017-02-18)
But EMFS are not only ‘gapfillers’. They can be used for numerous other purposes. Some of the most prominent are as follows (Fraport, 2016):

### 2.3.2.1 Automatic Detection of Timestamps

The process chains on airports are planned, coordinated and analyzed based on timestamps. These are represented by four letter abbreviations and a precise time. The combination of abbreviation and time depicts the time a specific process or status was either expected to take place or has taken place. An example for such a timestamp is EIBT. It stands for Estimated In-Blocks Time, which is the expected time for a specific aircraft to stop on a parking stand (Fraport, 2016). Correspondingly, AIBT, the Actual In-Blocks Time, is the time when a specific aircraft has actually stopped on a parking stand. EMFS can be used to detect various status of movements on the aerodrome surface, where corresponding timestamps are already generated manually, or where currently no technology is able to provide the necessary information (MobiliSis GmbH, 2016). As depicted above, the timestamps of the parking or docking processes can be generated with the help of EMFS. These are called Actual In-Blocks Time (AIBT) and Actual Off-Blocks Time (AOBT) (Fraport, 2016). New timestamps could be invented with the help of EFMS in order to close gaps in the 4D planning process of the ground trajectory, e.g. the time when an aircraft reaches the end of the queue in front of a holding point to a runway. Other fields of application include de-icing management and the exact detection of transgression of locally defined points on taxiways (Fraport, 2016).

Frankfurt Airport wants to use EMFS to detect and report AIBT and AOBT on parking stands where an Advanced Visual Docking Guidance System (A-VDGS) cannot be installed (Fraport, 2016). These systems assist flight crews in parking the aircraft the necessary distance from the terminal building and they can also detect the timestamps in question by means of a laser scanner (International Civil Aviation Organization, 2004). As A-VDGS need to be mounted on a wall or pole, they are only useful for about half the parking positions at Frankfurt as the other parking positions are so called ‘nose-in / nose-out’ positions with no wall or pole possible.
2.3.2.2 EMFS-based Docking Guidance Systems

Fraport uses A-VDGS on all stands where a wall or pole is available to mount the scanner and screen combination. On all other positions, AIBT and AOBT are currently detected manually and docking guidance is provided by certified personal in all weather conditions (Fraport, 2016).

With the new technologies protected by PCT/EP2014/054095 the need for a pole or a wall can be overcome: Instead of providing visual docking guidance as an A-VDGS does, the EMFS-based Docking Guidance System (DGS) can alternatively provide audible docking guidance information as synthetic voice instructions via the 75MHz Marker Beacon Receiver available in all aircraft (Fraport, 2016). The phraseology is still
to be developed, but should not be a problem as pilots are used to comparable voice instructions, e.g. in the landing phase.

Of course, EMFS can also be used in A-VDGS to overcome the deficiencies of the currently used laser scanners which have limited reliability especially in LVC or great heat. EMFS can then be used as a supplement to the laser or as a replacement (Fraport, 2016).

2.3.2.3 Holding Point Protection Systems

Not only the layout of Frankfurt Airport features a high number of intersections and converging traffic flows, this is a condition at most airports around the world. In addition, the runways all have numerous entrances and exits, as depicted in Figure 23 on the example of runway 18 of Frankfurt Airport, the famous ‘Startbahn West’ (Fraport, 2016). At the intersections and runways, holding points are marked on the ground, indicating the farthest possible point to stop the mobile in order to always guarantee safe movement of all other traffic. With the current precision available by fusing MLAT and SMR data, the accuracy of detecting mobiles in close proximity to the holding points is not always good enough to judge whether or not a mobile has violated the protected area beyond the marking (Fraport, 2016). In consequence, EMFS can be used to protect these important lines by precisely detecting whether or not a ferromagnetic object has crossed the marked border line. If a violation is detected, the corresponding CMAC Alarm will be triggered (Eurocontrol, 2016; Fraport, 2016).

Figure 23: Runway 18 at Frankfurt with Holding Points N-South, L (left), W1 and W3 (right). (Fraport, 2016)
2.3.2.4 Fully Automated Surface Traffic Management

In line with the control centers in other branches of industry such as power generation, the possible objective of fully automating the management of surface traffic can be developed based on the principle of management by exception. This could result in sensors and decision-making systems taking over traffic control in nominal conditions. Employees would then monitor the systems and intervene only in exceptional situations (Fraport, 2016).

The basis for a high (full) automation of ground traffic on airports is the precise and reliable surveillance of the mobiles on the aerodrome surface (Bloisi et al., 2012). Management systems suitable for complete automation of all routing and guidance-related functions are rare, but available on the market. Today, they are mainly offered as decision-support systems for political reasons, although they are technically capable of working self-sufficient.

In building a fully automated surface traffic management system, the following elements in addition to the decision-making system could be important building blocks (Fraport, 2016; International Civil Aviation Organization, 2004)

- EMFS as a surveillance gapfiller
- Automated DGS on all parking stands (can be EMFS-based systems)
- Follow-the-Greens as a visual Guidance and Alerting System
- VoiceLink 75MHz as an audible Guidance and Alerting System
- Radio communication as a fallback solution (Fraport, 2016; International Civil Aviation Organization, 2004)

2.3.2.5 Autonomous Transportation Systems on Airports

In general, two ways of providing autonomous transportation on airports are currently under discussion:

A.) The airborne solution approach, i.e. the transport of luggage and freight by Unmanned Air Vehicle (UAV) or ‘drone’, can be supported by EMFS in the field of ground-level flight control and the identification of the flying object via Bluetooth. The resulting data can then be integrated into the synthetic surface situation and used as input by the corresponding traffic management systems (International Civil Aviation Organization, 2004; Wilco, 2010).

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20 The capability of UAVs to transport people was also recently demonstrated. On the airport, this could be used for crew transportation or even for passengers having an extremely short connection time in the future.
B.) The ground-based solution approach, i.e. the transport of luggage or freight by means of an autonomous ground vehicle, can be supported by EMFS in a wide range of applications. The detailed design of this Use Case is yet to be developed, but various stakeholders are looking into solutions for currently labor intense procedures, e.g. crew transport to aircraft\textsuperscript{22} (Antonov et al., 2015).

Solutions based on UAVs and autonomous ground vehicles are not to be expected within a very short time frame, but more likely in mid-term or long-term. Nevertheless, the commercial pressure to introduce such solutions is high in leading economies and on large and complex airports. Hence, it is likely that at least some procedures in this field will be supported by EMFS in the future.

\subsection*{2.3.2.6 EMFS-based Block Control}

Another very promising idea is the use of the new sensors on airports that cannot afford to implement an A-SMGCS. This frequently results in airport closures in LVC or in the procedure to have only one single mobile operating on the entire aerodrome (Fraport, 2016; International Civil Aviation Organization, 2004). This leads to delays and cancellations and in the long run to a bad reputation of the airport. With chains of EMFS, the airport surface could be subdivided into areas, so called ‘blocks’, and the EMFS could then be used to identify those blocks as ‘vacant’, i.e. no mobile inside, or ‘occupied’, i.e. a mobile is inside the block. Under ICAO regulations, this allows for a procedure called


\footnote{This is an important scope of Lufthansa LEOS.}
‘block control’ with more than one mobile moving, as long as there is always a vacant block between two mobiles (International Civil Aviation Organization, 2004).

2.3.2.7 Other Use Cases

As the sub-sections above reveal, there is numerous options for EMFS applications on the aerodrome surface. Applications beyond those described in the sections above may be (not exhaustive) (Fraport, 2016; MobiliSis GmbH, 2016):

- Integrated Sensor-Guidance-Light: A TCL with EMFS and VoiceLink 75MHz integrated for detection and guidance.
- Surveillance Quality Assessment System for RPA: EMFS reference points for the calculation of offset between EMFS reported position and reported position in MSDF
- EMFS sequencing between traffic on aerodrome service roads and taxiways.

2.3.3 EMFS Evaluation at Frankfurt Airport

The objective of this section is to illustrate the actual tests currently being carried out at Frankfurt Airport with respect to the EMFS. Based on the test results, the future implementation at Frankfurt Airport will be proposed per Use Case. In order to validate the relevant Use Cases two steps representing one field tests and associated data analyses each, are carried out. To date, the first field test for the evaluation of the technology has taken place and the corresponding analyses have been carried out. The second test is in final stages of preparation (Fraport, 2016).

2.3.3.1 Field Test 1

The objective of the first field test was to prove that EMFS detect aircraft in general and to find out which elements of an aircraft can be detected in particular. This was done in order to validate that the detection of the aircraft’s position and heading is generally possible (Fraport, 2016; MobiliSis GmbH, 2016). For the latter, the detection of more than one point of the aircraft is necessary, as at least three known points are needed to reconstruct the position of the aircraft on a map. Further research objectives of the first field test are the detection of the absence of movement of a mobile, i.e. the condition of a mobile to be stationary, and the proof of the fundamental feasibility of a recognition of the type of aircraft on the basis of sensor data only.

The field test area for this test was selected on the basis of different criteria, e.g. the number of surface movements per day, the traffic mix in terms of type of aircraft moving in the area, and also the complexity of the construction work needed to implement the sensors and the concomitant factors on the infrastructure (Fraport, 2016; MobiliSis
GmbH, 2016). As a result of this decision-making process, two sensor bus systems were installed in the so called ‘A-West-Hof’, a large cul-de-sac area in the western part of Terminal 1 of Frankfurt Airport (Fraport, 2016). The sensors were installed in deepened grooves between the concrete ground plates of the aerodrome surface and sealed with so called ‘red cast’.23

The sensor busses each comprise 53 sensors and are arranged orthogonally to the taxiway centerline (Fraport, 2016). Starting from the center of the runway, the sensor distance is 50cm to each side of the taxiway centerline for the first 8m of distance and then 100cm up to a distance of 16m to both sides. The two sensor busses were installed 12m apart from each other and depicted red in Figure 25. The specific sensor arrangement was chosen to be able to identify which elements of an aircraft are detected by the EMFS. At least the detection of the nose gear, main landing gear and the engines was expected.

Figure 25: Field Test 1 (MobiliSis GmbH, 2016)

The data from the MagSense sensor busses could be viewed in real time during a field test on a MobiliSis laptop (please see Figure 26) (MobiliSis GmbH, 2016). The visualization showed the change of the EMF at each sensor of the test installation and as the sum of the deviations in the x-, y- and z-directions over time. In addition to real-time visualization, all measurement data were saved (MobiliSis GmbH, 2016).

23 More details on the implementation process will be presented further down in the document.
Data analyses later revealed that all research objectives were met by the MagSense EMFS in the test installation. MagSense (Fraport, 2016; MobiliSis GmbH, 2016).

- detected all mobiles,
- detects geometry defining components,
- detects aircraft precisely,
- delivers accurate heading information,
- can reliably identify aircraft types,
- can be installed very easily.

The positive results were communicated within Fraport AG and the project sponsor, the Flight Operations Department FTU-F, approved the execution of the second field test in the first quarter of 2017 (Fraport, 2016).

### 2.3.3.2 Field Test 2

The objective of the second field test is to provide tangible evidence that selected Use Cases with a high priority for the operations at Frankfurt Airport can be adequately supported with EMFS (Fraport, 2016). Important criteria for these Use Cases are the accuracy and reliability of the detection. A further important objective of the second field trial is the determination of the minimum necessary sensor arrangement for adequate results (Fraport, 2016).

In order to achieve the aspired results, additional sensor busses were added to the existing installation on taxiway N7. The additional EMFS busses are depicted in green in Figure 25 (MobiliSis GmbH, 2016). In addition, a suitable cabinet for recording the
technology was also installed on site and a video and photo camera with exact GPS-timing was purchased as a visual reference. The actual tests will be conducted in March 2017 and the visualization and playback tool MagView developed as part of this Master’s Thesis will be used to draw conclusions (Fraport, 2016).

