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Smart Cities

Smart Lighting based on Open Transport Data

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Vienna, 23rd November, 2016

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Abstract

Many modern cities around the world are applying ICT to address urbanization. Since a few years, bigger metropolitan areas especially use the concepts of so called Smart Cities to lower the impacts of progressing urbanization. Typically, impacts like overcrowding, high energy consumption, improper resource management, environmental pollution, traffic and technological challenges give cities enormous potential for improvement. Therefore, researchers and many companies are working on sample implementations of Smart Cities. Nevertheless, there are many unclear subtleties of Smart Cities. There is no real definition of the topic Smart City and there is a significant but quite undiscussed overlapping between Smart Cities and Open Data strategies. This thesis should cover both topics. The first theoretical part of this thesis will discuss the relevance and common definitions of Smart Cities while the second part will introduce Open Data and Open Transport Data. The last theoretical part will then give a lookout over different implementations of Smart Cities and Open Data to furthermore compare existing Smart City and Open Data initiatives.

To present the found similarities and potentials of both topics, the concepts and ideas that were made during the theoretical part will then be applied in form of a Smart City lighting project. The project will use the Open Transport Data interface of Vienna's public transportation agency to dim public street lights near unoperated stations. Due to the parallel existence of multiple file specifications for transport data, this thesis provides a reduced sample implementation for Vienna and will rather focus on the discussion of technical prerequisites to make portability and potential usage of the implementation in other cities more straightforward. For that purpose, this thesis also covers a GTFS converter for the interface of the public transport agency of Vienna. Further, the architecture of the street light itself will be discussed in favour of further extendibility and overall modularity. After all, the proof of concept shows that Open Data can enrich Smart Cities initiatives in new ways and further might serve as a rudimentary but modular base for other Smart City lighting projects around the world.

Contents

CHAPTER 1

Introduction

1.1 Motivation

Today, we share planet earth with about 7,35 billion other people [1]. The WHO expects this number to double by 2050. By 2050, 7 out of 10 people will live in a city which makes Smart Cities a term and research field which gains more and more attention. Existing city structures will need some reengineering to get more efficient and easier to use for their citizens.

Overcrowding, high energy consumption, improper resource management, environmental pollution, traffic and technological changes are typical problems that occur in urbanized areas [2]. There are many research efforts that try to find solutions for problems of urbanization. Some so called Smart Cities are already solving some issues in urbanized areas. Unfortunately, there is no general definition of a Smart City. Further, there are many projects that tend to implement Smart City strategies, mostly for demonstration purposes. Many projects use or provide Open Data that could be used for new cases of application or to pursue typical Smart City goals.

1.2 Problem statement & Aim of this thesis

There are many different definitions about Smart Cities. This work gives an overview over the relevance and the goals of Smart Cities to then compare different existing definitions and to find a broad-covering working terminology that fits best.

Furthermore, many countries and cities around the world started Open Data initiatives. That's why one aim of this thesis is to investigate on definitions about Open Data and also on Open Transport Data. Many Smart City strategies are linked to Open Data and a context between both topics should be discussed for clearance.

The discussion will find as a side result that many cities are providing Open Transport Data via standardized file formats while some do not. Smart Cities are a global movement but concrete implementations are often not usable in more than one city. Therefore, the method of using international standards for Open Transport Data, in favour of more portable implementations, will be examined.

To show that an implementation can also be used to reach a common Smart City goal like energy reduction, Vienna, Austria will be used as a sample city. In 2013, Vienna has started a project that focusses on the conversion of classic street lights to modern LED based devices. Due to the high energy reduction and the high operating efficiency that was met there, further details on how even better energy usage can be achieved via standardized Open Transport Data should be aimed in this thesis. Unfortunately, the public transportation agency of Vienna is currently not providing Open Transport Data in a standardized way. As a consequence, the aim of this thesis also includes a discussion about the feasibility of a file conversion to an international standard. A proof of concept that shows how the converted information can then be used to reduce energy consumption of the street lights should be the base for the further discussion. For that purpose, the aim of this thesis is also to focus on the design and concepts of the implemented smart street lights that are required for energy effectiveness and portability.

1.3 Structure of the work

This thesis discusses the relevance of so called Smart Cites and introduces different approaches for a uniform definition in chapter 2. It turns out that there is no common fit but the idea of Smart Cities is defined in form of a working definition in section 2.1.3. To discuss the overlapping of Smart City strategies and many Open Data initiatives, a brief overview of important Open Data terms is given in section 2.2.

Both, Smart Cities and Open Data are global movements and there are many active projects. To discuss similarities between both movements, chapter 3 presents relevant projects around the world to furthermore find a connection between Smart Cities and Open Data in section 3.2.

Chapter 4 then describes an implementation of the presented ideas. To meet major requirements like modularity and portability, the project uses GTFS for exchanging traffic schedules. After describing design decisions that are important for energy effectiveness in section 4.2, the thesis also analyzes problems and limitations of the conversion and implementation and describes how they were voided in section 4.3.

In the end, the thesis gets summarized in chapter 5. Furthermore, chapter 5 will note ideas of next steps, open questions and lessons learned from the topics.

