LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY

LUT School of Business and Management

Business Analytics

Master's Thesis

KEY PERFORMANCE INDICATORS AND THEIR VISUALIZATION IN AN ELECTRIC VEHICLE CHARGING COMPANY

Valeriya Bulaeva

May 2019

Helsinki, Finland

Examiner: Professor, D.Sc. (Econ. & BA), Mikael Collan

Instructor: Postdoctoral researcher, D.Sc. (Tech.) Jan Stoklasa

ABSTRACT

Author: Valeriya Bulaeva

Title: Key performance indicators and their visualization in an electric vehicle charging company

Year: 2019 **Place:** Helsinki

Master's thesis, Lappeenranta-Lahti University of Technology, LUT School of Business and Management, Business Analytics

76 pages, 13 figures, 7 tables and 3 appendices

Examiner: Professor, D.Sc. (Econ. & BA), Mikael Collan

Instructor: Postdoctoral researcher, D.Sc. (Tech.) Jan Stoklasa

Keywords: Key performance indicators, reliability assessment, electric vehicle charging, visualization, dashboard

In different industries companies implement KPIs in order to get an overview of a current situation, to maintain and improve the quality of service. Furthermore, KPIs are necessary for tracking and analyzing the most important processes in companies. The purpose of this study is to obtain and visualize a set of KPIs that will be used to monitor EV charging points reliability in the case company that provides EV charging services globally. Many KPIs development and ranking approaches that are applied in various industries can be found in literature. This thesis offers the 7- Step KPIs identification approach that was specifically developed for reliability assessment in the case company.

In the first part of the study the review of EV charging infrastructure, technologies and locations is presented in order to understand the industry in which the case company operates. Then the theories about performance measurement, KPIs and methods of their identification are discussed. In the second part of this thesis the process of KPIs identification approach based on data analysis in the case company is introduced. The failure rate calculation model, proposal for company's reporting system improvement and created dashboard of visualized KPIs are presented at the end.

According to the results of the research, nine KPIs were identified for tracking reliability of EV charging points. KPIs were validated and then visualized in a form of a dashboard. However, it was not possible to visualize all the defined KPIs and it was concluded that software that is currently used the company is not the best for KPIs visualization.

Recommendations related to failure rate calculation, visualization tool, and reporting system are presented in the end. Some of the proposed improvements are already taken in to consideration and will be implemented by the case company in the following months.

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LIST OF ABBREVIATIONS

AC - Alternating Current
AHP - Analytical Hierarchy Process
App - Application
BI - Business Intelligence
BSC - The Balanced Scorecard
CI – Charging Infrastructure
CPO - Charging Point Owners
DC - Direct Current
DLM - Dynamic Load Management
EAFO - European Alternative Fuels Observatory
EC - Electronic Cash
EV - Electric Vehicle
EVSE - Electric Vehicle Supply Equipment
ICT - Information and Communication Technology
ID - Identifier
IEA - International Energy Agency
KPI - Key Performance Indicators
kW - kilowatt
kWh - kilowatt hour
LAN - Local Area Network
OSH - Occupational Safety and Health
PLC - Powerline Communication
RFID - Radio-Frequency Identification
S.M.A.R.T. - Specific, Measurable, Assignable, Realistic, Time related
SMS - Short Message Service
SQL - Structured Query Language
TOPSIS - Technique for Order of Preference by Similarity to Ideal Solution
WLAN - Wireless Local Area Network

1. Introduction

According to Parmenter (2007), key performance indicators (KPIs) represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization. If defined correctly, KPIs can positively influence the performance of different operations such as production, finance, customer service, marketing, and others. That is why, monitoring, managing and analyzing KPIs is an important issue for many companies in different industries. (Anand and Grover 2015, Durkacova et al., 2012, Stricker et al. 2017)

This thesis focuses on creation of charging points KPIs and their visualization in an electric vehicle (EV) charging company. In the recent years EV charging infrastructure (CI) has been continuously developing worldwide and the case company is in forefront of this development. (IEA Global EV Outlook 2018) Due to the fast-growing amount of case company's charging points, the company needs to obtain the appropriate performance indicators for monitoring of EV charging points that can be used for further improvement of their usability and reliability. After the suitable set of KPIs is defined, it has to be visualized and introduced to the company's employees and customers. As a result, the benefits of key performance indicators implementation will be such as improved reliability of EV charging points and increased customer satisfaction.

1.1 The case company

The case company is an electric vehicle charging service platform that connects electric vehicle owners, manufacturers, charging point owners (CPO) and energy utilities. The company offers a wide range of functionalities such as dynamic load management (DLM), optimized charging based on prices at the local energy market, and grid frequency-controlled charging. The case company's mission is to solve the climate change through bringing mobility to the everyday life and energy systems.

The case company was established in 2013 and its headquarters is located in Helsinki, Finland. The company's network currently connects more that 8000 charging points in over

20 countries and it is a leading platform in France, Switzerland, Germany, Finland, Sweden, and Iceland. There are about 70 employees in Finland, Sweden, Germany and France.

1.2 Background of the study

EV charging industry is relatively new, however, it is rapidly developing. The number of electric cars worldwide exceeded 3 million in 2017. (IEA Global EV Outlook 2018) And it is estimated that by 2030 there will be more than 100 million electric vehicles in the world. (IEA Global EV Outlook 2017) Deployment of EVs is influenced by many factors such as the depletion of fossil fuels and the desire to reduce the pollutant emissions. EVs adoption can be significantly stimulated by evaluating and improving EV charging services.

Currently the case company does not have any defined performance indicators to measure the reliability of charging stations. Thus, in some cases it is complicated to determine and as a result to eliminate the problems that negatively influence the charging services. One of the most important goals that the case company is planning to achieve by implementing KPIs is a higher level of reliability that will lead to better reporting system in the company. Moreover, the appropriate way of KPIs visualizations has to be found in order to efficiently communicate the existing KPIs to company's employees and customers.

This thesis was requested by Services and Operations team that includes project managers, service developers, and technical support specialists. The ongoing project of the team is related to service development, reporting systems and support operations improvement. In the previous months the company hired some professionals who are working on improving security, reliability and quality of services. Moreover, the company is preparing for ISO certification that will take place in spring 2019. This thesis is a part of a bigger project intended to create appropriate metrics for measuring the overall performance of the company. This study describes the part of the project that focuses on developing a set of performance indicators for reliability measurement of charging points that can be visualized and communicated across the company. KPIs will be a starting point for EV charging experience monitoring and improvement.

1.3 Purpose of the study and research questions

The purpose of the thesis is to obtain a clearly defined and documented set of KPIs that can be quantified and further used to monitor EV charging points reliability. After defining the purpose of the thesis, the main research question was composed:

1. *What set of KPIs has to be used at the case company in order to measure reliability of charging points?*

The sub-questions of the study are the following:

1.1 How to define a suitable set of KPIs for the case company?

1.2 What is the appropriate way to visualize the selected KPIs?

1.3 What improvements can be proposed based on identified KPIs?

To answer the main research question, first the case company and its EV charging network are examined. As requested by company's management this thesis is particularly focused on creation of operational KPIs for company's EV charging points not taking into consideration any financial performance indicators. This study evaluates the technical performance of charging points that affects the reliability of EV charging service.

The first sub question is answered by creating the approach for KPIs identification in the case company. Furthermore, the available methods of KPIs identification are studied and researches by different authors are examined. The steps for KPIs selection are defined based of case company's specifications and limitations.

The aim of the second sub question is to define the most appropriate content, design and layout of KPIs visualizations. The visualization tool has already been chosen by the case company's management and has to be learnt by the author of the thesis. The conclusions related to visualization results and suitability of the selected tool will be presented in the end of the study.

The third sub question is answered by proposing the improvements that can be implemented in the case company in the future. The proposal is done based on the determined KPIs and related to case company's reporting system, database and visualization tool.

1.4 Research methodology and research process

According to different researches, the mixing of quantitative and qualitative approaches will result in the most accurate and complete description under investigation. (Tashakkori,et al 2003) For this study a combination of both approaches is used, starting with qualitative and continuing with quantitative methods.

The first part of the project is completed using qualitative research in a form of a case study. According to McMillan (1996) studies deriving from qualitative perspective focus on meaning and understanding and take place in naturally occurring situations. Yin (1989) states that even though case studies often use quantitative measures, most of the time they take qualitative perspective and focus on exploring and describing the phenomenon. He defines a case study as "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. [...]" There are two types of a case study: "a single case" and a "multiple case". (Yin, 2003, Baxter & Jack, 2008; Stake, 1995) Considering the fact that this thesis focuses on the analysis of one organization, the singe case study approach is followed.

Data collection was completed with respect to the defined research problem using various research methods. The theoretical research was done by conducting a literature review in order to familiarize readers with previous studies related to performance measurements and EV charging industry.

Another material collection method was active participant observation that aims to maximize discovery and description (McCal1 and Simmons, 1969). It is a method where a researcher takes an active part in the activities of the community. The author of this thesis worked fulltime as a Reliability Analyst in the case company, attended different company's meetings and workshops. As this study is a part of a bigger project that involves team work, the author

also participated in project planning and customer meetings. In participant observation method, a researcher's discipline-based interests and commitments define which events he or she examines are valuable and relevant to the research inquiry. (Emerson et al. 2001). That is why participant observation is supposed to be a subjective method that means that two different researchers can observe the same subject differently and end up with contrasting conclusions. It can be also considered as a positive thing because the method gives an opportunity to look at the same subject from various perspectives.

Interviews is the method that was actively used in the first months of this project. The interviews were semi-structured, meaning that the questions were selected beforehand, but there was an opportunity for an open discussion, depending on the role and experience of an employee. This interview type is "particularly good at enabling the researcher to learn, first hand, about people's perspectives on the subject chosen as the project focus" (Davies, 2007, p.29). All in all, 14 employees of case company from Technical, Services and Operations, Sales, and Marketing teams were interviewed. The questions were about their responsibilities in the company, their opinion about the level of reliability of EV charging points and ways of its improvement.

The second part of this research is quantitative, and it is executed in a form of data analysis. According to Leedy (1993), quantitative research approach is used to answer questions on relationships within measurable variables with an intention to explain, predict and control a phenomena (Leedy 1993). The major part of this project includes work with company's database and data visualization software. As a result of this research, the method for KPIs identification in the EV charging company was developed by the author of this thesis. Furthermore, the calculation models of KPIs an failure rate are done using quantitative data.

The total duration of the project was 6 months, starting with a kick off meeting with the case company's supervisor in October 2018. The scope of the study was defined and the interviews with the company's employees from different department were scheduled. After that the project plan was created and submitted to the company's and university's supervisors. The study started with reviewing available literature related to electric mobility, EV charging networks, and existing performance indicators in the industry. For better understanding of the company and EV charging industry the interviews with the company's employees were conducted during the first two months of a project.

Then analysis of case company's database started and the draft of a KPIs determination approach was created. The approach consisted of 7 steps that were conducted as the second part of the project. The outcome of every step was checked and confirmed by management of the case company. After that the determined KPIs were visualized using the case company's software. The conclusion of the study and recommendation for further work are presented in the end of the study. The project was completed in April and all the results were presented to company's management and university supervisors.

1.5 Structure of the Thesis

This thesis is composed of seven chapters that are demonstrated in Figure 1. Chapter one is an introduction and the next two chapters present the theoretical background of this study. Chapter two is dedicated to EV charging. In the beginning of the chapter the information about EV charging infrastructure and its development is introduced. Then EV charging process, technologies and locations are explained. Chapter three discusses the definition of performance measurement and key performance indicators. Furthermore, characteristics and ways of KPIs categorization are presented. In the end of this chapter various methods and frameworks for KPIs creation are summarized. Chapter four presents the approach that was created for KPIs identification. First, the seven steps that form the approach are introduced and explained. Afterwards, the model for failure rate calculation is presented and proposal for company's reporting system improvement is discussed. Chapter five focuses on visualization of KPIs. The visualization tool used in the company is described and the selected types of KPIs visualization are discussed. Chapter six is dedicated to conclusions and recommendations that present the outcome of this study. The last chapter is the summary of this thesis.