### 2.3.4 Installation of EMFS at Frankfurt Airport

The EMFS used for the two field trials at Frankfurt Airport were installed in deepened grooves as depicted in Figure 27: Taxiway and runway surface carving (MobiliSis, 2016). Groove cutting is one of the several options that is used, as the sensors can also be inserted in underground pipes. It is also feasible to install EMFS into the concrete of the taxiway, but this is appropriate when new taxiways are built or when taxiways are refurbished (Fraport, 2016).

![Figure 27: Taxiway and runway surface carving](http://www.mobilisis.eu/en/references/frankfurt-airport-detection-and-tracking-of-aircrafts/)

After the grooves were cut to a depth of around eight centimeters, a layer of quartz sand was evenly padded in. The EMFS when introduced on top, as shown in Figure 28 (MobiliSis, 2016).

![Figure 28: Arrangement of Sensor Cable](http://www.mobilisis.eu/en/references/frankfurt-airport-detection-and-tracking-of-aircrafts/)

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In order to protect the sensors and cables from mechanical pressure, a flexible PE cord is used to cover them in the groove. Finally, the groove was covered with a hot sealing compound as shown in Figure 29 (MobiliSis, 2016). The red color is required and indicates that a cable is installed below.

![Image](http://www.mobilisis.eu/en/references/frankfurt-airport-detection-and-tracking-of-aircrafts/)

**Figure 29: Hot Sealing and Hard Casting Compound**

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3 Requirements Engineering Approach

The influence of Requirements Engineering for profitable and consumer determined project results and technical solutions cannot be overrated. It is becoming an everyday praxis to support projects with certified RE personal capable of working independently and managing the product definition phase self-reliantly (Pohl & Rupp, 2015). At Frankfurt Airport, RE is considered an irreplaceable element of Information Technology (IT) projects, independent of affiliation to airside and landside. RE has improved the performance of numerous projects over the past years, as it has reduced the time needed to complete a particular job and the failure rate of projects was reduced drastically (Fraport, 2016).

It is very important that significant requirements of the project are been managed in an efficient manner in order to meet the customer’s objectives (SQS AG). In projects without an adequate RE process, misunderstandings and errors were usually noticed in later stages or after project results were implemented on the customer’s side (Pohl & Rupp, 2015). This led to project delays or major Change Requests (CR) after implementation and to additional time and money needed in order to fix the problems. Investigations often revealed that the negative results were caused by inaccuracies in the interpretation of the customer needs and wishes on the side of the development team (Nuseibeh & Easterbrook, 2000).

The RE process tries to avoid these errors by adding a RE phase to projects (Pohl, 1993). In this phase, the requirements engineer conducts structured conversations with the customers and stakeholders in order to finally provide precise, detailed, and unambiguous requirements to the development team (Nuseibeh & Easterbrook, 2000; Pohl & Rupp, 2015). Iterative creative and communication techniques are used by the requirements manager in order to achieve this goal (Haley, Moffett, Laney, & Nuseibeh, 2006).

It is also noticed that the major cause for unsatisfactory results are features considered to be ‘obvious’ by the customers (Rupp & Ehrlinger, 2016). In consequence, and without an adequate requirements process, these requirements often remained unmentioned. Hence, state-of-the-art RE processes also convey features and requirements regardless of being considered to be obvious or automatic by a stakeholder (Pohl & Rupp, 2015). It is always explicitly recommended to include self-evident features in the requirements process so that all the expectations of the consumer are fulfilled (SQS AG).
The costs related to figuring out errors also play an essential role in a requirements engineering process. It is important to identify and resolve the shortcomings found during the requirements engineering process rather than correcting it in the development or deployment stages (Rupp & Ehrlinger, 2016; SQS AG). The reason behind this step is that the costs of changing or modifying a bug are way higher in the later stages. The effort, time, and money needed to fix the issue increases drastically the later the identification. Sometimes this may even lead to complete failure of projects, as the costs for fixing the problems exceed the available budget (Pohl & Rupp, 2015).

3.1 Methodology Overview

Requirements Engineering (RE) is an ideology, where in order to achieve successful outcomes of a project, in this case MagView, it is very essential to identify the requirements of the application together with all stakeholders and to draft the requirements in well-structured form (Pohl, 1993).

Numerous terms are necessary to be introduced to understand the RE approach, some of them are as follows:

- **Requirement** - It is a state or potential required by a user to fix the issue or fulfill the intention. It can also be outlined as a condition or an ability to match or be retained by a system or an element of the system to accomplish an agreement, standard, specifics or other officially agreed records (Pohl & Rupp, 2015; Rupp & Ehrlinger, 2016).

- **Stakeholder** - It is defined as, “A stakeholder of an entity is an individual or an association that has linear or latent impact on the requirements of the entity” (Rupp & Ehrlinger, 2016). Stakeholder is a crucial term in the requirements engineering process. Stakeholders are those bodies or system that have some effects over the requirements. Stakeholders in this particular case are the three entities, Fraport AG (IUK-AO11), Mobilisis GmbH and Fraport AG (IUK-CI) (Fraport, 2016). The communication and negotiation process with stakeholders eventually results in the discovery of false or incomplete requirements (Pohl & Rupp, 2015).

- **Requirements Engineering** – “Requirements engineering is an organized and methodic technique to administer and understand the desired specifics of the requirements keeping in mind the objectives, which are, (i) recognizing appropriate requirements, concluding to a general agreement amongst the stakeholders with respect to the identified requirements, record them based on the defined standards, and maintain them in a well-structured form. (ii) Stakeholders requests and demand must be
understood and documented, these specify and manage requirements to diminish the fortuity to hand over a system which does not match with the needs and demands of the stakeholders “ (Pohl & Rupp, 2015; SQS AG).

The fundamental aim of requirements engineering is to discover the requirements needed by the stakeholder’s during development stages and to document the elicited requirements in a well-formed manner, certify and justify the requirements and also managing the defined requirements over the entire phase of the development and implementation phases (Pohl, 1993; Rupp & Ehrlinger, 2016).

3.2 Building Blocks of Requirements Engineering

The four core activities or the building blocks of requirements engineering can be practiced at different stages of requirements gathering, such as, customer requirements, project requirements and application requirements (Pohl & Rupp, 2015).

The four major activities of requirements engineering are as follows:

1 Elicitation
2 Documentation
3 Validation and negotiation
4 Management

3.2.1 Activity 1: Elicitation

Elicitation is the involvement of a requirements engineer with the customer or the stakeholders where numerous techniques are implemented in order to discover the in-depth requirements and desired outcomes (Rupp & Ehrlinger, 2016). Discovering of the requirements can be carried out through various methods, such as specifications meetings or creative workshops. These aim at creating broader perspectives. Those methods will be discussed in detail in section 3.4.

3.2.2 Activity 2: Documentation

The documentation exercise is recording the discovered requirements appropriately in a report format which has transparency to the needs of the stakeholders and also it can be an asset for the development teams. It is crucial that that the requirements are understandable, definite and realized (SQS AG). Different techniques can be implemented to draft the requirements (please see section 4).
3.2.3 Activity 3: Validation and Negotiation

This activity is to assure that the determined requirements are documented in a form that is comprehensible for the stakeholders and a common understanding can be achieved based on the written requirements (Pohl & Rupp, 2015). The validation and negotiation process is usually conducted as a series of conversations with the stakeholders. In all, the quality of the requirements stated shall be ascertained with this activity (please see section 5.4).

3.2.4 Activity 4: Management

The final and main activity of the RE process is referred to as ‘Requirements Management’. Its purpose is to ensure that the structure of the requirements and the way they are stored and maintained is accepted by all stakeholders (Rupp & Ehrlinger, 2016). It is crucial that uniformity is upheld to allow for constantly and precisely tracking changes and updates (please see section 5).

3.3 Project and Context Boundaries

The intention behind specifying the system (project) and the context boundaries in the RE approach is to classify the surrounding elements that could affect the requirements of the tool to be developed (Pohl & Rupp, 2015).

The project context is an element of the real world, which affects the tool to be developed. In consequence, it also influences the requirements within the project (SQS AG). In order to discover the requirements for MagView, it was essential to identify the project boundary to the context of the project and to communicate it to the stakeholders. This establishes a common understanding concerning what is part of the system MagView and what is outside of the system. In addition, also the boundary of the project context to the irrelevant environment needs to be identified and fixed (Ralytė, 1999). It is called the ‘context boundary’ and all potential influences coming from outside this borderline are not relevant for the system and can be set aside, while all influences from the project context need to be taken into account. Please see Figure 30, for a depiction of the various borders (Fraport, 2016; Pohl & Rupp, 2015).
To identify the border between project context and irrelevant environment, it is anticipated how the tool would look and feel in reality and also how it would be used and by whom. In doing so, the influencing factors of the real surroundings and their possible impact on the requirements can be identified as well as factors that do not have an influence on the project (Rupp & Ehrlinger, 2016). In other words, only those influences coming from the identified and unique project context will be taken into account in the later stages of the RE process. The project context is defined as a unique portion of the project surroundings which is important for specifying and interpretation of the requirements to be acquired (SQS AG).

There are numerous aspects that may influence the project context in general. The factors that influenced the production of MagView are listed below (Pohl & Rupp, 2015):

- Stakeholders (individual units)
- Business Processes (also technical processes)
- Circumstances (professionals or environmental)
- Documentation (organization laws, norms, requirements documentation)

It is very important to understand and consider correct and accurate circumstances amidst requirements engineering otherwise the outcome may result in a deficient and inaccurate set of requirements.

**Stating the project boundary:** While defining the project boundary, a conclusion is to be determined: Which are the factors pertaining to the project to be accomplished and which are the factors that belongs to the system context? (Pohl & Rupp, 2015)

**Stating the context boundary:** When stating the context boundary the query to be resolved is that: Which factors affects the project context (i.e., possess an association to the project to be developed) and which elements are considered to be part of the irrelevant environment? (Pohl & Rupp, 2015)
During the definition process of the project boundaries, in which it is clearly the role of the requirements engineer to present a proposal, also the project scope is detected. The scope constitutes those factors which can be constructed and modified during the development phase of the tool. In turn, also the elements that belong to the surroundings are identified (Rupp & Ehrlinger, 2016). These aspects are not part of the project or system and cannot be modified in the development phase.

3.4 Discovery of Requirements (Stakeholders)

A major activity of a RE process is discovering the requirements for the system (project) development. In general, stakeholders are considered to be the prime sources for requirements (Davis, Dieste, Hickey, Juristo, & Moreno, 2006). The foundation for requirements discovery relies on the information that is being presented by the requirements originators (in this case, the stakeholders) while defining the project context (Mishra, Mishra, & Yazici, 2008). They need to be asked for input and specific discovery techniques are available to get better results compared to an unstructured interview (Sharp, Finkelstein, & Galal, 1999).

The selection of the appropriate discovery techniques for a project is grounded on the specified research activity and domain-determined business perspectives for an easy way of cooperation and conversation (Mishra et al., 2008; Pohl & Rupp, 2015). Therefore, it is crucial at initial stages that the stakeholders and the requirements engineer agree on mutual authority and roles in order to perfectly integrate the stakeholders into the discovery process (Koch & Escalona, 2004; Pandey, Suman, & Ramani, 2010). In the specific case of MagView, the stakeholders were the sole source of requirements. Hence, their importance for the requirements discovery process was even higher compared to projects with additional sources, e.g. documents or previous versions of a tool or system (Sharp et al., 1999).

Stakeholders denominate an organization or independent bodies, which entirely or indirectly affect the requirements of a project. The identified stakeholders for the MagView project are Mobilisis GmbH (manufacturer of MagSense), Fraport AG IUK-AO11 (primary users of the tool) and IUK-CI, who sets the regulatory framework concerning IT architecture within Fraport AG.

To appropriately recognize relevant stakeholders is one of the main tasks of requirements engineering (please see section 3.4.1) (Rupp & Ehrlinger, 2016). It is a responsibility of the requirements engineer to identify or discover the stakeholders. If stakeholders are not recognized then the outcome in the progress of the project could be unfavorable as some important requirements may stay undiscovered. A checklist spreadsheet can be maintained to identify the stakeholders (SQS AG). This will help in
the elicitation of organized and determined stakeholders, especially if the project is large and the number of stakeholders as well (Sharp et al., 1999). It is important to update the spreadsheet whenever new stakeholders are identified or when objectives of stakeholders change.