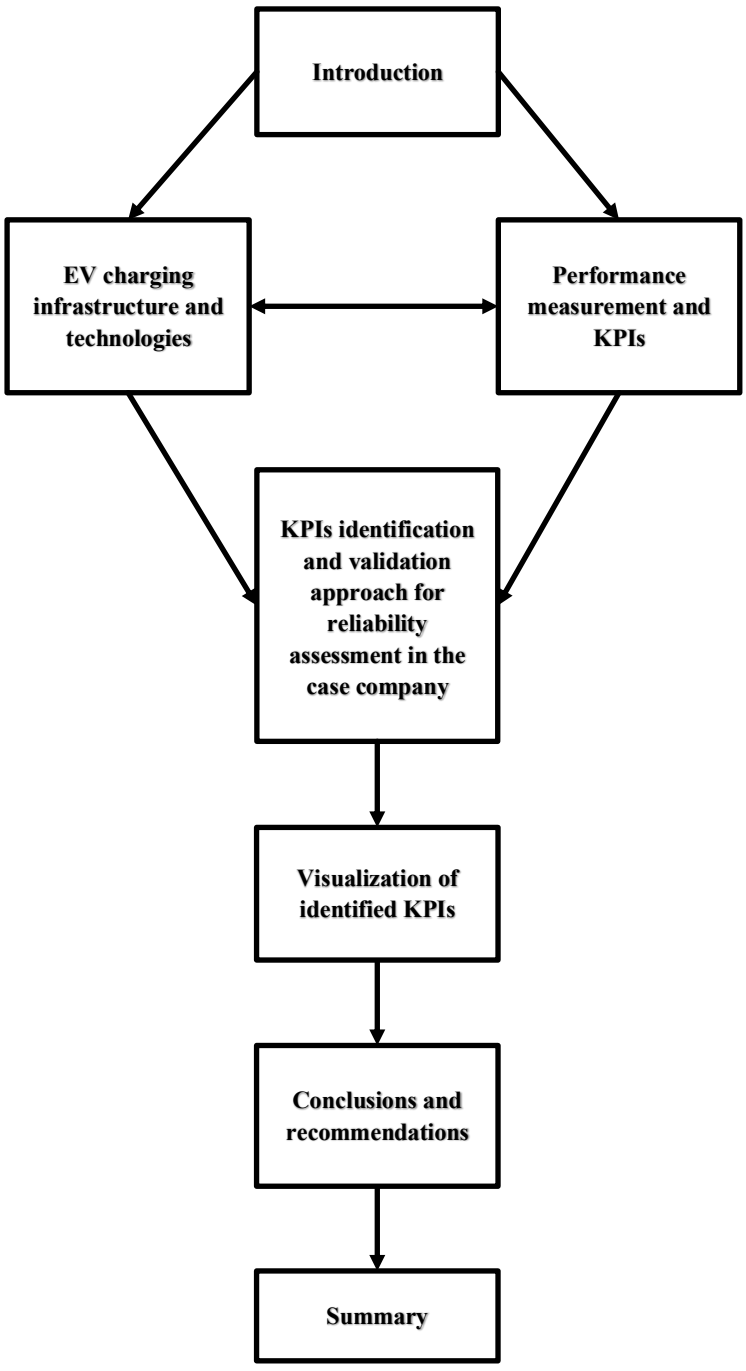

Figure 1 Structure of the thesis.

2. Charging of Electric Vehicles

2.1 EV charging infrastructure today

A sufficient infrastructure is required for EV charging points based on electric energy needed for recharging. (Trip et al. 2012) GTM Research predicts that the amount of charging points worldwide will grow up and range from 40 to 70 million by 2030. (Figure 2) The reason is the increase in sales of electric vehicles, GTM research sates that 11 percent of sold vehicles will be electric. In Europe the amount of residential charging points is estimated to raise up to 9 million, and the amount of public charging points will be around 1.6 million by 2030. (GTM Research 2018)

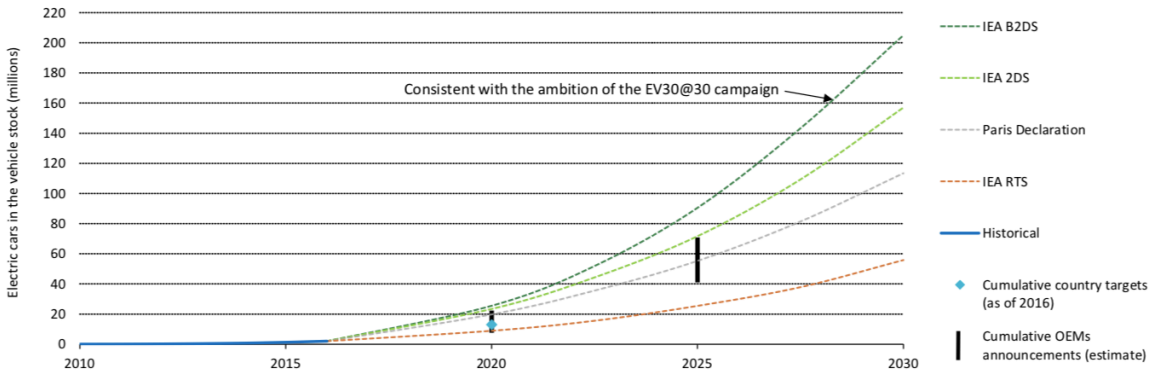

Figure 2 Deployment scenarios for the stock of electric cars to 2030. (IEA Global EV Outlook 2017)

The report about current and planned public charging infrastructure conducted by the Platform of Electromobility concludes that nowadays there is no lack of infrastructure and there are enough charging points available for the number of EV vehicles on the road. Moreover, the report estimates that if the goals for EV charging infrastructure roll-out are reached there will be an appropriate quantity of chargers until 2020 to charge the growing amount of sold EVs.

EVs are changing the automotive sector all around the world. For instance, such countries as the Netherlands, UK and Norway are in forefront of EV charging infrastructure development that stimulates the growth of EV charging companies. Thus, the competition

in EV charging industry is tough, that pushes companies to continuously work on providing the most convenient and reliable service for their customers. The demonstration of reliable charging services is an essential prerequisite for the successful EVs charging companies operation. The question that arises is how to monitor and evaluate the performance of EV charging networks. (J. Helmus, 2016)

CleanTechnica is a cleantech-focused website that presented a report "Electric Car Drivers: Desires, Demands, & Who They Are" (2017). Over 2000 electric car owners were surveyed in 28 countries located in North America and Europe. The responses were divided into three EV groups: Tesla drivers, pure electric but non-Tesla drivers, and plug-in hybrids drivers.

One of the questions was about the level of reliability of EV charging stations that drivers use. According to the report, from 10 to 30 percent of respondents stated that they experience reliability problems while using EV charging points. However, most of EV drivers evaluated the stations as somewhat or very reliable. 93 percent of Tesla drivers in North America and 83 percent of Tesla drivers in Europe consider the charging points to be reliable. A bit less positive were pure EV non-Tesla drivers, the results showed 82 percent reliability rate in North America and 79 percent in Europe. 84 percent of plug-in hybrids drivers in North America and only 70 percent plug-in hybrids drivers in Europe are satisfied with the reliability of charging points. The other questions were related to accessibility of charging stations and their convenience for EV drivers. The results presented in the report show the overall satisfaction of EV drivers but state that there is a need for EV charging points improvement.

2.2 Development of EV charging infrastructure in Finland

In 2017 it was announced that in 2017-2019 4,8 million euros will be allocated to development of EV charging infrastructure. The goal is to catalyze 15 million euros in investments and triple the amount of public charging stations. This initiative aims to raise the number of fast chargers in Finland, thus 35 percent of subsidy rate is allocated to fast chargers and 30 percent – to normal chargers. (Ministry of Economic affairs and Employment of Finland 2017)

According to statistics provided by European Alternative Fuels Observatory (EAFO 2018), in 2018 the total number of charging points in Finland was 973. (Figure 3) To see the growth of EV charging infrastructure in the recent years these statistics can be compared to statistics of year 2013. EAFO reported that in 2013 the total number of charging points in Finland was 267. (EAFO 2013)

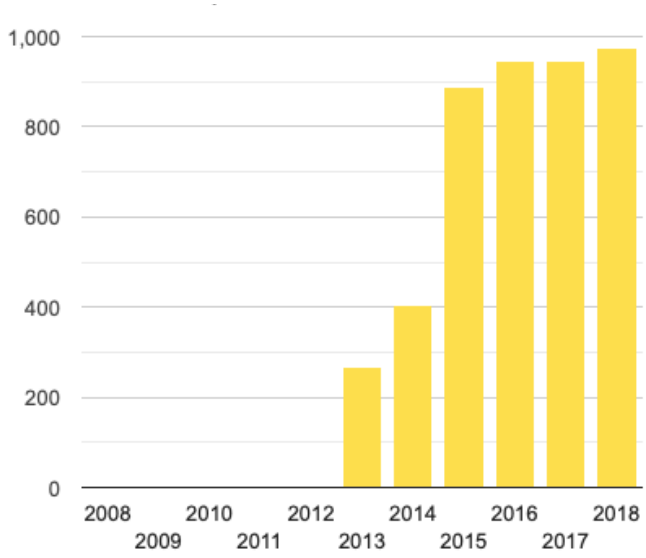

Figure 3 The number of EV charging points in Finland in 2013-2018. (EAFO 2018)

2.3 EV charging technologies and locations

Two components of an EV charging infrastructure can be defined: the electric charging facilities and the information and communication technology (ICT). Charging facility, also referred as charging equipment or EV supply equipment (EVSE) is an electric facility for charging EVs that can have several socket outlets or several connectors. ICT is used by the operators to use, operate, and control the charging infrastructure. In simple terms, EV charging can be done by connecting the EV to a charging point and transferring the electric power to the vehicle. Charging point is an arrangement of charging one EV at a time, and charging station is a group of charging facilities. (Wirges, 2016)

Manufacturers of charging facilities develop and implement different technologies of user interaction, identification, payment and communication to back-end systems. To start charging, EV drivers have to identify themselves using for instance radio-frequency

identification (RFID) card, website, mobile application (App) or SMS method. After verification is done, the charging can start by plugging the charging stations plug into the vehicle's power socket. Charging duration depends on the following factors: grid connection, EV type, charging station, socket, and charging cable. The payment for the EV charging service can be done via direct payment in cash, Electronic Cash (EC), credit card, cell phone bill, electricity bill, or via debit if the user is a registered customer at the charging station operator. Connection to back-end system can be maintained by different means such as connection to a local area network (LAN) or wireless local area network (WLAN). Another option is communication over mobile phone networks using SIM cards or powerline communication (PLC). (Wirges, 2016)

There are different available classifications of EV charging technologies available in literature. (Rautiainen, 2015, Jackson, 2016, Rahman et al, 2016) According to Jackson, 2016 EV charging methods are divided into 3 types:

- Slow charging or Level 1.

This type of charging provides power up to 3 kW that is suitable for overnight charging as it takes from 6 to 8 hours to fully charge an EV vehicle.

- Fast charging or Level 2.

This type of charging provides power up to 22 kW and it takes about 3 hours to charge an EV.

- Rapid charging or Level 3.

Rapid chargers are divided into two types: alternating current (AC) and direct current (DC). AC chargers supply power at the rate of 43kW and DC units reach 50 kW. These chargers fill about 80% of the EVs batteries in maximum an hour, the time depends on the battery.

The international standard IEC 61851-1 provides another classification of EV charging types. It specifies four charging modes that define the communication protocol used between the vehicle and the charging device. (IEC, 2003) Modes 1 and 2 are both AC methods and they are used for slow charging. But "Mode 1 charging is intended mostly for light vehicle charging and mode 2 for temporary or very restricted charging of cars". (Rautiainen, 2015, page 12)

Mode 3 is also an AC charging method that has the same safety protocol as Mode 2 but supports a higher power level. It also provides different control and safety functions. Mode 4 is a fast DC charging method that differs from other modes in a way that the charger is not a part of a car, but a part of a charging station. (Rautiainen, 2015, page 13) Mode 1 can be compared to slow charging Level 1, Modes 2 and 3 are referred to Level 2 fast charging, and Mode 4 is related to rapid charging Level 3. (Table 1)

There are three main locations where EV drivers can charge their cars. The first way to charge an EV is public charging. Public charging points are available to everybody and allow to charge an EV in less than an hour. Another way to charge an EV is to use a semi-public charger that is open to a certain community of people. For instance, companies can install EV charging points for their employees and visitors. One more way to recharge an EV is private charging. This type of charging is the most restricted one, because it is only open to one user, EV or household. (Filho, Kotter, 2015, Kley et al., 2011) In this categorization of EV charging locations accessibility is evaluated as a differentiation factor, and not the ownership of the ground on which the charging station is placed. (Wirges, 2016)

Charging method	**Charging mode**	**Current**	**Power (kWh)**	**Location**
Level 1 Slow charging	Mode 1	AC	Up to3 kWh	Private/domestic
Level 2 Fast charging	Modes 2 and3	AC	Up to22 kWh	Semi-public
Level 3 Rapid charging	Mode4	AC/DC	Up to 50 kWh	Public

Table 1 Classification of EV charging methods.

3. Performance measurements and key performance indicators

It is important for organizations to define the relevant indicators, their influence on the formulated goals and how they rely on the activities performed (Popova et al., 2012). Kaplan (1990) emphasized the importance of measurement with the following sentence ‘‘No measures, no improvement’’. In other words, if something needs to be improved, it has to be measured first. Gunasekaran & Kobu (2007) have presented six common purposes why measuring organizational performance is beneficial for any company. The purposes are:

- to identify success,
- to identify if the customer needs are met,
- to help organizations to define its processes and understand what information they are missing,
- to identify the bottlenecks, problems, waste, etc. and what improvements have to be done,
- to ensure that decisions are based on facts, not on intuition, emotion, etc.,
- to show that planned improvements are happening in reality.

The purposes listed above state how beneficial it is for organization to measure its performance. However, the process of performance measurement is long and complicated. Decision maker has to understand the main objective of performance measurement and focus on evaluating what really matters for the company. And the most important phase of measurement process is not to make the list of all the existing performance indicators, but to identify the performance indicators that will create value for the company and affect the main processes. These performance indicators are KPIs. (Franceschini et al. 2007, 7-10) Enns et al., (2005) define key performance indicators as “measurements that reflect the health of an organization, and the health of its business development system. They connect the firm’s goals and strategies to its activities and outcomes, keeping management informed of overall health: past, current, future.” (Enns et al., 2005). Franceschini et al. (2007) define performance indicators using the following requirements:

- Representativeness,
- Easy and simple to interpret the results,
- Possible to indicate time-trends,
- Adaptive to changes within or outside the company,
- Easy collecting and processing of data,
- Update can be done easily and quickly.

Dean R. Spitzer (2007) stated in his book that "93% of organizational leaders believe that measurement is important in influencing business outcomes, but only 51% are satisfied with their current systems, and only 15% are very satisfied." Eckerson (2009) conducted a survey and interviewed different performance management practitioners and solution providers. His goal was to define the status of these professional's initiative to develop KPIs. The results were based on the answers of 678 respondents and showed that more than one-third of them either partially (31 percent) or fully deployed (9 percent) an initiative to define KPIs. More than a half of of interviewees answered that the status of their KPIs development process is planned (24 percent) or under way (28 percent). And only about 8 percent of respondents stated that currently they do not have any KPIs projects.

Despite the fact that companies are developing and using KPIs, the results of performance measurement is not always positive. Parmenter (2007) states that many decision makers define the KPIs incorrectly and very few organizations really monitor their true KPIs". The researcher suggests that it happens because the definition of KPIs is not understood correctly. He defined three types of performance measures (Figure 4):

- Key result indicators (KRIs) show the results of the pervious actions.
- Performance indicators (PIs) define what has to be done.
- Key performance indicators (KPIs) state what has to be done to increase performance significantly.

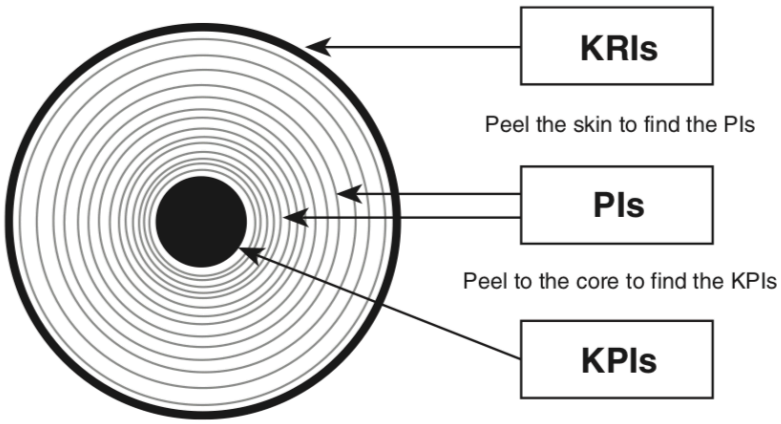

Figure 4 Three types of performance measurement presented by Parmenter (2007).

Different opinions about the required number of KPIs can be found in literature. Kaplan and Norton (1996) suggest that the appropriate number of KPIs is not more than 20. According to Franceschini (2012), this number has to be between 3 and 15. Parmenter (2007) proposed the 10/80/10 rule meaning that companies should use about 10 KRIs, 80 PIs, and 10 KPIs. Such factors as the organization's size and the industry in which the company operates can influence the number of required KPIs. Furthermore, KPIs have to be frequently measured in order to be efficient. Depending on their importance, KPIs can be tracked hourly, daily or weekly. The shorter the measurement interval the better for organization. (Parmenter 2007)

3.1 Characteristics of KPIs

The characteristics of KPIs were introduced by different authors in their publications. (Marr, 2015, Bauer, 2004, Parmenter, 2015, Eckerson 2005) In order to provide the overview of existing characteristics the list of KPIs attributes presented by Wayne W. Eckerson (2005) was chosen. The author provides a detailed description of 12 characteristics of effective KPIs that are listed and described below.

1. Strategic

The KPIs always have to be focused on the desired outcome.

2. Simple

KPIs have to be created in a way to be easily understood by users. They should not be based on complex indexes that can complicate their usability in the company.

3. Owned

All the indicators have to be assigned to a particular user or group of users who is accountable for the particular KPI and its outcome.

4. Actionable

KPIs have to actionable to allow users to take actions in order to continuously improve the performance and positively influence the outcome.

5. Timely

KPIs have to be constantly updated in order to immediately improve the performance if needed.

6. Referenceable

The users have to able to understand the origins of the created KPI in order to use and trust their outcome.

7. Accurate

KPIs have to be measured and communicated with the appropriate level of accuracy.

8. Correlated

KPIs can be used for achieving the desired results.

9. Game-proof

KPIs have to be checked and analyzed frequently in order to confirm their effectiveness.

10. Aligned

KPIs have to be connected to organization's strategy and goals.

11. Standardized

Standardized KPIs have to be communicated throughout the organization and everyone has to agree on them.

12. Relevant

KPIs tend to lose their effectiveness, thus they have to be revised and improved over time.

Parmenter (2009) in his book Key Performance Indicators: Developing, Implementing, and Using Winning KPIs presented a different list of effective KPIs. According to the author, the seven characteristics of KPIs are:

1. Nonfinancial

KPIs are not financial measures and they are not expressed in currency.

2. Frequently measured

Weekly and daily measures are preferred for KPIs tracking.

3. Acted on by the senior managers

Senior managers have a constant focus on existing KPIs.

4. Understood by the employees

Employees have to be able to understand what actions to take based on KPIs.

5. Assigned to the individual or team

An employee or a team have to take responsibility for KPI tracking.

6. Have significant impact

KPIs have to be bring value to the company.

7. Have positive impact

KPIs have to affect other performance measurements positively.

3.2 Categorization of KPIs

There are different ways to distinguish KPIs types depending on point of view of a decision maker and the purpose of the research. One of the most common categorizations is done by industry. In different industries companies actively use various KPIs in order to understand how to gain value to the company, define problems and reach customer satisfaction. Some of the performance indicators vary depending on business area, and some of them are the same for different type of industries.

Eckerson (2009) states that there are two most fundamental categories of KPIs: outcomes and drivers. Outcomes are lagging indicators that measure the results of the past activity. They can be financial in nature and include such KPIs as return on equity, revenue, margins, etc. They can be easily measured, but their improvement takes a lot of effort. Driver KPIs are also defined as leading or value drivers. They track the activities that have the important impact on the outcome KPIs. This type of KPIs measure current and future states such as number of scheduled meetings for this and next week. It is difficult to measure driver KPIs, but it is easy to influence them.

Parmenter (2010) and Kaplan et al. (1996), argued the reliability of categorization KPIs into lagging and leading. They stated that some KPIs can be related to both categories. Parmenter proved it with the example of “late-planes-in-the-air KPI” that can be a leading indicator because it is related to taking actions to land the plane on time. But at the same time, it can

be a lagging KPI because the plane is already late, meaning that there will be such consequences as dissatisfaction of passengers or extra consumption of fuel needed to speed up the plane.

Anand and Grover (2015, 141-142) in their work presented various categorizations of KPI done by different authors. Table 2 presents the researchers and KPIs types that they defined. The oldest classification that is included in the table was conducted in 1995 and the newest was done in 2006.

Author (year)	Categorization of KPIs
Hoffman (2004)	As top tier, mid-level, and ground level
Neely *et al.* (1995)	At three levels: the individual metrics; the set of measures, or performance measurement system as an entity; and, the relationship between the measurement system and the internal and external environment in which it operates
Huang *et al.* (2005), Gunasekaran *et al.* (2001)	In three levels – strategic, tactical and operational
Shepherd and Gunter (2006), Gunasekarana *et al.* (2004)	As quality and quantity, cost and non-cost, strategic/operational/tactical focus, and supply chain processes
Chae (2009)	As primary and secondary indictors
Augenbroe and Park (2005)	Grouped into energy, lighting, thermal comfort and maintenance
Hinks and McNay (1999)	Classified KPIs into business benefits, equipment, space, environment, change, maintenance/services, consultancy and general
Amaratunga and Baldry (2003)	Classified KPIs into customer relations, FM internal processes, learning and growth, and financial implications
Lavy *et al.* (2010), Gumbus (2005), Augenbroe and Park (2005), Amaratunga and Baldry (2003), Ho *et al.* (2000), Hinks and McNay (1999), Douglas (1996)	As cost-related and non-cost-related KPIs
Angerhofer and Angelides (2006), Shepherd and Gunter (2006), Gunasekarana *et al.* (2004), Bolstorff (2003), Beamon (1999)	Grouped KPIs into quality time, cost and flexibility
Chen *et al.* (2004), Gunasekaran *et al.* (2001), De Toni and Tonchia (2001)	As cost and non-cost measures (time, quality, flexibility and innovativeness)
Shepherd and Gunter (2006), Chan and Qi (2003)	Catergorized KPIs as cost, quality, resource utilization, flexibility, visibility, trust and innovativeness
Lee (2004), Morgan (2004)	As flexibility and innovativeness measures
Hieber (2002)	Grouped into collaboration efficiency; coordination efficiency and configuration.
Van der Vorst (2000)	At three main levels: the supply chain level; the organization level; and the process level
Li and O'Brien (1999)	At four levels: profit; lead-time performance; delivery promptness; andwaste elimination
Lai *et al.* (2002)	At three levels: service effectiveness for shippers; operational efficiency; and service effectiveness for consignees
De Toni and Tonchia (2001)	As financial and non-financial
Gunasekaran *et al.* (2001)	As quantitative and non-quantitative
Chopra *et al.* (2007)	Grouped as facilities, transportation, information, inventory, sourcing, and pricing
Chan and Qi (2003)	Grouped into input measures, output measures, and composite measures
Closs and Mollenkopf (2004)	Grouped into customer service, cost management, quality, productivity, and asset management
Agarwal *et al.* (2006)	Grouped into market sensitiveness, information driven, and process integration

Table 2 Classification of KPI done by different researchers. (Anand and Grover, 2015)

3.3 Methods and techniques for KPIs creation

Most of the authors come to the conclusion that KPIs have to be linked to strategy and objectives of the company, however, the universal approach for KPIs identification does not exist. (Parmenter 2007, Neely et al,1997) Various KPIs identification models and approaches were created in order to simplify the process of performance indicators identification. The process of KPIs selection is complicated and its success depends not only on selected model, but on the experience and initiative of the decision maker. (Franceschini, F., et al. 2007) The table below presents the work of the authors who developed different methods for KPIs identification.

Author	Introduced method(s)
Podgorski (2015)	The Analytical Hierarchy Process (AHP) method for the selection of leading KPIs for measuring OSH MS operational performance.
Parmenter (2010)	A 12-Step Model for developing and using KPIs.
Kaplan & Norton (1996)	Balanced Scorecard (BSC) to track KPIs.
Doran (1981)	S.M.A.R.T. method to write management's goals and objectives.
Shahin & Mahbod (2015)	The Analytical Hierarchy Process (AHP) technique and S.M.A.R.T criteria for KPI prioritization.
Kadarsah (2007)	Framework of measuring key performance indicators using Analytic Hierarchy Process (AHP) technique.
Sun (2010)	A performance evaluation model by integrating fuzzy AHP and fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) methods.

Table 3 The methods introduced by different authors.

Multiple researchers used Analytical Hierarchy Process (AHP) method for KPIs identification or ranking. In many papers, this method was used in combination with other approaches and frameworks. Podgorski (2015) worked on measuring operational

performance of occupational safety and health management system (OSH) and introduced the AHP method for the selection of leading KPIs. Kadarsah (2007) created a framework for KPIs measuring of higher educational institution. He categorized KPIs into academic, research and supporting KPI and then weighted them using Analytic Hierarchy Process, trend analysis and comparative data.

Parmenter (2007) in his book described a 12-Step Model for developing and using KPIs. The model is based on the following four foundation stones for KPI development:

- Collaboration with employee, unions, suppliers and customers,
- Allocation of power to the front line,
- Combination of measurement, reporting and performance improvement,
- Connection of performance measurement to strategy.