If the list of stakeholders is not updated, essential elements of the project will remain undiscovered (Rupp & Ehrlinger, 2016). This may result in missing the actual targets of the project and in extra money and time needed to solve the problems (SQS AG).

### 3.4.1 Types of Discovery Techniques

The objective of every single discovery technique is to support the requirements engineer to determine and understand the requirements of stakeholders. It is dependent on the state of the project that when or which discovery techniques are to be implemented. When the discovery technique was carried out, it was found that it delivered the desire in specifying the aware, ignorant and undersense requirements of the stakeholders (Pohl & Rupp, 2015). It was important to implement the discovery techniques in well-acquainted manner. It is necessary to imply it in an appropriate pattern in order to customize the at-present discovery of the requirements. This includes the impulsion of the project in order to discover exhaustive and understandable requirements (Rupp & Ehrlinger, 2016).

It is essential to identify the risk aspects before choosing a discovery technique for which an investigation must be carried out to analyze fateful hindrance of the project to be implemented (Pohl & Rupp, 2015). The major risk factors that should primarily be focused and explored are the managerial risk aspects, as they can influence not only a particular project, but to the entire organization, for example, distinct project and support service contracts must be fixed between the stakeholders and the organization (SQS AG). This will build a legacy system for the project to be implemented and adequate involvement and support from the stakeholders. Individuals are also of a great concern when risks are to be identified (Pohl & Rupp, 2015; Sharp et al., 1999). In consequence, trustworthy conversations with the stakeholders must be carried out during the discovery phase to maintain business relationships and to improve the clarity of the requirements. It is necessary to use a methodical approach while discovering the requirements as this will support the logical structure of the project (Pohl & Rupp, 2015). In general one can conclude that the more complex the nature of the project, the more important the methodical approach.

#### 3.4.1.1 Survey Techniques

The agenda behind conducting surveys with the stakeholders is to acquire honest, impartial, and explicit declaration of the requirements (Pohl & Rupp, 2015). This
technique is expected to be delivered with precise knowledge of the requirements from the stakeholders (Sommerville & Sawyer, 1997). It is assumed that in every survey approach the stakeholder or the requirements sources are able to share the genuine information and are able to express themselves completely and are ready to endeavor the discovery of the requirements.

The two main survey techniques are listed below (Pohl & Rupp, 2015; SQS AG):

- **Interview**: In this approach, a set of questions to be asked is decided well in advance by the requirements engineer. The role of the requirements engineer is to interrogate with a stakeholder and to record the interview answers, e.g. by taking notes (Sommerville & Sawyer, 1997). The questions are subsequently presented to further or all stakeholders and the answers and comments are then analyzed by the requirements engineer (Koch & Escalona, 2004).

- **Questionnaire**: In this technique, a predetermined collection of open-ended and closed-ended queries is formed to discover the requirements from the stakeholders (Koch & Escalona, 2004). The questionnaire can be in a form of multiple-choice questions and can be organized by circulating hard copies of the questionnaire to the stakeholders or via digital platforms.

### 3.4.1.2 Document-centric Techniques

The document-centric techniques imply a hierarchical course of action (Rupp & Ehrlinger, 2016). This assists in inheriting the previously applied acquaintance and solutions for the current (new) project. It is commonly applied when an older approach for a project needs to be replaced. Using the document-centric discovery technique ensures that the previous performance will be taken into account in the new project. This technique must be combined with other discovery techniques in order to ensure the effectiveness of the discovered requirements and also to allow for additional requirements to be specified (Rupp & Ehrlinger, 2016).

The document-centric technique is not suitable for the MagView project, as in this case, a new technology is being researched and being tested. There are no previous aspects of the tool implemented anywhere. Hence, there are also no elements that could be inherited from older versions.

The main concepts of the document-centric technique are listed below (Pohl & Rupp, 2015):

- **Project antiquity:**
‘Project antiquity’ is a method to inherit data necessary to develop a new project based on previous records or operations of a project used earlier within the organization or the outside world.

- **Objective-based examination:**
  ‘Objective-based examination’ is implemented when a specific aspect is in perception and previous records are referred to understand the aspects.

- **Reuse:**
  ‘Reuse’ refers to an approach to reiterate the defined and quality requirements that were formerly established.

### 3.4.1.3 Observation Techniques

This technique is implemented when the requirement sources are not able to invest the necessary amount of time to actively provide their knowledge to the requirements engineer and are not able to communicate their expert skills. In such situations, the observation techniques are very much effective for discovering the requirements (Pohl & Rupp, 2015).

- **Field investigation:**
  In this scenario, the requirements engineer observes the users while performing their task and scripts down the procedures and functional processes which are carried out in the field.

- **Learning:**
  Here, the requirements engineer should promptly adapt the operational methods which are carried out by the stakeholders and should also be able to practically implement them.

### 3.4.1.4 Creative Techniques

#### 3.4.1.4.1 Creative Techniques Implemented for MagView

The discovery techniques, which were performed to elicit the requirements for MagView belong to the category of ‘Creative Techniques’ (Pohl & Rupp, 2015).

While performing creative techniques, the initial image of the project is a prerequisite, i.e. the people involved must have an idea in their minds concerning the overall objectives of the project and how the tool may look and feel (Rupp & Ehrlinger, 2016). In this particular case, the methodology served the intention by establishing inventive requirements and appealing factors were also found. The creative techniques encouraged diverse thoughts and ideas amongst the stakeholders in discovery of the requirements. It produced a huge influence on the project as cooperative thoughts were being shared and carried out collaboratively (SQS AG).
Interactive sessions were organized with the stakeholders and the requirements engineer actively taking part. The advantage of such meetings is that vast amounts of information and ideas are being shared by the stakeholders which simplifies in the requirements elicitation (Hickey & Davis, 2004).

Some of the aspects, which were discussed for the discovery, are listed below (Pohl & Rupp, 2015):

- System Definition: The goals and administration aspects of the project were discussed in order to define the roles of different actors involved.
- Concept Generation: The identification of various outcomes that is expected from the project was produced.
- Concept Categorization: Based on the elicited project goals and requirements, high priority requirements were classified.
- Concept Selection: Selective measures were carried out to finalize the appropriate method for implementing the tool.
- Project Implementation: The outline for developing and factors influencing the outcome of the tool were pointed out.
- Project Mechanism: The structure and effort needed for completion of the tool were considered.
- Use-cases and more: The list of actions to be carried out were determined along with future scopes

The most common creativity techniques are (Rupp & Ehrlinger, 2016):

- Brainstorming Approach
- Brainstorming Paradox Approach
- Equivalence Approach
- Mind Mapping
- Workshops
- Support Techniques

In general, creativity techniques can be improved and learned if conducted on a regular basis. They are a systematic approach, which is not noticed in the early part of the events. If the stages of the creativity approaches are well known, then it influences the concepts and improved requirements conveyed by the stakeholders are assumed (SQS AG).

- **Brainstorming Approach**

In brainstorming activities, in a restricted time range, ideas and thoughts of the stakeholders were collected (SQS AG). As a starting point, all the thoughts and ideas were noted and drawn onto a whiteboard by the requirements engineer without any
arguments or judgments or any sort of discussions. This is a very important stage of the approach, as the strategy to note down all the inputs provided a ‘refusal-free’ space for all participants. This created the impression for all participants of being taken serious and also of being important for the success of the overall project (SQS AG).

Subsequently, the stakeholders exercised each other’s ideas and even altered some which eventually created an entirely new building block for the system to be developed. Once all the conceptual elements were composed, all aspects were thoroughly analyzed. Detailed discussions followed and in-depth suggestions were made. This appeared to be an effective approach as the stakeholders participated very actively (Rupp & Ehrlinger, 2016).

The advantage of this approach is that only a short span of time is needed for the group to produce a large amount of aspects to be discussed and that the various experiences and expectations are rapidly exchanged. The brainstorming approach seems less efficient if only a few people participate in the event. In consequence, it is always recommended to implement this approach for larger groups only (SQS AG).

- **Brainstorming Paradox Approach**

  The brainstorming paradox approach collects the concepts or a circumstances which should not arise. This helped the stakeholders in recognizing the risks involved at early stages which could cause adverse effects later on the project (Rupp & Ehrlinger, 2016). After this, the participants figured out strategies in order to avoid those adverse effects and integrated them into the project plan.

  The brainstorming paradox session was conducted according to the ‘Six Thinking Hats’ methodology (Rupp & Ehrlinger, 2016). Every person present in the session was given a hat color. Each hat color symbolizes a specific perspective which is then taken by the individual during the collection of inputs and the subsequent discussions (Rupp & Ehrlinger, 2016):

  - White: Facts & Figures, Neutral & Objective
  - Red: Intuitive & Emotional
  - Black: Negative & Critical
  - Yellow: Positive & Optimistic
  - Green: Creative & Generative
  - Blue: Process Control & Overview

  In this way, even the stakeholders who had their individual standpoint were activated to adopt the new suggestions. Supplementary, the ‘Equivalence Approach’ was conducted with the same people.
Equivalence Approach

This technique considers that every individual stakeholder has complete knowledge about the project and the components related to it. In the actual session, the stakeholders were actually experienced enough to suggest equivalent or similar concepts. This approach is conducted without any time bounds (Pohl & Rupp, 2015).

The similarity of the proposed concepts could be proposed individually to the stakeholders and only the similarities are discussed. It can also be discussed in general with all stakeholders. This was actually done in the MagView project. It is the task of the requirements engineer to map the equivalent concepts and to create awareness in the group that a large portion of the conceptual building blocks proposed by the various stakeholders are actually similar or identical (Pohl & Rupp, 2015).

Other Creative Techniques

Mind Mapping

A mind map is pictorial depiction of the developed relations and interdependencies amongst the concepts. It is usually a hub and spokes depiction, with
the developed concept as the hub in the center and the conceptual building blocks as the spokes around it (SQS AG), as depicted in Figure 32.

Figure 32: Example Mind Map on Time Management by Mindtools.com (Mindtools)

**Workshops**

Meetings or conferences can be organized and collaborative goals discussed which were proposed by the stakeholders and the requirements engineer and the stakeholders for the development of the tool. The necessary functionalities and risks can also be discussed during these meetings (Rupp & Ehrlinger, 2016).

During the requirements discovery process for MagView, no dedicated workshops were organized. Nevertheless, the brainstorming and brainstorming paradox sessions were usually followed by longer discussions that served the same purpose. Hence, the workshop character was actually present in the development process with Fraport and MobiliSis, but not in the form of dedicated workshop sessions.

**Support Techniques**

Support techniques function as additions to the discovery techniques and try to overcome the drawbacks and weakness of the selected discovery techniques. Any creative method is possible in this case, e.g. ‘Rose, Thorn, Bud’ or Design Thinking Workshops (SQS AG).
Figure 33: Design Thinking: A creative technique in 5 phases (Tableaufit)
4 Requirements Documentation and Modeling

In this module, the importance and the need for documentation of requirements, which were discovered earlier, will be illustrated. The number of requirements is dependent on the size of the project. Huge projects will consist of ample amount of requirements, so it is essential to define the requirements very precisely so that a third person is also able to understand them.

The documentation report of the requirements represents the fundamental character in requirements engineering (Rupp & Ehrlinger, 2016): If the requirements of the project are documented in well-structured form, it is feasible and fast to view or modify the requirements whenever necessary. There are no official quality standards for requirements documents (SQS AG). Nevertheless, it is advisable to practice a customized form based on an official agreement with the stakeholders. This simplifies the conversations with the stakeholders and enhances the characteristics of the requirements which are documented. In general, the documentation of requirements for a project can either be drafted in written form or modelled, i.e. graphically depicted in a mutually agreed way (Pohl & Rupp, 2015). Documentation in written form can either be done manually, i.e. in handwriting or with a word processing or spreadsheet analysis software tool, or by using a dedicated requirements engineering software tool such as Polarion®27 as depicted in Figure 34 (Fraport, 2016).

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27 Polarion is used by Fraport and is a mandatory tool for all projects leading to a software procurement process. MagView was not subject to this regulation as it was considered an ‘internal’ development project in coordination with IUK-CI.
Large numbers of individuals are generally dependent on the requirements document, so it is important to have a clear and structured form of documentation. For communication with the stakeholders and amongst the members involved, it plays a vital role. The primary intentions for documenting the requirements are (Pohl & Rupp, 2015):

- **Foundation Role:**
  Requirements are the fundamental aspects for the development of the system (project).

- **Legitimate Purpose:**
  The requirements in documented form are a source of official proof or agreement carried out between the clients (stakeholders) and the originator where all the requirements needs to be fulfilled, otherwise, legal actions can be carried out by the stakeholders. Also, it is significant in resolving issues as its evidence which is agreed by the parties.

- **Intricacy:** Larger projects often possess a vast number of requirements which are interdependent on each other and proper relationship amongst each of them must be highlighted. To understand the complexity, it is necessary to document requirements in suitable structure otherwise in later stages it will become difficult for everybody to understand and trace the project goals.

- **Approachability:** The requirements must be easily available to all the people that are part of the project or identified as stakeholders during the discovery phase. In the development phase of the tool, the project goes
through various activities related to the organizational perspectives. To prevent from confusions and ambiguity of the requirements, it is very important to document the requirements and to always make them accessible for everyone. This is also a benefit for newly hired employees as they can always find all the information necessary to understand the state of the project and its objectives.

In order to develop a system, documentation can be carried out from three different perspectives (Rupp & Ehrlinger, 2016):

- **Data Perspective:**
  In this perspective, the structures of input and output data as well as constant structural elements of using the system and dependency relationships of the system in the system context are recognized and documented.

- **Perspective 2: Functional:**
  The functional perspective of requirements deals with the conversion of input data received from outside the system (project context) into output data to be provided into the system environment 28.

- **Perspective 3: Behavioral:**
  This perspective is based on Use Cases and is generally used in order to add a user’s perspective to the RE process. The key question of the behavioral approach is: what shall the system do (how shall it behave) if the user does x?29 The answers to these questions are then recorded as requirements.30

### 4.1 Quality Criteria for Documenting Requirements

In order to establish a reliable basis for all consecutive developments, the requirements document needs to meet strict quality benchmarks. The requirements document must be reliable and complete, as proposed by ISO/IEC/IEEE standard 29148:2011 (Rupp & Ehrlinger, 2016). In addition, a requirements document must possess comprehensibility by stating all information in clear language and sentence structures. The structure of the document itself must be definite and the content must be

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28 There are a various models available to be used in order to model the functional perspective of requirements. Most of them are based on the structured system analysis approaches invented about 40 years ago, such as the structured analysis [DeMarco 1978, Weinberg 1978] or the essential system analysis [McMenamin and Palmer 1988].

29 This question has to be repeated for each Use Case and for each option the user has.

30 The perspective may also include that the users are not asked question, but observations are made on how the user uses the system or previous systems.
sensible and transparent. In all, the quality criteria for a requirements document are as follows (Rupp & Ehrlinger, 2016):

- **Certainty and Stability**
  The requirements document can be stable and accurate if, and only if, the quality of every single requirement is precise and constant. Additionally, it must be ensured that the requirements in one document do not contradict each other. Versioning of the requirements must be carried out to sustain the uniqueness in the identification of all items in a collection of requirements documents. The versioning is discussed in more detail in section 5 (Rupp & Ehrlinger, 2016).

- **Evident Design**
  In actual projects, it is difficult to classify or state whether a requirements document is evident or not. But the main agenda for an evident design of such document is that the structure or the design of the entire requirements document must be easily understood by the stakeholders. A reader must easily and quickly be able to find all information of relevance to him. If the requirements document is not well designed it will be time-consuming and disturbing for a stakeholder to locate relevant information (Rupp & Ehrlinger, 2016).

- **Adaptability and Progressiveness**
  The structure and the design of the requirements document must be capable of supporting any sort of modifications to be carried out easily. There are situations where a specific requirement or groups of requirements needs to be modified, changed, supplemented or deleted during different stages of the project. Therefore, it is necessary for the requirements documents to be extended or modified very easily. The changes or the modifications carried out for the requirements documents must be reflected in the versioning of the documents (Rupp & Ehrlinger, 2016).

- **Exhaustiveness**
  Generally, a requirements document is considered to be complete when it contains all the requirements which are of relevance and also all supplementary information which is required for the project. In addition, every single requirement needs to be drafted completely. The document must also illustrate the desired outcomes of the project, the inputs and significant aspects for every determined project operation. Formal aspects also play an important role concerning the exhaustiveness of the requirements document. The flowcharts, tables or diagram models used in
the documents must be denoted properly. Furthermore, it is an essential factor to provide correct references, definitions and links to relevant standards and regulations. To achieve the exhaustiveness of the requirements document, it is always advisable to negotiate based on the available resources and time (Rupp & Ehrlinger, 2016).

- **Track-ability**
  Track-ability represents the clear associations of requirements documents with other organizations’ documents, such as, business goals, design models or test strategies. Additionally, track-ability provides traceability of requirements when a document is updated or changed (Rupp & Ehrlinger, 2016; SQS AG).

Beyond the quality criteria defined by the ISO standard it is common practice in projects, e.g. in projects run by IUK-AO11 of Fraport AG, to also check the requirements document for its usefulness in the phases of operating the system and for maintenance purposes\(^3\). Hence, it is best-practice to also consider this aspect as a quality criterion.

### 4.2 Quality Criteria for Requirements

In RE, not only do quality criteria apply to the structure and content of the entire requirements document, but also to each individual requirement. The ISO/IEC/IEEE 29148:2018 lists the main quality criteria. They are as follows:

- **Settled:**
  A requirement is settled or agreed if all stakeholders approve that no further changes are needed.

- **Unambiguous:**
  Requirements shall be written in a way that leaves the least possible room for interpretation. The objective is to make sure that all stakeholders have a common and shared understanding of the requirement (Pohl & Rupp, 2015).

- **Necessary:**
  A requirement shall reflect its relation to the project scope in order to depict it is necessary for the system to achieve the aspired outcome (Pohl & Rupp, 2015).

- **Consistent:**

\(^3\) This is useful as in many cases the people who specify and design a system do not run or maintain it.
Requirements must be stable and reliable with respect to other requirements in the same document. Hence, requirements must not refute each other, irrespective of their hierarchy, granularity of the information, or the type of documentation. Furthermore, a requirement shall not contradict itself (Pohl & Rupp, 2015).

- **Verifiable**: A requirement is considered verifiable only if there exists an economical process that can be used by a person or machine to check that the system function or the entire system meets the requirement. If a method cannot be identified to determine whether the system complies with a particular requirement, then the requirement must be changed or deleted (Pohl & Rupp, 2015).

- **Feasible**: A requirement has to comply with all structural, official, technical or fiscal limits that are known in order to be categorized as feasible (Pohl & Rupp, 2015).

- **Traceability**: A requirement is traceable if all its sources or contributing sources are explicitly referenced (backward traceability). A requirement shall also have a unique identification number or code (forward traceability) (Pohl & Rupp, 2015).

- **Complete**: Each requirement shall be completely illustrated along with its specified functionality. Requirements that are so far unfinished, must be specifically marked. The marking could be stated by defining a status such as ‘to be examined’. These markings support the step-wise completion of the requirements document by completing all individual requirements (Pohl & Rupp, 2015).

- **Understandable**: Every single requirement must be understandable to all the stakeholders. It is very essential that precise definitions of the terms are provided in written form.

### 4.3 Requirements Modeling

It has been studied that modeling of requirements is an advantageous method as individuals memorize graphs and images more quickly and more sustainably than written scripts (Beecham, Hall, & Rainer, 2005). Also, requirements modeling supports to depict precise and accurate objectives to understand the flow of the project (Rupp & Ehrlinger, 2016). For the MagView project, modeling strategies were not applied. The size of the
project was small and only a few requirements had to be considered for the initial
development of the tool. Some of the modeling strategies, which are generally used for
bigger projects, are (Pohl & Rupp, 2015; SQS AG):

- Goal Model for requirements
- Flow Oriented Modeling
- Behavioral Modeling

### 4.3.1 Goal Model of Requirements

There are numerous approaches in RE that are grounded on precise and exclusive
ideas of the stakeholder’s purpose by defining the objectives or goals (A. Van
Lamsweerde, 2001).

Normally, goals are the perceptions or depiction of distinctive features proposed
by the stakeholders for the development and implementation of the project. Ordinarily,
the intention necessary to unambiguously determine the goals amid requirements
engineering is marginal (A. Van Lamsweerde, 2001). Nevertheless, if the goals are
graphically modeled, this usually gives the stakeholders the impression of a completeness
and quality of the process.

Goals are an appropriate means to enhance or polish the image of the project.
Improving or purifying a goal is called a ‘decomposition’ of goals. There are different
methods to document the goals, one of the methods is using AND/OR trees (please see
Figure 35) (Pohl & Rupp, 2015). In AND/OR trees, the goals of the projects are modeled
in top-down hierarchical structure where the prime objective is at the top position. For an
AND-decomposition, every sub-goal must be accomplished in order to fulfill the prime
objective in the top position. For OR-decompositions, in contrast, at least one of the sub-
goals must be fulfilled in order to accomplish the main goal (Pohl & Rupp, 2015).

![Figure 35: Example of AND / OR Tree (Pohl & Rupp, 2015)](image)

### 4.3.2 Flow Oriented Modeling

The flow oriented modeling generally deals with the functional perspectives of
the requirements. It depicts the transformation of input data into output data by the system
(SQS AG), as depicted in Figure 36.
The illustrative form used for flow oriented modeling is usually the data flow diagram (DFD). It generates models based on different abstraction levels of the project and is a common approach that is practiced. The modeling element notations of data flow diagrams are as follows as depicted in Figure 37 (SQS AG):

- **Process**: It is necessary to transform the data from input to output. Process is the data transformer.
- **External Source**: It can be a stakeholder or a customer. It is the origin of the data that must be delivered to the system.
- **Data Store**: The data is stored in the data store so that it can be accessed (read/write) whenever necessary.
- **Data flow**: Illustrates the transfer of information between the external sources, processes and the data store.

The notations are the building blocks for creating a Data Flow Diagram as exemplified in Figure 38. In the depiction, the data flows through the system, in this case a room booking system.
4.3.3 Behavioral Modeling

The Behavioral modeling strategy indicates how the tool would react to external actions. It models the dynamic behavior of the systems. In order to generate the model, e.g. a state model, the following steps must be carried out (SQS AG):

- In order to understand the sequence of interactions, all the use-cases must be thoroughly examined
- All influences on the order of interactions must be recognized and it needs to be fully understood how these are related
- A sequence for every use-case must be generated
- A state diagram is to be developed

A validation has to be performed in order to verify the behavior and precision of the state diagram (SQS AG).

The states or elements of the system are (Pohl & Rupp, 2015) (please see Figure 39):

- State: defines a collection of events that represents a specific behavior of the system at a defined point in time.
- Event: is an instance that exhibits predictable behavior of the system.
- State transition: is the change of state when a certain event has occurred.
- Action: is the process that gets generated in order to facilitate the transition.
Figure 39: Elements of a State Diagram (Pohl & Rupp, 2015)
5 Requirements Management

Requirements Management is considered one of the key activities in RE. It not only involves managing a particular requirement or a set of requirements, but it refers also to the main-framing of the requirements document (Jarke & Pohl, 1994; Pohl & Rupp, 2015). The actual work performed in the requirements management phase mainly consists of deliberately designating attributes to the requirements (Gerald Kotonya & Sommerville, 1996). This activity also comprises of assigning priorities to the requirements based on the initial goals of the project or the stakeholder’s demands. Proper versioning of requirements or documented requirements must be maintained. The views on the requirements are also described and the track-ability of the requirements as well as the assessment of requirements and all related change requests are managed and maintained in the requirements management phase (Jarke & Pohl, 1994; G Kotonya & Sommerville, 1992).