The Balanced Scorecard (BSC) introduced by Kaplan & Norton (1996) is a common way of KPIs selection. BSC is used for measuring performance from four perspectives: financial, customers, internal business processes, and learning and growth. By using these perspectives, decision-makers can translate company's strategy and objectives into performance measures that provide a framework for strategic measurement and management system.

S.M.A.R.T. method is also widely used in performance measurement systems. First it was introduced by Doran (1981) who created a managerial method for goal setting based on S.M.A.R.T. criteria. (specific, measurable, assignable, realistic, time related).

Shahin & Mahbod (2015) combined both AHP and S.M.A.R.T. methods in their work and established guidelines for KPIs ranking in organizations. They created an approach for prioritization of KPIs in terms of S.M.A.R.T criteria goal setting. AHP method was applied as the basis for S.M.A.R.T criteria comparisons for KPIs.

Fuzzy methodology is also used for performance measurement. Sun (2010) applied fuzzy TOPSIS method together with Fuzzy AHP. The research presents the combination of these methods in order to help industrial practitioners to evaluate performance measurements in a fuzzy environment.

Depending on the operational industry and goals of a researcher the suitable KPIs identification method can be chosen. The methods presented above can be divided into manual (BSC, S.M.A.R.T) and selection (AHP, fuzzy TOPSIS) groups. Such methods as S.M.A.R.T and AHP are typical for KPIs identification and used in multiple works presented in the Table 2. Fuzzy methods are not so widely used, but also getting more common for measuring the performance. Furthermore, machine learning and data mining techniques are used for making predictions and recommendations on KPIs.

4. Identification of EV charging points KPIs in the case company

A lot of information about EV charging infrastructure can be found in literature. Infrastructure development and improvement are the topics widely presented by different authors. (San Roman 2011, Rahman 2016, Nie 2013) However, there is also a lack of information on KPIs used in EV charging companies and only a few research works related to this topic were found. Different performance indicators applied in various industries can be found in literature, but they cannot be an appropriate base for KPIs creation for such complex industry as electric vehicle charging.

The research "Key Performance Indicators of Charging Infrastructure" conducted by J. Helmus (2016) presents KPIs that can be used to monitor and improve the public EV charging infrastructure in the Netherlands. The author concludes that the amount of literature related to this topic is limited and develops his own approach for KPIs identification. As the large number of stakeholders such as municipalities, EV drivers, CPOs, etc. are interested in CI development, he takes a stakeholder perspective in his research. In the context of this thesis work that focuses on one case company, the approach presented by J. Helmus cannot be followed.

Part of the methods listed in Chapter 3.3 are intended for KPIs selection in the companies that already have the list of performance indicators. Another part is suitable for ranking or improvement of performance measurement in organizations. However, there are not methods presented in the literature that can help to define KPIs for EV charging company. This study is focused specifically on developing KPIs for charging points reliability monitoring and not for the whole organization. Thus, it was necessary to create a new approach for KPIs identification based on the example of the case company.

As EV charging companies are growing and developing, the need for performance monitoring of charging points occurs. The approach presented in this study can be a guidance for decision makers who are in the beginning of KPIs identification for EV charging

companies. The next chapters present the developed approach that consists of seven steps of KPIs identification in an EV charging company.

4.1 A 7-step KPIs identification approach for CI reliability assessment in the case company

As mentioned before, currently the case company does not have any established KPIs for monitoring reliability of their EV charging points. Thus, performance indicators had to be created from scratch. When starting the project, the available resources included company's database and documentation. Hence, a lot of information needed for the project completion was obtained during the interviews and meetings with the company's employees.

The methods created by different researchers for KPIs determination were studied first in order to choose the suitable one for the case company. As concluded before, none of the reviewed methods can be selected as a framework for KPIs identification in the case company. However, S.M.A.R.T method will be used in the fifth step of the approach.

The approach for KPIs identification in the case company includes the following steps (Figure 6):

1. The definition of reliability of charging points.
2. Reliability goals setting and result indicators recognition.
3. EV charging points problems identification.
4. Assigning the variables from the database for the defined reliability goals.
5. KPIs identification based on S.M.A.R.T. method.
6. Data evaluation for KPIs calculation.
7. Validation of identified KPIs.

As KPIs were required for monitoring of reliability of EV charging points, it was crucial to define what is a reliable charging station. The definition included seven important characteristics that define a reliable charging station in the case company. Then the goals for reliability of EV charging points were established based on the notion of reliability. The result indicators were also defined and linked to reliability goals. After the desired level of

reliability was described, the current state of charging points was evaluated. As a result, the detailed list of existing EV charging problems was composed. The next step included identifying of variables from the database and assigning them to the reliability goals. After that the selected variables were tested against SMART method and a set of KPIs was identified. The company's database was analyzed in order to define whether it is possible to calculate the defined KPIs. The quality and availability of required data was also evaluated and discussed. As a final step of the method the KPIs were validated by testing them against such properties as quantifiability, sensitivity, congruency, reliability, efficiency and improvement-orientation. Every step of the research process was checked and approved by support team and managers of the case company.

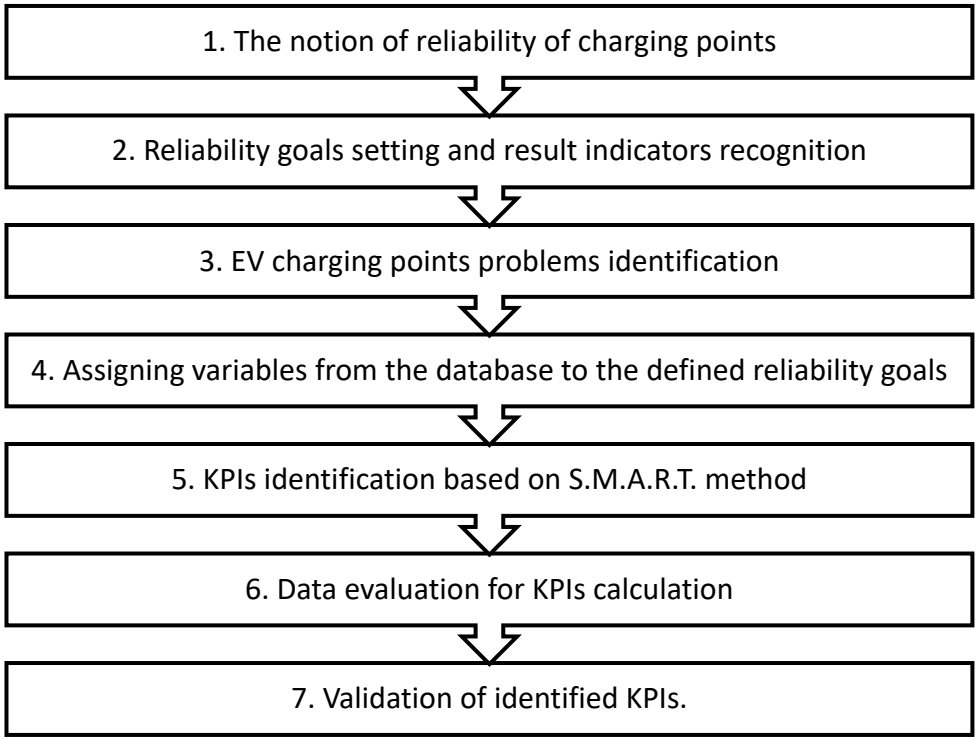

Figure 5 A 7-step KPIs identification approach for reliability assessment in the case company.

4.1.1 Step 1. The notion of reliability in the case company

The first step to create a set of KPIs is to define the notion of reliability in the case company. In other words, it has to be specified what is a reliable charging station from the point of

view of the case company. According to Kececioglu (2002), reliability is "the conditional probability, at a given confidence level, that the equipment will perform its intended functions satisfactorily or without failure [...]" For the case company it was decided that the term of a reliable charging station includes seven characteristic that are listed below.
Reliable charging station:

1. is easily accessed,
2. allows fast and easy start of charging event using RFID, App or SMS,
3. allows smooth charging process without any problems or interruptions,
4. allows fast and easy ending of charging event using RFID, App or SMS,
5. provides all the data related to charging event to back end and to customers,
6. is constantly maintaining connection to back end, e.g. shows that it is online,
7. provides up to date and useful information about its status.

4.1.2 Step 2. Reliability goals setting and result indicators recognition

The characteristics of reliable charging station described in Chapter 4.1 form a desired state for company's chargers. They are also the base for reliability goals in the case company. If all of them are met, the charging point is considered to be functioning correctly. Reliability goals and result indicators are shown in the first and second columns of Table 3.

The following EV charging reliability goals were defined for the case company:

- Accessibility of a charging point.
- Fast and easy start of charging event.
- Smooth charging process without any problems or interactions.
- Fast and easy ending of charging event.
- Data related to charging event is provided to back end and to customers.
- Connection to back end is maintained.
- Up to date information is provided to back end and to customers.

Result indicators show the benefits for the case company and for the customers that can be obtained if the reliability goals are met. Based on the reliability goals the following result indicators were identified and presented in the second column of the table 4:

- Customer is always able to access the station.
- Customer is able to start charging using RFID, App or SMS method without a need to call support.
- The electric vehicle is charged without any problems or interruptions.
- Customer is able to stop charging using RFID, App or SMS method without a need to call support.
- Support team and customers get up to date and trustworthy data such as station id, customer id, start and stop time, kWh charged, price of charging event. Payment is done correctly, and the data related to charging event and payment is visible in the reporting system - Admin Panel.
- Chargers stay online permanently.
- Chargers send up to date and useful data about its status.

4.1.3 Step 3. EV charging problems identification

The next step is to evaluate the current state of charging points at the company. The case company's employees from Support or Technical teams are aware of the problems related to their charging network. Based on available data and interviews with company's employees the list of all the problems related to charging points is created. The data required for this study was retrieved from SQL database. From several tables data about charging points, charging events, created bills, stations disconnects and alerts was analyzed. Employees of the case company perform tests of chargers and testing data is also stored in the same data tables as data from normal charges.

This step is important in order to see where charging stations do not comply with the reliable station definition. Precisely defined problems will give an overview of charging points reliability and will lead to better solutions to these problems. All in all, 14 problems are defined and listed below:

1. The charging station goes offline.
2. Charging event does not start or stop.
3. The system does not identify customers, e.g. roaming customers.
4. Charging stops unexpectedly, e.g. car or cable problem.
5. Reservation on the App does not work well, e.g. the App shows that the charger is reserved for you, but it is not, so another EV drivers can use this charger.
6. There are chargers that do not function properly, but they are visible to the customers. The App shows the availability of a charging station, even though it is taken, broken, offline, reserved, or not activated yet.
7. RFID or App does not work well, e.g. does not start or stop charging.
8. Error messages from the charging points do not specify what is the problem. It is difficult to define if there are any problems with actual charging station and where is the problem.
9. Data that comes from back end or stations is not always trustworthy, e.g. charger does not provide data about the amount of used energy.
10. If customers experience problems while using the chargers, they use hot line call service. In some cases, hot line waiting time can be about 30 minutes.
11. The car is connected to the charging point, but there is no energy coming.
12. Charger does not recognize the car, e.g. car-to-charger communication problem.
13. Sim card problems, e.g. weak signal in a parking garage, so sim card loses the connection completely and needs to be rebooted on the site.
14. Payment problems based on lack of data or incorrect data. There are situations when energy is not coming from charger, but the customer pays for the time his or her car was connected to the charger

The mentioned problems negatively influence the usability of charging points and have to be eliminated in order to reach the desired level of reliability. However, there are some charging problems that the case company cannot solve due to some constraints. The following limitations to reaching the reliability goals are identified:

- Parking next to EV chargers due to some reasons might be impossible.
- Bad quality of connection cables purchased by customers might influence charging negatively.

- Due to weather conditions such as snow falls access to chargers might be blocked.

4.1.4 Step 4. Assigning variables from the database to the defined reliability goals

For each defined goal from 4 to 8 variables were defined using the company's database. Reliability goals can be assessed and judged using the following variables that are also presented in the third column of Table 4:

1. Usage frequency, low utilized stations.
2. Number of hotline calls, number of complaints.
3. kWh charged.
4. Number of frequent users per charging station.
5. Number of online stations.
6. Average occupancy of charging point, occupancy rate.
7. The option that customer uses to start charging: RFID, App or SMS.
8. Number of errors in Admin System.
9. The option that customer uses to end charging.
10. Number of long charges.
11. Database update frequency, heart beat every 1-15 minutes.
12. Number of payments.
13. Charge time and connection time ratio.

Goals	**Result Indicators**	**Variables**
Accessibility of a charging point	Customer is always able to access the station	▪ Usage frequency (low utilized stations) ▪ Number of hotline calls/complaints ▪ kWh charged ▪ Number of frequent users/charging station ▪ Number of online stations

		▪ Avg. occupancy of charging point- occupancy rate
Fast and easy start of charging event	Customer is able to start charging using RFID/App without a need to call support	▪ Number of online stations ▪ The option that customer uses to start charging (RFID/App/SMS) ▪ kWh charged ▪ Number of errors in Admin System ▪ Number of frequent users/charging station ▪ Usage frequency (low utilized stations) ▪ Number of hotline calls/complaints
Smooth charging process without any problems or interactions	The electric vehicle is charged without any problems or interruptions	▪ Number of online stations ▪ Usage frequency (low utilized stations) ▪ Number of hotline calls/complaints ▪ kWh charged ▪ Number of frequent users/charging station ▪ Number of errors in Admin System
Fast and easy ending of charging event	Customer is able to stop charging using RFID/App without a need to call support	▪ Number of errors in Admin System ▪ The option that customer uses to end charging ▪ Number of frequent users/charging station ▪ Usage frequency, low utilized stations ▪ Number of long charges ▪ Number of hotline calls/complaints
Data related to charging event is provided to back	Support team and customers get up to date and	▪ Database update frequency- heart beat 1-15 min ▪ Amount of errors in admin system

end and to customers	trustworthy data. Payment is done. This data is in Admin Panel	▪ Number of hotline calls/complaints ▪ Number of online stations ▪ Number of payments
Connection to back end is maintained	Chargers stay online permanently	▪ Number of errors in Admin System ▪ Number of hotline calls/complaints ▪ Usage frequency, low utilized stations ▪ Charge time/connection time ratio (e.g. car is connected but no energy coming) ▪ kWh charged ▪ Database update frequency- heart beat 1-15 min ▪ Number of payments ▪ Number of online stations
Up to date info is provided	Chargers send data about their status	▪ Number of hotline calls/complaints Database update frequency - heart beat 1-15 min ▪ Number of errors in Admin System ▪ Number of online stations

Table 4 Goals, result indicators and variables assigned from the database.

4.1.5 Step 5. KPIs identification using S.M.A.R.T. method

The problems that were identified in Step 3 can be divided into the following main groups that have to be covered by KPIs:

- Station errors.
- Frequency of charging and number of frequent users per charging point.
- Monitoring and reports that station sends.
- Energy transfer.

- Type of initiation or completion of charging events.

Variables that were repeated multiple times and assigned to the groups mentioned above were selected and then tested against S.M.A.R.T. criteria. Doran (1981) introduced the S.M.A.R.T. goal setting method that was later adapted to KPIs identification process. The S.M.A.R.T. acronym refers to the following concepts: specific (S), measurable (M), assignable (A), realistic (R), time related (T). And the goal of applying this method is to check if KPIs are referred to each of these concepts.

- Specific (S) – It has to be clearly defined and communicated what the KPI measures. The definition has to be precise and it has to be understood and accepted across the organization.
- Measurable (M) – It has to be possible to measure the KPI. To do that there should be a possibility to access the necessary data and to interpret it in a right way.
- Assignable (A) – A person or a group of people have to be defined as responsible for a KPI. They have to continuously monitor, improve and report the results of this KPI.
- Realistic (R) – It has to be possible to achieve the defined KPI. On the other hand, KPIs should be motivating and set at right level.
- Time related (T) – The timeline for measuring and reviewing a KPI has to be set in advance. KPIs are meaningful only if the time frame in which it is realized is determined.

As a result, the variables that covered the problems of EV charging points and complied with S.M.A.R.T criteria were identified as KPIs in the case company. The set of 9 KPIs is presented below:

KPI 1: Usage frequency of chargers.
KPI 2: Number of hotline calls/complaints.
KPI 3: kWh charged.
KPI 4: Number of frequent users per charging station(s).
KPI 5: Total number of offline stations.
KPI 6: The option that customer uses to start charging (RFID/App/SMS).
KPI 7: Number of errors in admin system.

KPI 8: Number of long charges.
KPI 9: Number of payments/ the amount of bills created correctly.

Table 5 consists of four columns and represents the defined key performance indicators, available data required for calculation, KPI interpretation and problems related to data. Below the description and interpretation of each KPIs is presented. The content of the table is specific to the case company, however the structure of the table can be generalized and applied to other companies.

The first selected KPI is usage frequency of EV charging points. This indicator provides an overview of utilized stations and helps to spot the low utilized ones. High usage frequency of a charger is an indicator of a well performing station, on the other hand low usage frequency identifies possible problems. It is important to note that low usage frequency might also mean the remote location of the charger. Hence the usage frequency results have to be compared to the perilous period of time, e.g. two weeks, in order to spot the difference in usage rate.

Number of hotline calls received from an outsourced service is an another identified KPI. The increased number of complains can point out the drop in the reliability of charging points, it is also important for measuring the customer satisfaction. The reports related to the number of hotline calls are sent to the case company every week and analyzed by the Support team.

Amount of kWh charged is another KPI that is useful for monitoring the performance of station. The drop in the charged energy is a potential identification of a problem. The same as with user frequency if a charging point is not used often and there are not sudden drops in usage it can also mean the remote location of the charger.

The number of frequent users per charging station is a KPI that identifies well performing stations by counting the number of frequent customers of public charging stations. If EV owners prefer to use the same charger(s) frequently it means the high reliability of these charger(s). However, for measuring this KPI home chargers have to be filtered out.

The number of offline stations is another KPI relevant to EV charging industry. It provides information about the number of offline chargers that directly influences usability and reliability of the whole charging network.

The next KPI is the option that customer uses to start charging: RFID, App or SMS. It shows the most popular thus the most reliable method of charge initiation. It also identifies what method is the worst from the point of view of customers and has to be improved or discontinued.

The number of errors in admin system is a KPI that identifies the most problematic stations based on the amount of error messages coming from charging points. There are various errors received from chargers that can be classified according to type and level of severity.

The number of long charges is the KPI that counts the charges that used more than 100 kWh. It is evaluated as an abnormal event, that can mean that the charging process did not stop due to some reason. Long charges can identify bus charging, on other hand it can pinpoint the unreliable stations.

The number of payments or the number of bills created correctly shows that charging event was successful, and the payment can be processed. The sudden drop in created bills can indicate the chargers that do not function properly or the ones that were set to free charging by mistake.

KPI	**Data**	**KPI interpretation**	**Problems with data**
KPI 1. Usage frequency of chargers	Table: Charge Columns: Station ID Start_time Stop_time	High usage frequency-well performing station. Low frequency- problem or remote location. Compare to the last period of time e.g. 3 weeks to see the changes in usage frequency	▪ Watt hour data is not always correct, contains “0” and numbers with ”- “

	Watt_hour		▪ Not clear why start time and stop time are the same
KPI 2. Number of hotline calls/complaints	Outsourced reports	The less complains the better	▪ Reports are sufficient, sent to Virta every week
KPI 3. kWh charged	Table: Charge-energy usage Columns: Station_id Watt_hour	High amount of kWh charged-well performing station. Low amount of kWh charged - problem or remote location. Compare to the last e.g. 3 weeks to see the changes in kWh charged	▪ Watt hour data is not always correct, contains '0' and numbers with'-'
KPI 4. Number of frequent users per charging station(s)	Table: Charge-energy usage Column: Station_id Customer_id	This KPI can identify well performing stations or home chargers	
KPI 5. Total number of offline stations	Table: Station status notification,	KPI shows % of time the charger is online	▪ Difficult or impossible to understand

	Stations disconnects Columns: Offline		what the error is
KPI 6. The option that customer uses to start charging (RFID/App/Sms)	Table: Charge start Columns: Method	KPI shows the most reliable charge initiation method	▪ Difficult or impossible to understand what the error is
KPI 7. Number of errors in admin system	Table: Station status notification, Station alert Columns: Error code	An increase in error reports indicates problems	
KPI 8. The option that customer uses to start charging (RFID/App/Sms)	Table: Charge start Columns: Method	KPI shows the most reliable charge initiation method	▪ Difficult or impossible to understand what the error is
KPI 9. Number of payments/	Table: Bill Columns: Created	If there is a drop in a number of created bills, there might be a possible problem	

number of bills created correctly	Status		

Table 5 KPIs, data for their calculation, KPIs interpretation, and data problems.

Such variables as average occupancy of charging points, charge time and connection time ratio, and database update frequency are not included in the set of identified KPIs. These variables can be indicators of the charging points problems, but they do not measure the critical processes and cannot create a value for the company.

Average occupancy of charging points was not chosen as a KPI because it is similar to previously described usage frequency KPI. Exactly the same data (table: charge; columns: station ID, start_time, stop_time) is required for calculation of both usage frequency and average occupancy of charging points.

Charge time and connection time ratio can show when a car is connected to a charger, but the energy is not being transferred. This variable is too weak to become a KPI, because it does not measure a process critical for the company.

Database update frequency is related to charger's status data update frequency. It can be set differently for each charging point and varies from one 1 to 15 minutes. It means that charging points send signal that they are online every 1- 15 minutes. This signal is also defined as "heart beat" of a charger. And if a charger has not sent a signal 3 times in a row, it is considered to be offline. Database update frequency was not chosen as a KPIs because it is directly related to another KPI – the number of offline stations. Thus, there is no need to monitor how often the database is updated, it is enough to track the number of online stations.

4.1.6 Data evaluation for KPIs calculation.

After KPIs identification the database of the case company was analyzed in order to evaluate the quality and availability of data that can be used for further KPIs calculation. The second and the fourth columns of Table 5 include information about data. After describing the

selected KPIs, it is necessary to discuss the data quality and availability at the case company. Wang & Strong, 1996 described data quality as “fitness for use” and emphasized that quality of data is judged by particular data consumers.

The second column presents the list of the tables and columns that include the data used for KPIs calculation. All the KPIs can be calculated using the available data from the database except the number of hotline calls. It can be concluded that in general the company’s database stores a lot of valuable data that can be used for analysis and KPIs identification.

The remarks related to data quality are listed in the last column of Table 5. First of them is about the kWh data stored in the database. It is not always correct and can contain zeros or negative numbers. In some cases, the chargers do not send the kWh data or send incorrect data. In other cases, the incorrect numbers are displayed due to the changes made in the database manually. All that complicates the usage frequency calculation and causes inaccurate results.

Another data problem is related to start time and stop time of a charging event that can be exactly the same. It can have two meanings such as the unsuccessful charging attempt or the incorrect data sent by stations.

Furthermore, stations send error notifications, but it is problematic to understand their meaning. For instance, some charging points send such notifications as “other error” or “OCPP error” that are not clear. As a result, it is complicated and time consuming to investigate what is the actual problem.

Test data is stored in the same data tables as data from normal chargers and has to be filtered for analysis. But sometimes the data from test stations is displayed in company’s Admin Panel visualizations that can distort the presented results. For instance, test data is included in today’s overview of charging network that gives incorrect information.

4.1.7 Validation of identified KPIs.

Several researchers (Scholten 2017, Ella Roubtsova 2013 and Vaughan Michell 2013) in their work applied the KPIs validation framework presented by Kitchenham (1996), Kueng (2000), Winchell (1996). These researchers performed validation of KPIs by testing them against the following properties: quantifiability, sensitivity, congruency, reliability, efficiency and improvement-orientation.

- Quantifiability of KPIs means that they have to be presented in a quantifiable form. In the case of this study, quantifiability means that it is possible to get the data for calculation of selected KPIs.
- Sensitivity means that KPIs have to be sensitive to possible changes. Even small changes in the values of the database influence the value of the performance measured through the indicator.
- Congruency or linearity means that changes in performance have to be in line with the indicator's value via a clear mathematical relationship. For instance, if a value changes negatively, KPI changes negatively too.
- Reliability means that KPIs are semantically reliable, free from subjective factors and measurement errors. Reliable KPIs specifically measure what they claim to measure.
- Improvement-orientation KPIs are referred to possibility to improve the system or process in the future. Conformance is not the goal of improvement-oriented KPIs.

The KPIs determined for the case company were tested using the properties described above. Table 6 shows the obtained validation results. If cell is colored in green color, it means that a KPI complies with a property that is shown on the left side of the table. Gray color indicates the opposite result. (Table 6)

	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9
Quantifiability									
Sensitivity									
Congruency									
Reliability									
Improvement-orientation									

Table 6 Checklist for KPIs validation.

The list of identified KPIs is the following:

KPI 1: Usage frequency of chargers.
KPI 2: Number of hotline calls/complaints.
KPI 3: kWh charged.
KPI 4: Number of frequent users per charging station(s).
KPI 5: Total number of offline stations.
KPI 6: The option that customer uses to start charging (RFID/App/SMS).
KPI 7: Number of errors in Admin System.
KPI 8: Number of long charges.
KPI 9: Number of payments/ the amount of bills created correctly.

All of the identified KPIs comply with quantifiability and sensitivity properties. It means that the data for their calculation is available and they are sensitive to changes in the values of the company's database.