It must be ensured that the arrangement of the information is maintained in well-structured form (Jarke & Pohl, 1994). It is the responsibility of the requirements engineer to provide a persistent requirements document and also to distribute appropriate information throughout the entire project cycle. The requirements engineer must also guarantee for selective accessibility of the information (Jarke & Pohl, 1994).

In general, the requirements management consists of approaches based on the following classifications (Pohl & Rupp, 2015):

- **Defining properties to stakeholders requirements:** Properties of stakeholders’ requirements are documented by defining attributes to the requirements.
- **Requirements prioritization:** The prioritization of requirements is carried out at different points in time, while performing various tasks, and based on the desired use-case. Various prioritization techniques are implemented based on the aim of the project.
- **Track-ability of requirements:** In requirements management, in order to utilize cross-layer dependencies of requirements, the information are stored and maintained so that they are easily available when required.
- **Requirements versioning:** By storing a history of requirements or versions of documented requirements helps in recording the information which could be utilized over the entire course of project.
• **Requirements change management:** Commonly, there are authorized individuals or groups who are responsible for the management of changes for the stakeholder’s requirements (SQS AG). The official individuals are responsible to approve whether or not the request for change must be accepted or rejected. They are also responsible for prioritizing change requests. Furthermore, the influence of the change request on other requirements and the estimation of resources and time required to process the change must also be evaluated by the authorized persons (Rupp & Ehrlinger, 2016).

### 5.1 Assigning Properties to Requirements

As described in the sections above, various quality criteria apply to requirements and to requirements documents. In order to fulfill these criteria, it is unavoidable for the requirements engineer to constantly monitor their quality over the entire project cycle (SQS AG).

Requirements need to be drafted well and a reader of the document must be able to quickly find all relevant information (Gerald Kotonya & Sommerville, 1996). This is one of the reasons why an exclusive Unique Identification (UID) of a requirement needs to be assigned to each requirement for a system32 (Pohl & Rupp, 2015). In addition, other properties such as requirement name, description of the requirements, requirements sources, requirements priority etc. which the requirements engineer attaches to the requirements allow for quick categorization of requirements (please see Figure 40), e.g. in order to compile all requirements originating with one specific stakeholder.

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32 Requirements engineers in large airside projects at Frankfurt Airport made the experience that the experts working on large requirements documents, e.g. with 3,000 requirements, usually have problems in quickly finding specific requirements by their names. Instead, it is very often the case that they remember the UID code. At Fraport, where the use of Polarion is mandatory for large projects, the UID usually consists of three letters and four digits.
5.2 Requirement Prioritization Methods

The prioritization of requirements is based on different criteria during the entire requirements engineering approach. It is probably the simplest approach to set the priorities according to the order of the deployment of the requirements (Gerald Kotonya & Sommerville, 1996). In this case, the sooner a requirement would be implemented the higher the priority. This is a simple approach with obvious deficiencies, e.g. when it comes to dependencies on external developments or customer priorities. In consequence, different ways of prioritizing requirements were developed over the years, taking into account various influencing factors, e.g. the individual stakeholders’ priorities or the importance of a requirement for the project’s success (Rupp & Ehrlinger, 2016).

In an actual project, the first step towards prioritized requirements is to define the objective of the prioritization process and to note the limitations involved, e.g. if some stakeholders only have limited access to some of the requirements or if a stakeholder is not able to participate in the process (SQS AG).

In general, the criteria for requirement prioritization processes are as follows (Pohl & Rupp, 2015):

- Significance
- Risks involved
- Effort calculation
- Resource estimation
- Loss for unsuccessful deployment
• Unpredictable behavior

**Stakeholders Involvement**

It is absolutely essential to involve stakeholders during the process of prioritization of requirements (Rupp & Ehrlinger, 2016). By involving the stakeholders, their expert opinions and knowledge is brought in. This makes prioritizing easier and more beneficial with regard to the goals of the project. Stakeholder involvement is also important for the identification of the stakeholders with the project (Sharp et al., 1999). It can be assumed that the more a stakeholder gets involved in a project, the more the people get the impression that the resulting system is also ‘their product’.

**Methods**

Based on the prioritization criteria’s which were specified above, one or multiple prioritization approaches or techniques are used in actual projects.

As depicted above, numerous prioritization techniques are available. The selection process shall be made taking into account the duration of the project and based on the estimated effort required. Additionally, the method shall best support the stakeholder’s objectives and the overall project goals. The techniques to prioritize can either be ad-hoc methods, analytical methods or both (Rupp & Ehrlinger, 2016).

If the requirements engineer and the project team focus on a simple and basic approach for the classification, e.g. because they want to complete the task quickly or as the project needs are straightforward, an ad-hoc prioritization technique is to be preferred (Gerald Kotonya & Sommerville, 1996; Pohl & Rupp, 2015). Similarly, if the project needs are too elaborated and there is sufficient time bounds and an elegant and descriptive analysis is required to prioritize the requirements, then it is recommended to adopt an analytical prioritization technique. Some of the approaches for the latter are: Analytical Hierarchy Process (AHP), Quality Function Deployment (QFD) or Cost Value Analysis (Pohl & Rupp, 2015; Rupp & Ehrlinger, 2016).

In the MagView project, the situation was special compared to many other projects, as the stakeholders and the requirements engineer had only selected the ‘bare necessities’ in terms of requirements for the first version of the tool. This decision was based on the very restricted time and the stakeholder’s need to have a visualization tool for EMFS data by the end of February 2017, latest. Therefore, elementary ad hoc prioritization approaches were practiced to identify those requirements with the highest priorities for the stakeholders. The approaches employed were the Single Criterion Technique, Ranking Techniques and the Kano Model Approach (Pohl & Rupp, 2015). Based on the resources available, it was advisable to use these three prioritization techniques. In other cases, when too many errors are to be dealt with, then it is desirable
to use at least one analytical approach in addition. But this was not in case in the MagView project. The prioritization techniques which were implemented are discussed below.

5.2.1 Single-Criterion Technique

The Single Criterion Technique is the most commonly used technique to prioritize requirements. It is a powerful process providing good results in a short amount of time (SQS AG).

In the MagView project, the requirements were classified with reference to the significance and other criteria of the recognition of the requirements for the successful development of the project. This was done with all the stakeholders present. As a first step of this process, priority groups were defined according to the list below, i.e. from P1 to P5. After that, each requirement was assigned to a priority group and these were maintained in the requirements checklist table (Appendix A1). The priority groups were as follows:

- **P1 priority:**
  The P1 priority requirements are the requirements with the highest priority, i.e. to be implemented in any case. These are the prime requirements which must be fulfilled in order to successfully develop the tool and they are mandatory to satisfy the stakeholder’s needs.

- **P2 priority:**
  The P2 priority requirements are the requirements of high significance. They should be implemented sooner or later during the development of the project.

- **P3 priority:**
  The P3 priority requirements are preferential kind of requirements which are good to have but it’s not compulsory to include them as these will not have an effect on the success of the implementation.

- **P4 and P5 priorities:**
  The P4 and P5 priority requirements are requirements which are proposals or ideas to further improve the tool or to add additional functions. They are considered as a part of a future scope or as an extension of the project which could be implemented in the future processes.

5.2.2 Ranking techniques

Once the classification of the requirements were finalized according to the groups specified above, the ranking prioritization technique was implemented. It was carried out in two steps: Initially, all the requirements were presented to the stakeholders, keeping in
mind the criteria each stakeholder was asked to rank the given list of requirements starting from rank 1 (most significant requirement) to rank n (least significant requirement) (SQS AG). After the stakeholders had ranked the requirements, the ranking order of the requirements were then finalized based on the majority of the stakeholders. There were some negotiations during this approach. Further detail on requirements negotiations is provided in section 5.4.2. (Rupp & Ehrlinger, 2016).

### 5.2.3 Kano Model Approach

The Kano Model Approach is used in order to identify the perception and acceptance of a requirement when implemented and from user’s (market) perspective (Pohl & Rupp, 2015). The basic question behind the Kano Model is: how satisfactory is a specific requirement for the user (customer)? (SQS AG)

The prioritization according to the Kano Model is carried out as an expectation and based on the following categories (Pohl & Rupp, 2015):

- **Satisfiers:**
  A requirement is defined as a satisfier if a stakeholder has explicitly demanded for this requirement as a functionality of the system. In all, the rate of satisfaction of the stakeholders is dependent on the number of satisfiers that the system provides and if all functionalities consciously required by the stakeholder are fulfilled, the stakeholder’s requirements are satisfied (Pohl & Rupp, 2015; Rupp & Ehrlinger, 2016). If some of the specified or commanded functionalities are not present, there is a probability that the stakeholders will not accept the system. In consequence, it is very crucial to implement all the demanded requirements of the stakeholders in order to provide enough satisfiers (SQS AG).

- **Dissatisfiers:**
  A requirement is specified as a dissatisfier when a functionality of the system was subconsciously expected and is not included in a release or final version of the product or it is included, but in an unsatisfactory manner, e.g. the function is slower than expected, but the time needed was not mentioned in a requirement (SQS AG). Dissatisfiers clearly make the affected stakeholder unhappy. Hence, requirements engineers have to make sure, e.g. through thorough investigation before a software development begins, they try to identify previously uncommunicated expectations and turn them into official requirements (Pohl & Rupp, 2015).

- **Delighters:**
A requirement is defined as a delighter if the stakeholders have not commanded for a particular functionality and they are unaware of its availability during the development phase (Pohl & Rupp, 2015). The functionality gets discovered in the testing or operational phases only. It is a positive surprise for the stakeholder as a corresponding requirement had never been specified, but the functionality is considered very helpful and good.

The following figure, Figure 41: KANO Model Approach, depicts the Kano Model and also features some requirements of the MagView project. Their position in the model reflects their status as delighters (e.g. EMFS_Tool_1), satisfiers (e.g. EMFS_Tool_10) and dissatisfiers (e.g. EMFS_Tool_11). A full list of all requirements of the MagView project is to be found in the Appendix A1.

Figure 41: KANO Model Approach (Fraport, 2016; Pohl & Rupp, 2015)

5.3 Requirements Change Management

The requirements of the stakeholders do change over the entire progress of the project to be developed. This means that, generally, there is a request for new requirements to be implemented or added and also some modifications or changes for the

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33 At typical example for a delighter from actual project experience at Fraport AG is a „night mode“, i.e. an alternative HMI graphical mode for night operations in control rooms. It features accentuated contrast and other colors in order to better support people working in darkness. The first time it was implemented it was a delighter. Now it is considered an important feature and whenever new products or HMIs are defined, a corresponding requirement is written. Hence, the „night mode“ turned from a delighter into a satisfier over the last years.
existing list of requirements. The reason for change of requirements cannot be determined without knowing the actual goal of the project (SQS AG).

It is very important to identify and discover necessary changes in early stages of the project as a change of requirements in later development stages would be difficult and costly to be implemented. There are miscellaneous reasons for changes in requirements (Pohl & Rupp, 2015).

In general, if the requests for change during the implementation of the tool are not very frequent, this indicates that the stakeholders are satisfied with the list of requirements. But if there are frequent requests to modify or change or delete the requirements which were predefined, this can be seen as a sign for improper requirements engineering approaches during the discovery stages (Rupp & Ehrlinger, 2016).

5.3.1 The Change Experts Group

Generally speaking, change requests can be put up for a specific requirement or for the complete set of documented requirements. Therefore, it is important to have a group of experts who manage and possess a decisive authority for the change requests. It is the job of these experts to evaluate the changes or modifications requested by the stakeholders and to come to a decision with proper justification and reasoning (Rupp & Ehrlinger, 2016).

It is essential to create a descriptive document which portrays what is to be changed and the effects of these changes in a precise form and for all the requirements which are to be added or modified. In addition, justifications must be conveyed with valid reasoning that why these changes are necessary, etc. (SQS AG).

There are various jobs that must be executed by the change experts group, some of which are as follows (Pohl & Rupp, 2015):

- Identifying adequate requirement change requests
- Evaluation of change requests
- Estimation of time and effort to execute the change
- Specifying new requirements based on the requested change
- Decision on approval or disapproval of the requested change
- Prioritizing approved change requests
- Immediate actions on exceptional requirements change requests and more.

5.3.2 Change Requests in the MagView Project

The MagView project is a development project contributing to a larger research & development project. This leads to the potential of new insights, changing
technological or technical fundamentals and in all, to a number of uncertainties not to be expected in other environments. As a consequence of this environment, a change became necessary at a later stage of the software development phase.

While analyzing the data from the first field test (for further detail on the activity, please see section 2.3.3.1), it was realized that the raw sensor data of the x-, y- and z-values are not normalized to a shared zero-value (ZV). Typically the ZV should be zero, but two effects are able to change that ZV:

1. (random) noise
2. (slowly) reference drift

As this was not identified during the requirements discovery phase and also not mentioned in any of the following phases, the current version of MagView does not normalize the average noise of the axes to one shared zero-value\(^{34}\). But the formula to calculate the vector magnitude works properly only if this shared zero exists. If the formula is used without proper normalization, the peaks of, for example, x have a much lower relevance for the final magnitude than the average noise of z. This results in a loss of distinct peaks and in disproportionate results.

To stop this, the values first need to be normalized.

After manually testing the normalization in this way: First, calculate the mean value of all values of one axis. Then, subtract the mean value from the actual value. The result does now describe the distance between a value and the average noise of the axis. The results can then be used to calculate the magnitude.

Additionally, it is proposed to use a moving average instead of the mean value.

It could be wise to create a floating ZV, i.e. during a phase without a signal (no aircraft or other ferromagnetic material present in the vicinity of the sensor bus systems) affecting the sensors. A comparison with the last known ZV could result in a new ZV. For comparison a floating average value (FAV) should be used. If the result of the comparison is that the ZV must be changed, a sliding adjustment should happen.

\(^{34}\) From a scientific point of view, this problem leads to an important insight. Even if all stages of the RE process are carried out with the best possible methods and concepts, one important issue will prevail: If only one stakeholder, or in extreme cases only one specific expert of one stakeholder, has an important knowledge that nobody else is aware of, and if this person, for whatever reason, does not provide this insight to the RE process, important aspects may be lost and the final result may be unsatisfactory.
In the MagView project, a corresponding change request was put in place. But, as the time on this Master Thesis is limited, this change is not implemented for the initial version of the tool. It is added in the requirement list for the next version.

5.4 Validation and Negotiation

Validation and Negotiation techniques are key elements of RE. Validation focuses on producing the right product by keeping a close eye to it (please see section 5.4.1). In contrast, Negotiation is about aiming to obtain the desired product as per the view of the stakeholders. It safeguards the quality of the product by predetermining the necessary requirements, to establish mutual agreement, exactness in terms of conveyed meaning, etc. (please see section 5.4.2) (Rupp & Ehrlinger, 2016). In all, validation and negotiation are mainly used to prepare and establish an agreement among the stakeholders (SQS AG).

In the upcoming subsection, a detailed overview on the techniques and principles will be provided. While requirement validation includes requirement review, perspective dependent study, validation using prototypes and checklists, requirements negotiation covers the aspects of conflict management and strategies for the settlement of those conflicts (Axel Van Lamsweerde, Darimont, & Letier, 1998).

5.4.1 Requirements Validation Principles

In RE, quality checks are performed through validation activities that analyze whether the input, the activities performed, and the output obtained, meet the criteria of the stakeholders involved (Koch & Escalona, 2004; Villegas, 2013). The result of such activity is the identification of the variation between the actual needs of the stakeholders and the defined requirements (Sharp et al., 1999).

In the RE process, all necessary requirements are defined and with the help of quality checks the requirements are accepted. This is known as approving requirements (Pohl & Rupp, 2015). The approved requirements are then used to perform activities like implementation, testing, etc. (please see section 4). Errors affect the quality of the product and the activities related to it. The detected errors are revised and adapted as required. In all, the prime aim of requirements validation is to determine the errors and to revise the requirements as necessary. The correction of the errors also reduces the legal risk associated with faulty requirements (SQS AG).

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35 As a workaround, Fraport decided to hire an external developer from 1/3/2017. He will develop a converter that reads the text files with the x-, y-, and –z-axis values, calculates a ZV and re-writes the text file with values normalized with the ZV. By reading and parsing the converted text files, MagView will then depict the expected peaks.
Principles of Requirements Validation

Five principles of requirements validation are well-known and will be discussed in this sub-section (Pohl & Rupp, 2015):

- **Involvement of correct stakeholders:**
  According to this principle, it is necessary to choose the appropriate stakeholders depending on the validation goals. Together with the identified stakeholders, internal and external validation has to be performed, i.e. just with the one stakeholder and finally with all of them as a group (Pohl & Rupp, 2015).

- **Identification of errors:**
  This principle is about identifying the bugs. The identified bugs need to be cross verified and documented properly. Identification of errors and the correction of errors are two different and not directly linked processes (Pohl & Rupp, 2015).

- **Validation from different views:**
  The validation from different views is performed in order to take into account different perspectives on the requirements. Aspects that may not be a problem from one point of view may be a critical error from another one (Pohl & Rupp, 2015).

- **Construction of development artifacts:**
  The main desire of this aspect is to develop the artifacts in order to check the quality of the requirements so that it can design artifacts or test cases. The artifacts are generally validated in different phases. Each phase consists of small packages which are reviewed separately. For example, the reviewer thoroughly examines the requirements notified in the test cases. If requirements are examined in detail, it ultimately results in minimization of the errors (Pohl & Rupp, 2015).

- **Repeated validation:**
  This kind of activity takes place during the development phase and the number of cycles and their intensity are depending on the knowledge of the reviewer. Along with it, consumers acquire more information about the system. Even with repeated validation performed in a project, a final (legal) guarantee concerning the status of the requirements to be ‘error-free’ clearly remains arguable (Pohl & Rupp, 2015).

Validation Techniques
Validation techniques are mainly used to review the requirement engineering through several means. Different types of review processes are known (Rupp & Ehrlinger, 2016):

- **Feedback:**
  In case of feedback, requirements are passed over to other experts for an expert view on the requirements. The expert reviews enhance the quality of the requirements and fixes errors. The diagnosed errors can be mentioned in the updated requirements to increase the learning curve for all involved (Rupp & Ehrlinger, 2016).

- **Investigation:**
  Investigation is about the examining or evaluating the requirements described by undergoing a certain process (Pohl & Rupp, 2015). This can be done in various ways like planning, testing, defect correction, etc. The output obtained upon investigation is evaluated based on the requirements described (Pohl & Rupp, 2015). In case of planning and testing, a dedicated planning method is used to test the performance of the product. Here the errors are collected, analyzed and evaluated accordingly, this in turn increases the performance of the product. The goal is determined in the planning phase itself. In order to make the investigator aware of all the requirements, the requirements are communicated in the team to have a common understanding about the process and the requirements. The team works individually or together to find out the errors from the requirements defined. Finally, the identified errors along with the corrections are documented (Rupp & Ehrlinger, 2016).

- **Dry run:**
  Dry run is a form of peer review. In this process, inspectors, developers, etc. go through the requirements together in order to understand the requirements and carry out the testing process successfully. A step-by-step process is carried out under the supervision of the leader and all findings are documented in minutes. The author discusses the minute details along with the additional information with all involved stakeholders (Rupp & Ehrlinger, 2016).

The abovementioned review processes are to be characterized as manual processes mainly. The following approach may assist the review process (SQS AG)

- **Perspective dependent study:**
  In the perspective dependent study case, different perspectives are taken into account to check the requirements (SQS AG). It is mainly carried out...
during the investigation or dry run phases (SQS AG). The following perspectives are known (Pohl & Rupp, 2015):

- **Stakeholder’s perspective:**
  In order to deliver any product to the stakeholders, firstly the stakeholders’ perspective shall be taken into account. The requirements of the stakeholders are then verified to see whether their content is available in the defined and documented requirements.

- **Project Designer perspective:**
  The project architecture or design is taken into consideration to verify the availability of all requirements.

- **Investigator perspective:**
  According to this perspective, test cases are derived for quality check. The derived test cases are tested by the investigator.

- **Substance perspective:**
  The substance (content) is verified by the individuals who check for the quality of the requirements that are documented.

- **Document perspective:**
  In this case, the document is used for quality check to verify all the guidelines are perceived well.

- **Legal perspective:**
  The individuals responsible for quality check, verifies stakeholder’s agreements are met and the encountered issues are resolved.

During this study process, the reviewer is provided with the perspective to check for the requirements and the quality (Koch & Escalona, 2004). Later, a follow up is planned to analyze and validate the results of the processes study, e.g. by applying the following concepts (Rupp & Ehrlinger, 2016):

- **Prototype validation:**
  In a prototype validation, the reviewer validates using the prototypes to performing the respective steps (SQS AG). This is one of the most effective methods to find the errors and to rectify accordingly.

- **Validation using checklist:**
  A set of questions is prepared after observing some assets. The quality is measured based on the checklist. This simplifies the error detection (Rupp & Ehrlinger, 2016). The checklist can also revised based on the stage of development of the system (SQS AG).
5.4.2 Requirements Negotiation Fundamentals

Requirement negotiation is about dealing with requirements of two or more stakeholders or consumers at a same time in order to come to a settlement of common requirements. The fundamental of requirement negotiation is to determine the conflicts and to fix them (Axel Van Lamsweerde et al., 1998). This includes several processes that are commonly referred to as ‘conflict management’ processes.

The management of conflicts takes place in different steps, as depicted below (Pohl & Rupp, 2015; Axel Van Lamsweerde et al., 1998):

- **Identification:**
  In this task, the conflicts are identified taking the consumers view into consideration. The conflict may arise due to various demands of the several consumers at the same point of time. Thus, the requirements can vary (Sharp et al., 1999).

- **Analysis:**
  During analysis, the identified conflicts are analyzed. The conflicts can be identified as conflicts of interest, value, relationship, structural and various other reasons. The identified conflicts are analyzed based on the kind of conflicts that actually occurred (Axel Van Lamsweerde et al., 1998).

- **Resolution:**
  In this phase, the concerned developers, customers, etc. are involved in the process of resolution. The point of view is taken into consideration to resolve the conflicts and to provide all involved with the required output. The important factor in conflict resolution is communication, as all involved persons shall be made aware of the conflicts and the solutions provided (Pohl & Rupp, 2015).

- **Documentation:**
  The conflicts which were noticed during the abovementioned process are recorded in the form of a document. This document can be referred when necessary in the coming processes and also to keep record of the errors that came into action and caused conflicts (Rupp & Ehrlinger, 2016).

An established theory concerning conflict management is called the ‘Thomas-Kilman Conflict Modes’. For the MagView project, no conflicts were to be expected or came into existence, as all stakeholders had the same objectives and as cooperativeness was at the core of working together from the very beginning (Axel Van Lamsweerde et al., 1998). The Conflict Modes are depicted in Figure 42.
Figure 42: Thomas-Kilman Conflict Modes\textsuperscript{36}

\textsuperscript{36} http://stevton.com/services/od-training/conflict-management-resolution/
6 The MagView Tool and Discussions

The superordinate purpose of graphically depicting the stored sensor data is to analyze the capabilities of the sensor which, when finally implemented and fully integrated into the airside system environment, will improve the data quality and reliability of the A-SMGCS system. The availability of such a visualization and analysis tool (MagView) will allow in-depth evaluation of the sensor’s abilities. Based on the results, the use of these sensors for actual operational functions on the aerodrome surface will be decided.

6.1 Implementation of the Tool

The initial requirements were prioritized by conducting various meetings with the stakeholders and implementing prioritization techniques which are discussed in the earlier sections. Based on the prioritized and harmonized package of requirements development of the tool was started, i.e. the requirements document was used as the starting point for the software development process. The MagView tool was produced as specified and validated. The implementation of the tool was executed using Matlab. The tools which were used are as follows:

- Matlab R2015b
- Matlab runtime9.0
- Maths toolbox

The following sub-section depicts a simplified overview on the work principle of the MagView tool:

1. Initially, it reads the sensor file name (text file).
2. It then parses the file name and checks whether it is a valid name or not.
3. It then reads the data from the file and puts it into the cells.
   Two cells are formed: (i) Time and (ii) Data.
   Time cell contains time information of the sensor Data and Data cell contains respective data. The cell structure of Data cell is as follows (see figure 43):
The detailed algorithm for data parsing is presented in Section 6.2.