KPI 2 is not in line with the indicator's value via a clear mathematical relationship, thus it is not congruent at the moment. KPIs 4,7 an 8 do not fully satisfy the reliability property,

because of the possible errors in the case company's database. These KPIs can also point out the regular situations such as distant location of a charger. KPIs 4 and 8 are not improvement-oriented, but they are still important for measuring the reliability of charging points.

If there is a possible problem to comply with one of the properties, the validation is not considered to be passed. Gray color was used even if some KPIs point a regular situation that cannot be filtered from a charging problem. However, KPIs that currently do not comply with some of the properties can be improved in the future and pass the validation.

4.2 Failure rate calculation

One of the selected KPIs is the number of errors in admin system that requires the failure rate calculation. Failure rate can be described "as the anticipated number of times that an item fails in a specified period of time. It is a calculated value that provides a measure of reliability for a product." (Greeff, Ghoshal, 2004) The Greek letter lambda (λ) represents the failure rate that is calculated by taking the number of failures that occurred in a specific length of time and dividing it by the length of time. (Jones, 2006) The formula of failure rate calculation is presented below:

$$\lambda = \frac{number\ of\ failures}{total\ measured\ usage}$$

Figure 6 The formula for failure rate calculation (Jones, 2006).

In the case company failure rate is the measure of reliability of charging points and it can be calculated as the percentage of time the station is faulted in a period of time. The management of the company requested the failure rate calculation model to be done in Microsoft Excel. The created model is presented in Appendix 1.

For the failure rate calculation, the "station status notification" table was used, and the following data was required:

- Station identification number.

For each station a unique identification number is assigned, and it can contain from four to six numbers.

- Status of a charger.
  There are three types of status notifications in the company's database: available, faulted, and occupied.
- Timestamp.
  The timestamp indicated the date and time when the charger became available, faulted or occupied.

The failure rate calculation for the case company is based on the "faulted" charging events or error that the station sends. According to database, chargers send data about its status and a timestamp, that defines when the error happened. But the data table does not contain data related to time when the error was eliminated. Thus, it is not possible to calculate the period of time the station was faulted.

However, it is possible to estimate for how long the station was faulted using time intervals. It was decided to create 15 minutes time slots for one month (31 days) and calculate the number of 15 minutes slots when the fault was reported. It means that if the fault was registered at 0.03, it has to be assigned to the time period of 00.00 - 00.15.

For the case company the failure rate calculation formula is the following:

$$\lambda_1 = \frac{number\ of\ faulted\ 15\ minutes\ slots}{number\ of\ 15\ minutes\ slots\ in\ a\ month}$$

Figure 7 The formula for failure rate calculation in the case company.

The charger number 3039 was used as an example for failure rate calculation in a month of December 2018. To calculate the number of 15 minutes slots when faults were reported the columns that represents the time slots were created in Excel. All in all, the charger reported the faulted status 1436 times and all of these faults were assigned to created time slots. Then the sum of the time slots when faults were reported was calculated and the result was 106.

As mentioned before in the case company failure rate is the percentage of time the station is faulted in a period of time. In this calculation the period of time is one month. Thus, to obtain the failure rate in December 2018 the number of 15 minutes slots when fault was reported was divided into the number of 15 minutes slots in December 2018. It has been already calculated that the sum of the time slots when faults were reported is 106 and the number of 15 minutes slots in December is 2976. Thus, when dividing 106 by 2976 the result is 3,46 percent.

Each charging point has its own failure rate. And by calculating the average number of the individual failure rates of charging points, the average failure rate of the whole charging network can be calculated.

As the calculation described above is not precise enough, it was decided to add the second timestamp to the "station status notification" table in the database. The developers will work on that in the following months. The timestamp will indicate the time of error elimination that will help to calculate the duration of time the station was "faulted".

4.3 Admin Panel improvement

Admin Panel is a system that provides various tools for managing and monitoring the charging points. Case company's employees and customers can access different reports, statistics, and inform about problems using Admin Panel.

As stated earlier, Kibana was chosen as a tool for dashboard creation of KPIs for charging points. But currently only a limited number of case company's employees are using this tool and the clients do not have access to it at all. Furthermore, it has not been decided yet if Kibana will be used in the company in the future. Hence, together with the company's manager it was decided to make a proposal for changes in Admin Panel that is the commonly used tool by both employees and customers.

4.3.1 Current state of maintenance section in Admin Panel

Currently the maintenance section in Admin Panel presents the review of charging network performance and consists of three parts. The first part presents the today's overview, such as:

- Latest error message,
- Latest station went offline,
- Latest zero kWh event,
- Latest charge started, and
- Latest messaging error.

The second part of the maintenance section includes statistics presented in the following charts:

- Total error messages from stations.
- Count of offline stations.
- Total zero kWh events from stations.

The last part of the maintenance section includes the stations uptime information that is shown in a form of a data table that contains uptime percentage, duration and number of disconnects.

4.3.2 Maintenance section improvement proposal

The improved maintenance section will include four parts instead of three. The first part will not be changed and as the current version of maintenance section it will present the todays overview. The second part will also contain the charts, but their type will be different. The following visualizations will be shown:

- The failure rate of a total network in a period of time.
- The uptime/downtime percentage ratio of a total network. (Appendix 2)

The third pat of maintenance section will display the network KPIs scorecard. It is a form of reliability report that presents reliability results on each station and includes (Appendix 3):

- the station's identification number
- the number of charging sessions,
- the number of errors,
- percentage of time the station was offline,
- kWh charged, and
- profit generated by stations.

The last part stations that shows the station uptime information will remain the same. The filter that will allow choosing the station model has to be added to the Stations Uptime part of the Maintenance section.

5. Visualization of KPIs in the case company

5.1 Dashboard visualization

Visual management is used by many organizations in order to improve performance through connecting and linking vision, values, goals and culture of the company with other management systems, processes, and stakeholders. (Liff and Posey, 2004).

Dashboard is a common way to visualize key performance indicators in the form of graphs, gauges, or charts. Dashboards can be built in a different way, but all of them have the same goal – to provide the relevant information to the right people quickly. Usually dashboards are created by KPIs users to visualize what has to be done to improve their business. (Rasmussen et al., 2009) Bose (2006) gives the similar definition of a dashboard, he states that dashboard is a software application that provides a single screen layout of the most important data that enables managers to take the necessary decisions faster. Malik (2005) states that dashboards are essential for growing companies as the amount of data is rapidly growing and it requires information flow and decision-making process improvement. As per Pauwels et al. (2009) dashboards have three main objectives such as monitoring, planning and communicating the obtained results.

Nowadays a big variety of KPIs dashboard tools such as Tableau, Excel, Qlik Sense, QlikView are available. Kibana is a software that is currently used for data visualization and monitoring at the case company. As requested by the case company, KPIs have to be visualized in a dashboard. In the next sub chapter, the KPIs visualization tool that is used in the company will be discussed.

5.2 Kibana as a tool for visualization

Kibana (Elastic.co., 2018) is an open source data visualization tool for Elasticsearch that can be easily accessed with a browser. The benefits of Kibana include interactive charts and reports such as histograms, line graphs, pie charts, heat maps. Moreover, it provides geospatial capabilities that allow to present geographical locations in maps. Another feature is pre-build aggregations and filters, that makes data analysis and visualization easier and

faster. With Kibana it is also possible to create various dashboards and share them with others. Moreover, the tool provides such options as unsupervised machine learning and advanced time series analysis and allows to customize the data using Canvas feature.

It is possible to customize the dashboard according to the needs of the company and customers. Furthermore, the speed of producing different types of visualizations in Kibana is relatively fast and efficient. Figure 9 represents the example of a dashboard created in Kibana.

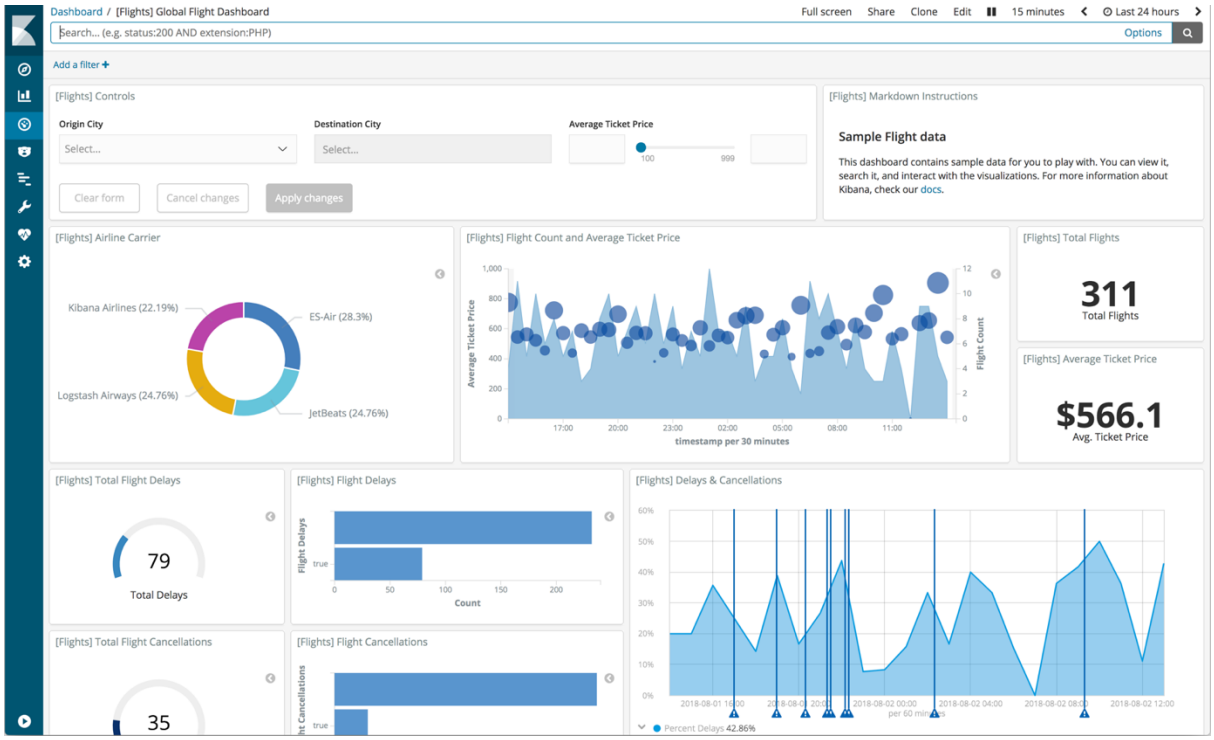

Figure 8 The example of a dashboard created in Kibana using global flights data. (Retrieved from: https://www.elastic.co/guide/en/kibana/current/dashboard.html [Accessed: 05.01.2019])

5.3 KPIs Dashboard in the case company

After the KPIs are identified and validated, the process of visualization can start. The case company requested KPIs to be presented in a form of dashboard using the company's software. This process and visualization results are presented in this chapter. As described in the Chapter 4.1.5, the following KPIs were defined for the monitoring EV charging points reliability:

- KPI 1: Usage frequency of chargers.
- KPI 2: Number of hotline calls/complaints.
- KPI 3: kWh charged.
- KPI 4: Number of frequent users per charging station(s).
- KPI 5: Total number of offline stations.
- KPI 6: The option that customer uses to start charging (RFID/App/SMS).
- KPI 7: Number of errors in Admin System.
- KPI 8: Number of long charges.
- KPI 9: Number of payments or the number of bills created correctly.

However, at the moment the following KPIs cannot be visualized in Kibana:

- Number of hotline calls or complaints

As mentioned before hotline service is outsourced and data received from hotline service company is not stored in Elasticsearch. It is received by Support team once a week and stored in Excel files in the company's Dropbox.

- Number of payments or the number of bills created correctly

The data related to created and paid bills is not currently available in Elasticsearch and as a result it cannot be visualized in Kibana.

The following KPIs were visualized using time series visual builder: kWh charged, usage frequency, the number of offline stations, the option that customer uses to start charging (RFID/App/Sms), the number of errors in Admin System, and the number of long charges. Furthermore, for some of them additional visualizations such as data table, pie chart, coordinate map, and data table were created.

The table below includes KPIs that were visualized in Kibana and the types of their visualization.

KPI	The type of visualization in Kibana
kWh charged	1. Time series visual builder,

	2. Coordinate map
Usage frequency	1. Time Series Visual Builder, 2. Data table
Total number of offline stations	1. Time series visual builder, 2. Data metric
The option that customer uses to start charging (RFID/App/Sms)	1. Time series visual builder
Number of errors in Admin System	1. Time series visual builder, 2. Pie chart
Number of long charges	1. Time series visual builder

Table 7 The types of visualizations created in Kibana.

KPIs dashboard combines different types of charts and structured in the same order as presented in the table. The examples of created Kibana visualizations are presented below.