4. Once X, Y, Z data for all the sensors is divided into respective matrices, it then calculates the ‘Vector Magnitude’ using the following formula:

   \[
   \text{Vector Magnitude} = \sqrt{x^2 + y^2 + z^2}
   \]

### 6.2 Sensor Data (Output)

The output data of the EMFS sensors is stored in text files (please see Figure 44). The data values of EMFS sensors are in format of three-dimensional axis values (x-axis, y-axis and z-axis), number of sensors, length of vector and time respectively.
For Data parsing (sensor output), the following steps were carried out:

1. First, it opens the sensor data file
2. It searches for the comments present in the file, if any comments are present then it ignores or deletes that line
3. It searches whether any headers are present in the file or not. This is done by searching the string ‘Time’ in first line. If there is a match then header is present else not present.
4. If headers are present then:
   4.1. Split the first row with ‘;’ as a delimiter
   4.2. Read number of columns present in the file
   4.3. Search for the header ‘Type’ in the file and split the file whenever this header occurs. This will result into different cells for different sensor lines because each sensor line data starts with the header ‘Type’
   4.4. Find all X values indices in the matrix. This is done by searching header ‘X’ in the file and copying all the data in X column in one common matrix
   4.5. Find all Y values indices in the matrix. This is done by searching header ‘Y’ in the file and copying all the data in Y column in one common matrix
   4.6. Find all Z values indices in the matrix. This is done by searching header ‘Z’ in the file and copying all the data in Z column in one common matrix
   4.7. Repeat point 4.3 to 4.6 till all there are no more ‘Type’ header present in the file.
5. If headers are not present in the file then:
   5.1. It splits the first row with ‘;’ as a delimiter
   5.2. Read number of columns present in the file
5.3. Search for the string ‘D’ in the file and split the file whenever this string occurs. This will result into different cells for different sensor lines. D represent type in the file.

5.4. Find all X values indices in the matrix. This is done by reading second column after the column where string ‘D’ is present at first and then every third column next to it till end.

5.5. Find all Y values indices in the matrix. This is done by reading third column after the column where string ‘D’ is present at first and then every third column next to it till end.

5.6. Find all Z values indices in the matrix. This is done by reading fourth column after the column where string ‘D’ is present at first and then every third column next to it till end.

5.7. Repeat point 5.3 to 5.6 till all there are no more ‘D’ strings present in the file.

6. Once the indices are known then the data is divided according to the column number. Read First line in the file.

7. Split the line with ‘;’ delimiter.

8. Check whether total number of columns is equal to expected number of columns. If not, then error is present. In this case, delete that line.

9. Read time from the line and convert it into ‘HH:MM:SS:FFF’ format.

10. Split X, Y and Z data into respected matrices according to the indices found in step 4 or 5.

Repeat step 6 to 10 for all the lines present in the file.

6.3 Visualization Results

The figure 45 displays the initial appearance of the MagView window after the application is opened. The white area is the place where peaks in 3-Dimensional (3D) form will be depicted.

![Figure 45: MagView Application](image-url)
As required, the stakeholder will have to browse or can also write the path manually to select the location where the text files are stored locally. After the path is entered, the user would have to click on the parse button where the sensor data output in form text files will perform its calculation in the backend to depict the required outcome in form of 3D peaks.

![Select File](image1.png)

**Figure 46: MagView Parsing**

![Select File](image2.png)

**Figure 47: Parsing**

Figure 48 displays the 3-Dimensional view in form of peaks of the sensor data which was initially stored in the form of text. The X-axis denotes the time, Y-axis denotes the number of sensors and Z-axis denotes the cumulative values.
In contrast, Figure 49 depicts the cumulative length of vector and also there is a possibility to select the bus line and the graph will depict the output accordingly, i.e. for bus line 1 only, or for bus line 2 only.

The image shown in the figure 50 displays the value of the sensor data recorded at the X-axis.
The image shown in the figure 51 displays the value of the sensor data recorded at the Y-axis.

Figure 51: MagView Y-Axis

The image shown in the figure 52 displays the value of the sensor data recorded at the Z-axis.

Figure 52: MagView Z-Axis
6.4 Playback tool Results

Once the data is parsed correctly to display, the next step is that the playback buttons should operate correctly. The figure 53 below illustrates various playback options such as start, pause and stop. Also, there is a possibility to select the bus line and plot the length of vector or X, Y, Z axes respectively.

The playback functions of the MagView tool are as follows:

- **‘Start’ Function**
  1. Check whether counter is set or not. If set then take that value to resume playing or if not set then set the counter to zero
  2. Set stop flag to false
  3. Read Time matrix and set the values from counter to (counter + 10) at x-axis
  4. Read sensor matrix and set the values at y-axis
  5. Read X, Y, Z or Vector Magnitude data from the matrix according to radio button selected and set the values from counter to (counter + 10) at z-axis
  6. Plot the data on 3D view using surf function of MATLAB
  7. Increase counter by 1
  8. Repeat steps ii to vi until all the data in the matrix is plotted or stop flag is set

- **‘Stop’ Function**
  1. Check whether plot is running or not by checking stop flag. If stop flag is true then plot is not running and don’t take any action.
  2. If flag is false, plot is running, then
a. Set stop flag to true  
b. Set counter to zero  
c. Update GUI data so that plot function will get updated values of counter and stop flag and it will stop playing accordingly

- ‘Pause’ Function
  1. It Check whether plot is running or not by checking stop flag. If stop flag is true then plot is not running and don’t take any action.  
  2. If flag is false, plot is running, then  
     a. Set stop flag to true  
     b. Update GUI data so that plot function will get updated values of counter and stop flag and it will stop playing accordingly

- ‘Set Time’ function - This playback functionality helps in determining the values read at a dedicated time which is read by the sensors as shown in figure 54.
  1. It reads the string from text box in GUI  
  2. Convert the string into numerical format  
  3. Check whether the input time is matched with any value in the time matrix and read index of the matched value  
  4. If no, then show error – Please enter valid time!  
  5. If yes, then set counter to the index of the matched value  
  6. Set stop bit to true so that plot will get stopped at that particular value  
  7. Update GUI data so that value of counter and stop flag will get updated  
  8. Call start function to set the plot at that particular time
The Figures 54, 55, and 56 depict some add-ons which help using the application such as shortcuts for opening the file, saving the figures in the form of pdf, etc.

Figure 54: MagView SetTime Feature

Figure 55: Add-On Features 1

Figure 56: Add-On Features 2
Figure 57: Add-On Features 3

This functionality shows the feature ‘Rotate 3D’. The peaks can now be viewed from different angles as required.

Figure 58: MagView 3D Rotational View
6.5 Discussions

As stated in section 5.3.2, a problem was identified at the very end of the development program. As depicted there, the reasons for the problem are now understood and Fraport will soon start to have a workaround developed.

In all, and with disregard of the problem stated in 5.3.2., the results stated above resolve the problem stated in section 1.2. The results answer the scientific research question of the thesis, ‘What is the most appropriate way of depicting the sensor data and how are the requirements of different stakeholders concerning basic analysis features best taken into account?’

The detection quality of the sensors can now be analyzed thoroughly. Users can now identify the ground movements of the mobiles within the sensor data spectrum. The data which could only be viewed in real-time can now be also viewed offline. The requirements engineering approach not only helped in finding the requirements of the stakeholder’s but it also produced a broader perspective for implementing the sensors.

The different approaches and discovery techniques used during the requirements engineering identified the objectives of the stakeholders and the priorities which are needed for the initial development process. It is very important to maintain the quality criteria of the requirements document and the requirements itself. If this is not as expected, it affects the organizations relationship with the stakeholder’s.

It was also observed that managing the requirements was a crucial step for the successful development of the tool. It was necessary to note down each and every requirement stated by all the stakeholders. In the requirements management step, it is essential to prioritize the requirements based on the stipulated time. In this thesis, different prioritization techniques were used which are discussed in section 5.2 which helped in getting better results. The change of requirement requested by the stakeholders must also be taken into consideration which are mentioned in section 5.3. Necessary validation and negotiation techniques were used based on their principles to produce the correct product and aiming to obtain the desired outputs. Since the change was found at a very late stage of this thesis, it was no more possible to implement it. Nevertheless, it was added to the list of requirements for the next version with highest priority and will be executed in future.

After the development process was carried out, data revealing good performance of EMFS sensors were obtained despite the missing normalization\textsuperscript{37}. It was found that the sensors are reliable for the aerodrome surfaces and the solutions can further be improved

\textsuperscript{37} All movements still produce visible peaks, but some of them are smaller than expected.
and optimized based on the availability of the tool. The motivating element behind working with the MagSense sensors is that they will certainly improve the safety on the aerodrome surface and hence all for passengers.
7 Conclusion and Future Research

This section will focus on summarizing the contribution of the work carried out throughout the thesis along with the scope of future research that can be carried out. The central point on which the whole thesis was focused was the Requirements Engineering Process.

7.1 Conclusion

The idea of Requirements Engineering is to organize and identify appropriate requirements of various stakeholders and consolidating these requirements to a general agreement and maintain them based on the defined standard in a well document form. The purpose of the study is to select suitable elements from the requirements methodology and applying the outcomes in order to develop an appropriate tool which would visualize the output of sensor data in form of 3D peaks. The importance of determinates of the sensor data is immense for this paper as it is completely based on it. The summary of the results was based on analyzing the applications and selection of the elements from IREB-CPRE methodology to create a suitable request document for the stakeholders.

The output of the sensor bus can now be viewed with the MagView tool developed during the research. The tool displayed the vehicle or aircraft detected by the sensors which passed over them in the form of 3D peaks. The research questions were justified with the live results collected from the sensors installed on taxiway N7 of the airport.

The literature was clustered based on three major facts, A-SMGCS, earth magnetic field sensor in aviation domain, Requirements Engineering. After carefully reading the literature and the data collected from sensor, the MagView tool was developed. The paper highlights utmost suitable methods of portraying the output of sensor data and how the requirements of various stakeholders concerning elementary analysis and playback features. The findings of the research have a significant and positive impact on the aviation community towards fulfilling the requirements of the stakeholders.

The findings of the paper can be later used for other research purposes. The research question mentioned is answered in the paper to the utmost extent. Nevertheless, there is plenty of scope for future research on this particular topic left, as plenty of unsolved questions for researches of various fields remains available.
7.2 Future Research

This study has a few limitations, which can be the topic for future research. Initially, low priority requirements stated by the stakeholders, which could enrich the performance of the tool, can be integrated in the tool in future releases. The duration for parsing the sensor output data can be optimized. This will result in a depiction of the graphs in less time.

The requirement change, requested by the stakeholders at late stage, needs to be adopted into the tool. To ensure that requirement changes of that kind do not occur in future projects, it seems advisable to conduct more interactive meetings or to implement iterative creative techniques with the stakeholders, which are highlighted in this thesis, in order to identify the missing requirements.

The tool can be worked on to collect more information from the sensors, e.g. in order to calculate the speed of the mobiles. This could be used for more precise predictions, e.g. whether or not a mobile will be able to stop in front of a holding point. It will also be beneficial if the performance of these sensors (EMFS) is compared with the current technology (MLAT) used at the airport. This will not only show the impact of these sensors but it can also be used collaboratively to further improve the currently existing systems at Frankfurt Airport. In addition, the stakeholders wish for a function that ‘scans’ the data for the next event, i.e. the next time a mobile is detected and also for the option to enter formulas for alternative ways of calculating the peaks. In all, and finally, MagView will contribute to improving the quality of data and the reliability of the A-SMGCS at Frankfurt Airport.

The scope for future research is vast beyond the valuable results obtained. Our main aim was to identify the stakeholder’s requirements and to produce the initial version of the tool. In all, the MagView tool is an important part of this Master’s Thesis and a big help for Fraport and IUK-AO11 in particular.
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24(11), 908–926.


## Appendix

### A1 - EMFS Requirements Checklist

<table>
<thead>
<tr>
<th>Requirement ID</th>
<th>Requirement</th>
<th>Description</th>
<th>Priority</th>
<th>Stakeholder(Source)</th>
<th>Date of Origin</th>
<th>Date of Review</th>
<th>Reviewed / Approved By</th>
<th>Comments</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMFS_Tool_1</td>
<td>Visualization and Playback Tool</td>
<td>Select appropriate elements from the methodology as well as the outcomes from applying them on a specific software production process and develop a tool where the stored output (text) can be viewed in a visual form</td>
<td>P0</td>
<td>Mobilis GmbH and Fraport AG</td>
<td>28.09.2016</td>
<td>19/01/2017</td>
<td>ILK-AC01, Mobilis and IUK</td>
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<td>Completed</td>
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<tr>
<td>EMFS_Tool_2</td>
<td>Calculate the Length of Vector</td>
<td>Cumulated values of x, y, z axis.</td>
<td>P0</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
<td></td>
<td>Completed</td>
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<tr>
<td>EMFS_Tool_3</td>
<td>3D - Graph to display the peaks</td>
<td>Visual depiction of the data which is outputted by the sensors in form of text files.</td>
<td>P0</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
<td></td>
<td>Completed</td>
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<tr>
<td>EMFS_Tool_4</td>
<td>Display each axis individually</td>
<td>View values read by only one of the axis (x, y or z axis)</td>
<td>P1</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<tr>
<td>EMFS_Tool_5</td>
<td>Display all 3 axis together</td>
<td>View all the 3 axis values, differentiating it with different colours</td>
<td>P0</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<tr>
<td>EMFS_Tool_6</td>
<td>Equation Box</td>
<td>Entering mathematical formulas and a graph should be formed accordingly</td>
<td>P3</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td></td>
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<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_7</td>
<td>Axis Names</td>
<td>r-axis = Time; t-axis = No. of Sensors; z-axis = Vector Magnitude</td>
<td>P0</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<tr>
<td>EMFS_Tool_8</td>
<td>User-Friendly and Flexible</td>
<td>The tool should be easy to understand and flexible enough to read the number of sensors and adjust the range accordingly</td>
<td>P1</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<tr>
<td>EMFS_Tool_9</td>
<td>Extendable and Reusable</td>
<td>Support modifications and changes in future</td>
<td>P2</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<td>Completed</td>
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<tr>
<td>EMFS_Tool_10</td>
<td>Stand-Alone</td>
<td>Easily accessible at all places</td>
<td>P1</td>
<td>Mobilis GmbH</td>
<td>06.10.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<td>Completed</td>
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<tr>
<td>EMFS_Tool_11</td>
<td>Date</td>
<td>A Box to display the original date of the output file</td>
<td>P1</td>
<td>Fraport AG</td>
<td>21.11.2016</td>
<td>19/01/2017</td>
<td>ILK-AO11, Mobilis and IUK</td>
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<td>Completed</td>
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<td>Requirement ID</td>
<td>Requirement</td>
<td>Description</td>
<td>Priority</td>
<td>Stakeholder(Source)</td>
<td>Date of Origin</td>
<td>Date of Review</td>
<td>Reviewed / Approved By</td>
<td>Comments</td>
<td>Status</td>
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<tr>
<td>EMFS_Tool_13</td>
<td>Play Back Buttons</td>
<td>Play, pause, Stop, Forward, Rewind, fast forward (2x,2x…), Fast Rewind (2x,2x…).</td>
<td>P2</td>
<td>Fraport AG</td>
<td>21.11.2016</td>
<td>15/01/2017</td>
<td>IUK-AO11, MobilSis and IUK CI</td>
<td>Only Start, Stop and Pause functionality available</td>
<td>Completed</td>
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<tr>
<td>EMFS_Tool_14</td>
<td>Split Buses</td>
<td>Show two graphs for buses or show different colors for different bus lines w.r.t. the sensors</td>
<td>P2</td>
<td>Fraport AG</td>
<td>21.11.2016</td>
<td>15/01/2017</td>
<td>IUK-AO11, MobilSis and IUK CI</td>
<td>Completed</td>
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<tr>
<td>EMFS_Tool_15</td>
<td>Print Screen option</td>
<td>Click snapshot of the current page and able to save it as JPEG(Image) and send it via email or Upload it</td>
<td>P3</td>
<td>Fraport AG</td>
<td>21.11.2016</td>
<td>15/01/2017</td>
<td>IUK-AO11, MobilSis and IUK CI</td>
<td>Save image in form of pdf</td>
<td>Completed</td>
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<tr>
<td>EMFS_Tool_16</td>
<td>Change in direction</td>
<td>Analyze the peaks and display if there is change in direction of the vehicle</td>
<td>P5</td>
<td>MobilSis GmbH</td>
<td>06.10.2016</td>
<td></td>
<td></td>
<td>Future Scope</td>
<td></td>
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<tr>
<td>EMFS_Tool_17</td>
<td>Playback button for Peaks</td>
<td>Next-previous buttons to jump from one peak to another</td>
<td>P4</td>
<td>MobilSis GmbH and Fraport AG</td>
<td>06.10.2016</td>
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<td></td>
<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_18</td>
<td>Peak Sizes</td>
<td>Find and display high and small peaks. (This can be used in future to identify the parts of the mobilities detected)</td>
<td>P4</td>
<td>MobilSis GmbH and Fraport AG</td>
<td>06.10.2016</td>
<td></td>
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<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_19</td>
<td>Find Airplane</td>
<td>Based on the analysis of the peaks, it should be able to identify the Airplane</td>
<td>P5</td>
<td>MobilSis GmbH</td>
<td>06.10.2016</td>
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<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_20</td>
<td>Orthogonal Sensor Line</td>
<td>-</td>
<td>P5</td>
<td>MobilSis GmbH</td>
<td>06.10.2016</td>
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<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_21</td>
<td>Connect to a database</td>
<td>-</td>
<td>P5</td>
<td>MobilSis GmbH</td>
<td>06.10.2016</td>
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<td></td>
<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_22</td>
<td>Distance of front wheel/Time</td>
<td>-</td>
<td>P5</td>
<td>MobilSis GmbH</td>
<td>06.10.2016</td>
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<td></td>
<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_23</td>
<td>Start and End Time Playback option</td>
<td>The play back tool should display start and end time</td>
<td>P2</td>
<td>Fraport AG (Steffen)</td>
<td>06.12.2016</td>
<td></td>
<td></td>
<td>Completed</td>
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<tr>
<td>EMFS_Tool_24</td>
<td>Compare Sensors</td>
<td>Compare 2 sensors on one screen</td>
<td>P5</td>
<td>Fraport AG (Steffen)</td>
<td>06.12.2016</td>
<td>15/01/2017</td>
<td>IUK-AO11, MobilSis and IUK CI</td>
<td>Completed</td>
<td></td>
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<tr>
<td>EMFS_Tool_25</td>
<td>Multiple Sensor readings</td>
<td>Upload 2-5 files and the system combines all the files and gives you the total output</td>
<td>P5</td>
<td>Fraport AG (Steffen)</td>
<td>06.12.2016</td>
<td></td>
<td></td>
<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_26</td>
<td>Display all peaks</td>
<td>An option to display all peaks occurred in the file</td>
<td>P5</td>
<td>Fraport AG (Steffen)</td>
<td>06.12.2016</td>
<td></td>
<td></td>
<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_27</td>
<td>Manual Input for Flight Info</td>
<td>A box to enter manual flight information e.g. Type of aircraft</td>
<td>P3</td>
<td>Fraport AG (Steffen)</td>
<td>06.12.2016</td>
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<td></td>
<td>Future Scope</td>
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<tr>
<td>EMFS_Tool_28</td>
<td>Identify Metadata</td>
<td>The info should be displayed when the user hovers the mouse on the peaks</td>
<td>P5</td>
<td>Fraport AG (Steffen)</td>
<td>06.12.2016</td>
<td>15/01/2017</td>
<td>IUK-AO11, MobilSis and IUK CI</td>
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<tr>
<td>EMFS_Tool_29</td>
<td>Re-calculation of the magnitude of the vector</td>
<td>Create a floating ZV i.e. during a phase without signal (no aircraft or other metal) affect the sensors a comparison with the last ZV could result in a new ZV. For comparison an floating average value (FAV) should be used. If the result of the comparison is that the ZV must be changed a sliding adjustment should happen.</td>
<td>P1</td>
<td>MobilSis GmbH</td>
<td>02.08.2017</td>
<td></td>
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<td>Future Scope</td>
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## A2 - ED-87C Requirements

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>Manoeuvring Area</th>
<th>Apron Taxiways, Parkpositionen und Rollbahnen</th>
<th>Active Stands</th>
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<tr>
<td>PTR</td>
<td>≥ 95% (1 s)</td>
<td>≥ 90% (1 s)</td>
<td>&gt; 95% (5 s)</td>
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<tr>
<td>PFTR</td>
<td>≤ 10^4 per report</td>
<td>≤ 10^4 per report</td>
<td>≤ 10^4 per report</td>
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<tr>
<td>PID</td>
<td>≥ 99.9%</td>
<td>≥ 99.9%</td>
<td>≥ 98%</td>
</tr>
<tr>
<td>PFID</td>
<td>≤ 10^-4 per identified report</td>
<td>≤ 20 m (95%)</td>
<td>&lt; 25 m (95%)</td>
</tr>
<tr>
<td>RPA</td>
<td>≤ 12 m (95%)</td>
<td>≤ 20 m (95%)</td>
<td>&lt; 25 m (95%)</td>
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<tr>
<td>TRUR</td>
<td>≥ 1 Hz</td>
<td>≥ 1 Hz</td>
<td>≥ 1 Hz</td>
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<tr>
<td>RVA</td>
<td>&lt; 5 m/s (90%) or</td>
<td>&lt; 5 m/s (90%) or</td>
<td>Not applicable.</td>
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<tr>
<td></td>
<td>+/- 10% of the actual speed (the higher value applies)</td>
<td>+/- 10% of the actual speed (the higher value applies)</td>
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<tr>
<td>TDL</td>
<td>≤ 0.5 s</td>
<td>≤ 0.5 s</td>
<td>≤ 0.5 s</td>
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<tr>
<td>PRTOP</td>
<td>≤ 4 s</td>
<td>≤ 4 s</td>
<td>≤ 10 s</td>
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<tr>
<td>IRTOP</td>
<td>≤ 30 s</td>
<td>≤ 30 s</td>
<td>≤ 30 s</td>
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<tr>
<td>TC/GAPS</td>
<td>Gaps &gt; 5s:</td>
<td>Gaps &gt; 5s:</td>
<td>Gaps &gt; 5s:</td>
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<td></td>
<td>TC: ≤ 10^-4 per Target Report</td>
<td>TC: ≤ 10^-3 per Target Report</td>
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<tr>
<td></td>
<td>3s ≤ Gaps ≤ 5s:</td>
<td>3s ≤ Gaps ≤ 5s:</td>
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<tr>
<td></td>
<td>TC: ≤ 10^-3 per Target Report</td>
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<td>TRIT</td>
<td>≤ 5 s</td>
<td>≤ 8 s</td>
<td>≤ 15 s</td>
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<tr>
<td>TRPR</td>
<td>≤ 1 m</td>
<td>≤ 1 m</td>
<td>≤ 1 m</td>
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<tr>
<td>TRVR</td>
<td>≤ 0.25 m/s per cartesian velocity component</td>
<td>≤ 0.25 m/s per cartesian velocity component</td>
<td>≤ 0.25 m/s per cartesian velocity component</td>
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<tr>
<td>TRTR</td>
<td>≤ 0.1 s</td>
<td>≤ 0.1 s</td>
<td>≤ 0.1 s</td>
</tr>
</tbody>
</table>
Declaration

* Statement of Authorship

I hereby certify to the Technische Universität Chemnitz that this thesis is all my own work and uses no external material other than that acknowledged in the text.

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