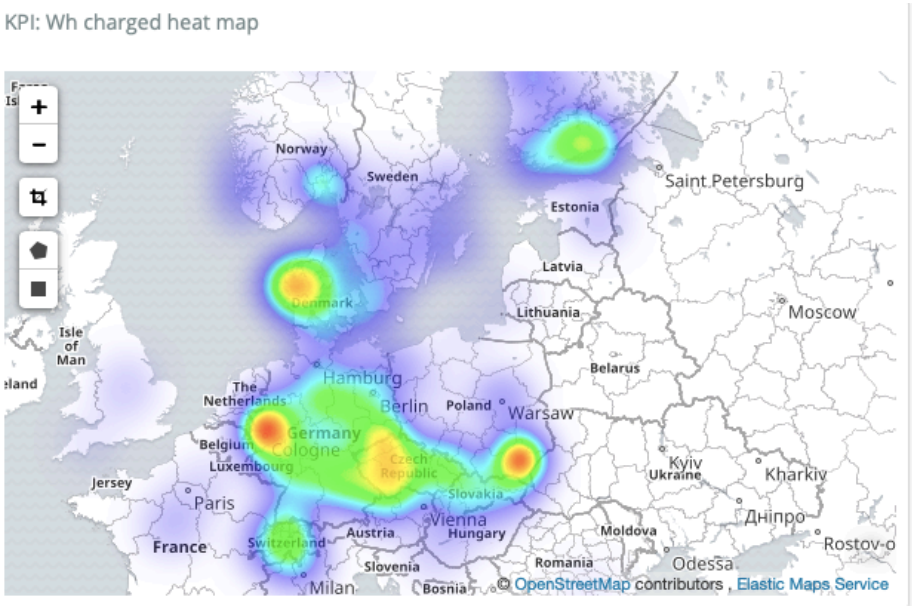

Figure 9 kWh charged heat map.

The map displayed in Figure 9 shows in red color the geographical location of places where the highest amounts of kWh are charged.

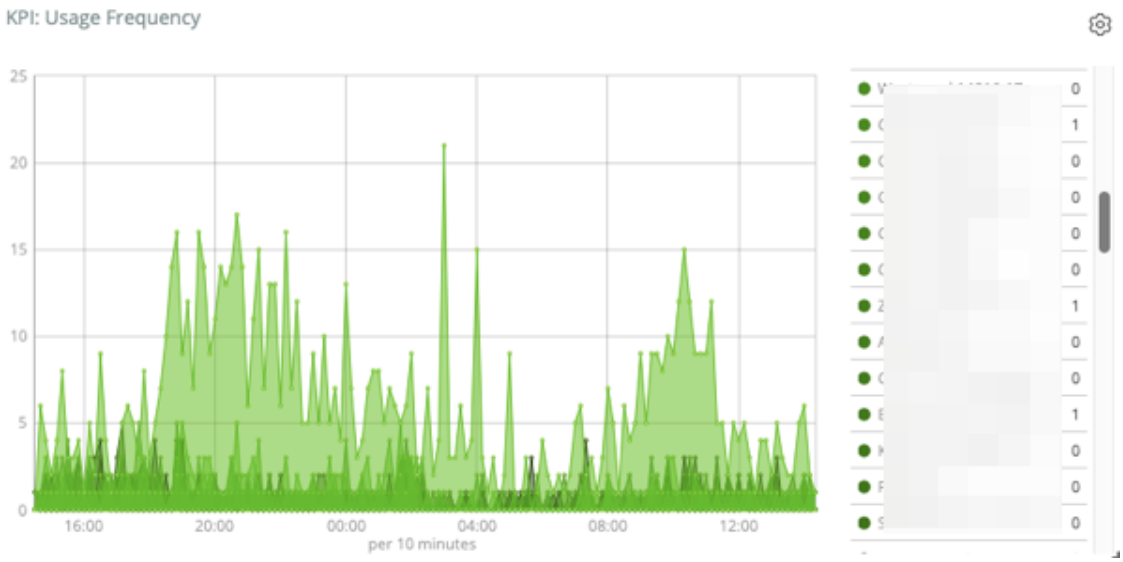

Figure 10 Usage frequency per station in the last 24 hours.

Figure 10 presents the usage frequency of charging points per station in the last 24 hours. The station names on the right side of the visualization are blurred.

KPI: Usage frequency table

Station id and name	Number of charges
[redacted]	39
[redacted]	37
[redacted]	36
[redacted]	28
[redacted]	27
[redacted]	26
[redacted]	26
[redacted]	24
[redacted]	23
[redacted]	22

Figure 11 Usage frequency data table.

The data table shown in Figure 11 was created to visualize usage frequency KPI. It shows station ID, name and the number of charging events that happened in the last 24 hours.

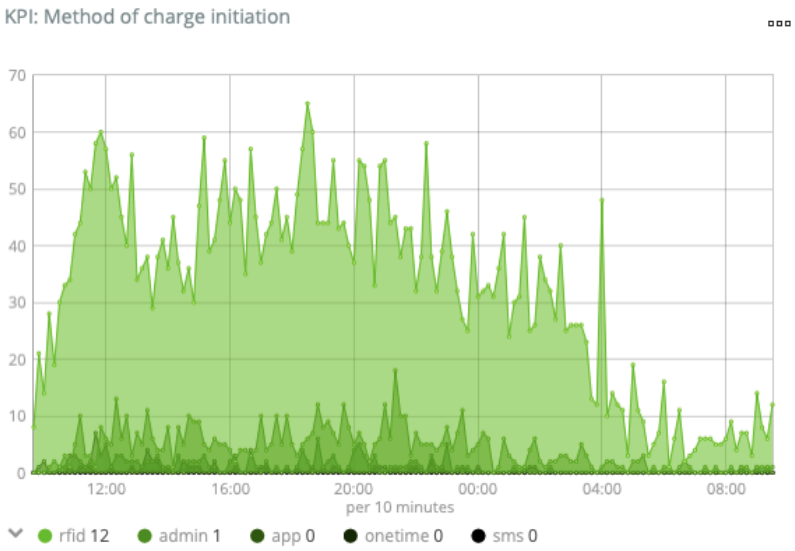

Figure 12 The option that customer uses to start charging in the last 24 hours.

Figure 12 presents such methods of charge initiation as RFID, admin, App, onetime, and SMS. Admin option means that case company's support team started a charging event. Onetime payment option is used by the customers that are not registered as case company's customers and payed online using their bank card.

6. Conclusions and recommendations

6.1 Conclusions of the study

The case company is continuously working on improving EV charging experience for their customers. And the topic of charging points reliability is an important issue that takes a lot of attention from the management team of the company. This study's aim was to create a value for the case company by identifying and visualizing EV charging points KPIs for reliability monitoring.

In terms of the thesis practical contribution to the case company:

1. KPIs for EV charging points reliability tracking were identified,
2. EV charging problems were recognized,
3. database analysis was performed and as a result data errors were discovered, and data that has to be obtained was defined,
4. KPIs dashboard for EV charging points reliability tracking was built,
5. recommendation for further improvement were stated.

One main research question and four sub questions were defined and introduced in the beginning of the thesis. In order to make conclusions of the study, the answers to these questions are provided in this chapter. Figure 14 shows the outline of research questions and answers.

1. *What set of KPIs has to be used at the case company in order to measure reliability of charging points?*

For the case company a set of nine key performance indicators was created. They cover such areas as station errors, frequency of charging and number of frequent users, monitoring and reports sent by stations, energy transfer, and the type of initiation or completion of charging events. The KPIs are the following: the usage frequency of chargers , the number of hotline calls/complaints, the amount kWh charged, the number of frequent users per charging

station(s), the number of offline stations, the option that customer uses to start charging (RFID/App/SMS), the number of errors in admin system-failure rate, the number of long charges, the number of payments or bills created correctly. All together these KPIs give an overview of reliability of EV charging points and help to spot the negative changes. After the KPIs are implemented and tracked for a period of time, they should be evaluated again. If needed, they can be improved, eliminated, or replaced with more suitable KPIs.

1.1 How to define a suitable set of KPIs for the case company?

To answer this question the case company's charging network was analyzed first and then different methods for KPIs identification were evaluated. Based on that it was decided to create a unique approach that will help to identify KPIs for measuring reliability of charging points. The approach is created in a way that it can be applied in other EV charging companies if needed. It included seven steps and focused on identifying KPIs specifically for tracking reliability of charging points. It was supported with literature review of EV charging, performance measurement and various methods for KPIs creation. The approach that was described in detail in chapter 4 combined the idea of current and future state evaluation, data analysis and KPIs validation.

The KPIs identification process started with defining reliability in the case company and as a result the term included seven characteristics. Then the goals for reliable charging stations were defined that formed a desired level of reliability in the future. After that the list of EV charging points was composed that gave an overview of the current situation. Database analysis was performed in order to assign the variables from the database for the defined reliability goals. Data errors were also defined during this step. A set of nine KPIs was selected using S.M.A.R.T. method and then data was defined for their calculation. The final step included KPIs validation by testing them against the following properties: quantifiability, sensitivity, congruency, reliability, efficiency and improvement-orientation.

1.2 What is the appropriate way to visualize the selected KPIs?

Dashboard is a popular way of KPIs visualization that was also used in the case company. KPIs dashboard for the case company was composed using Kibana that offers various

visualization opportunities for instance data tables, line graphs, pie charts, and heat maps. As shown in chapter 5.3, for the KPIs dashboard such types of visualization as time series visual builder, data table, coordinate map, and data metric were chosen. Most of identified KPIs were displayed using time series visual builder and then supported by other types of visualizations depending on the nature of a KPI. The reason to select time series visual builder was that the KPIs have to be measured on daily basis and their results have to be compared to previous periods of time. Not all of the KPIs were visualized in a dashboard because not all of the data is available in Elasticsearch at the moment. Furthermore, Kibana is not the best tool for KPIs tracking that is more discussed in sub chapter 6.2 that discusses recommendations of this study.

1.3 What improvements can be proposed based on identified KPIs?

This thesis offers two improvement proposals related to failure rate calculation and maintenance section in Admin Panel. The failure rate calculation was done using 15 minutes intervals that provides a percentage of time the EV charging network was “faulted”. The more precise calculation is not possible at the moment due to nonexistence of required data. This calculation can be improved by adding the second timestamp that indicates the time of error elimination. If we know the duration of time the station was “faulted”, the failure rate calculation can be done easily. A detail description of a proposed failure rate calculation can be found in chapter 4.2.

Maintenance section in Admin Panel displays an important information regarding charging network that is used by the case company’s employees and customers. It has to be improved in order to provide more insights on reliability and also display different type of visualizations. First, KPIs scorecard has to be added to the maintenance section. And then the current visualizations have to be substituted with the ones that provide information about failure rate and uptime percentage of a total network.

The company has already started a project that aims to make the changes that were proposed in this thesis. The developers are currently working on making Admin Panel improvements that were described more thoroughly in Chapter 4.3. Furthermore, the necessary data will be added to database that is required for calculating failure rate of EV charging network.

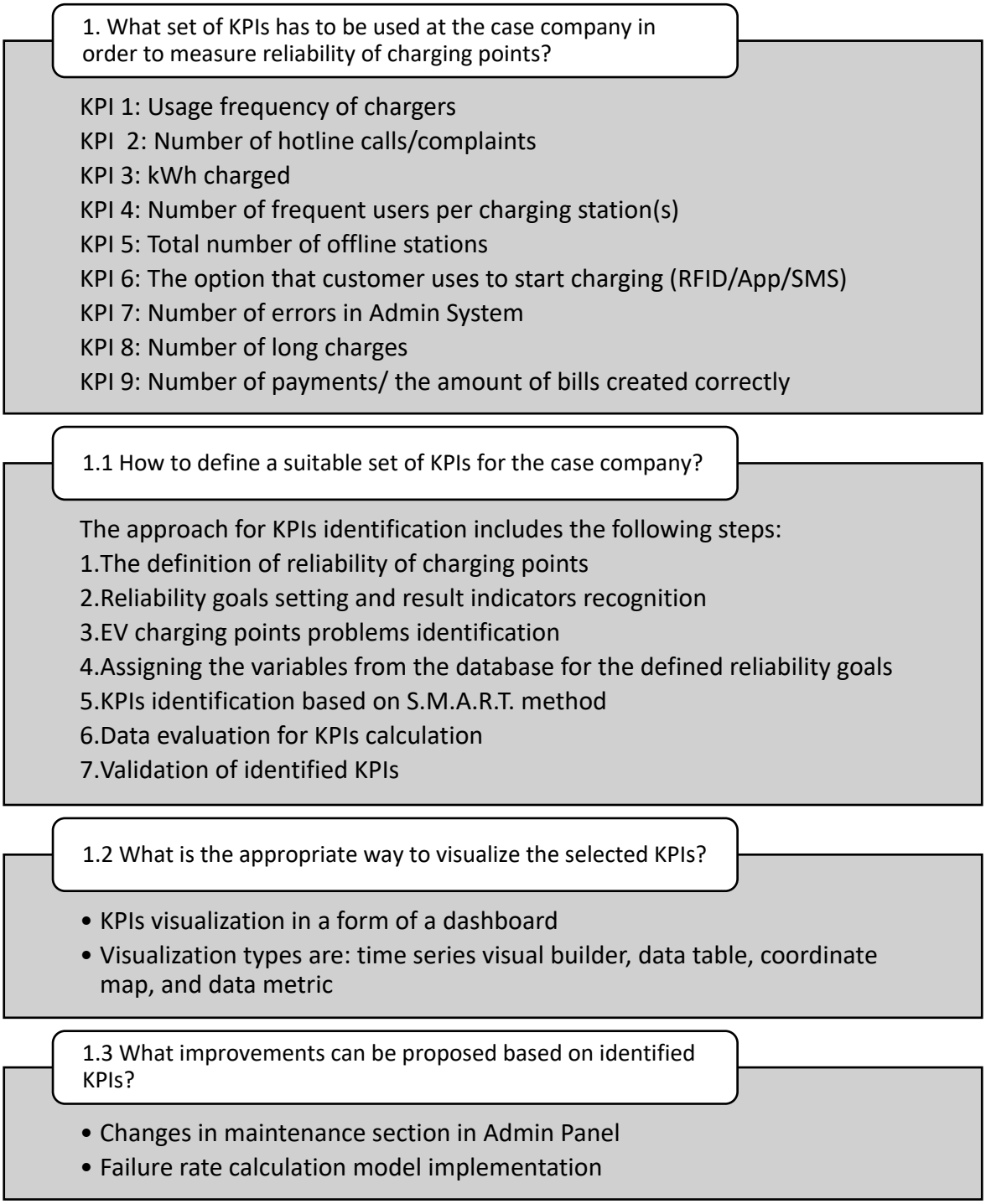

Figure 13 The outline of research questions and answers.

6.2 Recommendations for further development

The improvement proposals related to Admin Panel and Failure rate calculation were already introduced in Chapters 4.2 and 4.3. In this chapter recommendations concerning other topics are described.

Kibana is a tool that has been tested in the company for a period of six months. It allowed to create most of the defined KPIs, but it can be concluded that it is not the best software for KPIs dashboard creation. The reason is that it is not possible to make a visually appealing time series that will present the comparison of values obtained. For example, it is complicated to create a chart that will visualize and present the clear difference in kWh charged this and the last month. It is already investigated by the company's management with what tool to substitute Kibana for internal monitoring of charging network and dashboard visualization.

Furthermore, the dashboard is intended to be used not only internally but also by case company's customers. It is crucial to communicate the KPIs dashboard in an efficient way so it will be understood and used by different user groups. For this purpose, the KPIs have to be integrated into Admin Panel that is actively used by customers. KPIs can be presented in a form of reliability report and visualizations that will provide the most valuable information related to charging points usability and reliability. The style of reports and charts has to be simple, visually appealing and it also has to be easily found in one of the sections in Admin Panel.

Defined and visualized KPIs for EV charging network reliability cannot bring any real value to the company if they are not shared and communicated to the responsible stakeholders. KPIs dashboard immediately shows the occurring problems that simplifies the process of charging network monitoring. It also allows to take faster decisions and promptly react to changes.

As for the possible changes in Admin panel, Business Intelligence (BI) section also requires some improvements. The section consists of a big variety of reports in a form of visualizations such as active customers and charging events per country. The presented

information is definitely important, but the style of the charts is not easily understandable and visually attractive. The change of charts type and the order of their location on the page will make the BI section more useful and user friendly.

One of the most important KPIs that was defined is the number of errors sent by charging points. The case company monitors various errors that are differentiated by type. The error types are set by charger's manufacturers and may vary. The problem is that it is not always understandable what the error actually means and how severe it is. The research related to the error classification has to be done that will help to better understand the error notifications and be able to react to them in a short period of time. Moreover, it will be useful for further selection of the most reliable manufacturers of hardware.

Error notifications is not the only topic that needs attention. It also has to be defined on the company level what is abnormal event and what charging events belong to this category. It is also critical to identify such terms as long charge, downtime, failure rate, and some others. These terms have to be documented and explained to company's employees, partners and also customers.

It was stated in Chapter 6.1 that the proposed failure rate calculation can be modified by adding the second timestamp that indicates the time of error elimination. If it is done, the precise failure rate can be calculated easily. The ticket that describes this required change has already been created and explained to developers.

7. Summary

The case company is an EV charging services provider that connects more than 8000 charging stations globally. The company is focused on increasing performance of their charging network and improving the quality of their services. This Master's thesis was commissioned by Services and Operations team in order to identify a set of KPIs that can be visualized and further used specifically for monitoring EV charging points reliability. First, the theoretical part of the study was conducted and then followed by the practical part of the study. The literature review of EV charging and performance measurement was introduced and followed with available frameworks for KPIs determination. Such methods as practical observation and interviews with company's employees were used to learn about the company and the industry of its operation. Then the data analysis part started and the created approach for KPIs identification was introduced and described. The big part of the project required working with company's database and with the tool used for charging points monitoring.

The final results of the research include the KPIs that can be used for monitoring of EV charging points reliability. In the beginning of the project the available recourses were limited to company's database and documentation. Furthermore, there is a lack of information concerning the methods for creating EV charging points reliability KPIs. Thus, the method had to be created from scratch based on EV charging company specifications.

The approach proposed in this thesis consists of 7 steps that aim to determine KPIs for monitoring of EV charging points reliability. These steps can be also used as a guideline for other EV charging companies that plan to track the reliability of their stations by applying KPIs. The created approach combined the evaluation of current and future state of charging points, data analysis, S.M.A.R.T. method and KPIs validation.

This study is focused on providing a practical contribution to the case company by defining EV charging problems and goals, executing data analysis and discovering data errors, creating KPIs for EV charging points reliability tracking, validating and visualizing them. The presented approach can be also applied in other EV charging companies. KPIs dashboard does not present all the identified KPIs due to the reason that not all the data is

available for visualization. The recommendations for further improvement of dashboard, Admin Panel, and other issues related to charging points reliability were proposed in the end of the study. The improvement proposals that are described in Chapter 4.3 will be executed in the following months.

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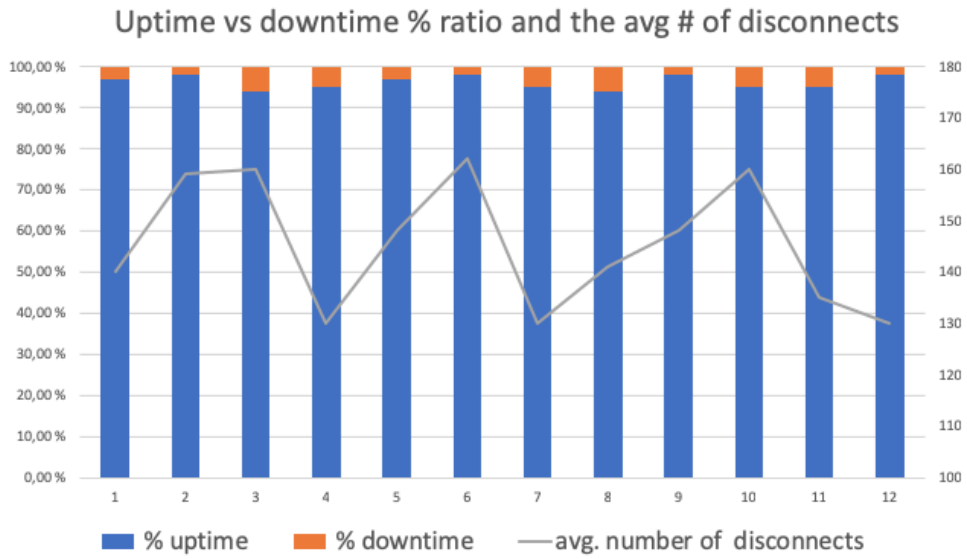
Appendix 1. Failure rate calculation model created in MC Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													0
2					STATUS	TIMESTAMP	station_ID		TIMESTAMP	timeslot length	Is faulty during the timeslot? (1=YES):	1	
3		number of 15-min slots when fault was reported								0.15.00	Timeslots (starting time of each):	01/12/2018 0.00	01/12/2018 0.15
4		106			Faulted	01/12/2018 0.00.15	3039		01/12/2018 0.00	0.00.15		1	0
5					Faulted	01/12/2018 0.02.34	3039		01/12/2018 0.00	0.02.34		1	0
6		number of 15-min slots in december 2018			Faulted	01/12/2018 0.02.42	3039		01/12/2018 0.00	0.02.42		1	0
7		2976			Faulted	01/12/2018 0.02.52	3039		01/12/2018 0.00	0.02.52		1	0
8					Faulted	01/12/2018 0.02.54	3039		01/12/2018 0.00	0.02.54		1	0
9		Failure rate:	3,56 %		Faulted	01/12/2018 0.02.58	3039		01/12/2018 0.00	0.02.58		1	0
10		Reliability rate:	96,44 %		Faulted	01/12/2018 0.03.30	3039		01/12/2018 0.00	0.03.30		1	0
11					Faulted	01/12/2018 0.03.50	3039		01/12/2018 0.00	0.03.50		1	0
12					Faulted	01/12/2018 0.03.52	3039		01/12/2018 0.00	0.03.52		1	0
13					Faulted	01/12/2018 0.04.00	3039		01/12/2018 0.00	0.04.00		1	0
14					Faulted	01/12/2018 0.04.02	3039		01/12/2018 0.00	0.04.02		1	0
15					Faulted	01/12/2018 0.05.57	3039		01/12/2018 0.00	0.05.57		1	0
16					Faulted	01/12/2018 0.06.15	3039		01/12/2018 0.00	0.06.15		1	0
17					Faulted	01/12/2018 0.06.20	3039		01/12/2018 0.00	0.06.20		1	0
18					Faulted	01/12/2018 0.06.40	3039		01/12/2018 0.00	0.06.40		1	0
19					Faulted	01/12/2018 0.06.45	3039		01/12/2018 0.00	0.06.45		1	0
20					Faulted	01/12/2018 0.06.47	3039		01/12/2018 0.00	0.06.47		1	0
21					Faulted	01/12/2018 0.06.51	3039		01/12/2018 0.00	0.06.51		1	0
22					Faulted	01/12/2018 0.06.53	3039		01/12/2018 0.00	0.06.53		1	0
23					Faulted	01/12/2018 0.06.57	3039		01/12/2018 0.00	0.06.57		1	0
24					Faulted	01/12/2018 0.06.59	3039		01/12/2018 0.00	0.06.59		1	0
25					Faulted	01/12/2018 0.07.04	3039		01/12/2018 0.00	0.07.04		1	0
26					Faulted	01/12/2018 0.07.22	3039		01/12/2018 0.00	0.07.22		1	0
27					Faulted	01/12/2018 0.07.27	3039		01/12/2018 0.00	0.07.27		1	0
28					Faulted	01/12/2018 0.07.29	3039		01/12/2018 0.00	0.07.29		1	0
29					Faulted	01/12/2018 0.14.20	3039		01/12/2018 0.00	0.14.20		1	0
30					Faulted	01/12/2018 0.14.28	3039		01/12/2018 0.00	0.14.28		1	0
31					Faulted	01/12/2018 0.32.40	3039		01/12/2018 0.00	0.32.40		0	0
32					Faulted	01/12/2018 0.32.42	3039		01/12/2018 0.00	0.32.42		0	0
33					Faulted	01/12/2018 0.32.45	3039		01/12/2018 0.00	0.32.45		0	0
34					Faulted	01/12/2018 0.32.56	3039		01/12/2018 0.00	0.32.56		0	0
35					Faulted	01/12/2018 0.33.02	3039		01/12/2018 0.00	0.33.02		0	0
36					Faulted	01/12/2018 0.33.04	3039		01/12/2018 0.00	0.33.04		0	0
					Faulted	01/12/2018 0.33.08	3039		01/12/2018 0.00	0.33.08		0	

Appendix 2. The uptime/downtime percentage ratio of a total network for months from 1 to 12



Appendix 3. Reliability report created in MC Excel

Station ID	# Sessions	# Errors	% downtime	Wh charged	€
1026	19	7	0 %	156880	1,23 €
1027	20	15	0 %	143730	1,24 €
1036	4	9	0 %	41430	0,29 €
1037	57	6	0 %	226720	2,10 €
1054	49	12	2 %	129470	3,07 €
1058	79	9	0 %	568120	12,88 €
1059	117	0	0 %	734480	20,41 €
1064	29	57	0 %	124010	29,27 €
1065	41	6	0 %	336640	13,63 €
1068	79	0	0 %	740590	17,65 €
1069	54	0	0 %	491560	15,31 €
1078	54	16	0 %	491560	15,31 €
1081	19	9	0 %	141880	2,43 €
1092	5	8	2 %	18290	0,20 €