CHAPTER 2

State of the Art

2.1 Smart Cities

This chapter will first introduce the topic Smart Cities, to then justify the relevance of research on this topic. Later on, Smart Cities will be defined more clearly and precisely. Due to the existence of many different definitions, some important ones will be compared and summarized in a proper working definition.

2.1.1 Overview

According to a study of the EU, there are multiple definitions of a Smart City but it's uncertain what a city exactly needs to do to be characterized and called as a Smart City [3]. There is no clear, common definition. One major goal of the study was to find a working definition of a Smart City.

While finding the working definition, the study indicates that every city is unique. Due to the current characteristics paired with historical and prospectively planned development paths, many cities call themselves a Smart City, or are labelled as such by others in enormously varying ways [3].

Further, many characteristics of those so called Smart Cities overlap with the concepts of "*'Intelligent Cities', 'Knowledge Cities', 'Sustainable Cities, 'Talented Cities', 'Wired Cities', 'Digital Cities', 'Eco Cities'*" [3].

Against this background, there are many similar research fields for those concepts. To get an idea for the relevance of Smart Cities, the possible definitions for Smart Cities are presented after a brief overview and discussion of the relevance in the following section.

2.1.2 Relevance

Overall, Smart Cities are relevant for different reasons. The five most important reasons why cities and researchers should get used to concepts of the Smart City are:

Urbanization

First, the increasing population of cities requires new concepts and ideas. This comes along with a lot of challenges for the citizens, the climate and the city's authorities. Smart Cities tend to solve problems that correspond to urbanization.

Research about urbanized areas is currently less focusing on metropolitan areas, than on broader regional urbanized areas. Edward W. Soja spotted, that especially regional urbanized areas have a bigger imbalance in jobs, housing and transit [4]. He describes that regional urbanization in those areas can be seen as division of metropolitan areas into multiple different and separated parts of suburban worlds or ways of life. He writes that today the mass transit facilities often do not match the distance between jobs and areas with affordable housing and living. Furthermore he notes that today's urbanization not only concerns metropolitan areas but that regional urbanization emerged far enough to be observed, too. Typical problems of urbanization outside of the metropolitan areas are diverse and complex.

Urbanization in metropolitan areas was complex now and then. Washburn and Sindhu name some problems like shortages on resources, shortages on energy, outdated infrastructure, health of the citizens, demand in economic and social fairness and global environmental "weirding" [5]. They note that rapid urbanization is not only creating challenges but also opportunities because many Smart City approaches combine economic opportunities and social benefits while lowering the problems of urbanization [5].

Using Smart Cities as an approach against urbanization justifies and even requires further research and sponsorship of Smart City projects.

Already Existing Approaches

Second, as the study of the EU reveals [3], there are already a lot of cities that can be classified as a Smart City. 240 of all 468 EU-28 cities with at least 100.000 inhabitants fulfil at least one Smart City characteristic and could therefore be classified as a Smart City. As Section 3.1 will present later on, there are also many ongoing projects outside of the EU.

Internet of Things

Third, A. Zanella et al. [6] show that there is also a relevance of Smart Cities in the context of the Internet of Things (IoT). IoT focuses on the interconnection of many small devices and sensors. IoT is heavily used in today's news and currently gains lot of attention from many companies and researchers. Smart Cities often use technologies

Table 2.1: Overview of the characteristics and impacts of generic Smart City solutions [3]

Solution Category	Smart City Solution	Where implemented	Impacts
Transport and Mobility	Smart cycling plans	Copenhagen, Paris, London	CO2 emission reduction, healthy living
	Integrated multi-modal transport	Copenhagen, London, Helsinki, Glasgow, Hamburg, ...	CO2 emission reduction through congestion reduction, increased public transport, competitiveness
	Smart Traffic flow system	Barcelona, Eindhoven	CO2 emission reduction by reducing travel and transit times, enhanced traffic flow
Building Technologies	Smart building technology and management	Amsterdam Helsinki, Bremen	CO2 emission reduction, awareness
	Smart City lighting	Barcelona, Milan	CO2 emission reduction, safety
Smart Governance	Smart open services platforms	Barcelona, Helsinki, Copenhagen, Malmo, Amsterdam, ...	CO2 emission reduction, knock-on effects for environment, jobs and economic growth
	Single access points for government services	Barcelona, Manchester	CO2 emission reduction, reduced travel to municipal offices
	Local integrated sustainability initiatives	Amsterdam, Barcelona, Cologne	CO2 emission reduction, loss energy consumption, better inclusion

from the IoT or implement examples for new approaches in the field of IoT. Section 3.1.1 shows a Cisco project that uses multiple IoT sources in the Smart City Songdo.

Europe 2020

Fourth, a big influence on the rise of Smart Cities was given in 2010, when Jose Manuel Barroso wrote that "*2010 must mark a new beginning. I want Europe to emerge stronger from the economic and financial crisis*" [7]. He used those words in the preface of the strategic publication for Europe 2020. Europe 2020 is the EU's growth strategy for the current decade. They want the EU to become a smart, sustainable and inclusive economy. This should help to reach high levels in employment, productivity and social cohesion [7].

The study of the EU exposes, that the metrics of Smart Cities and the goals of Europe 2020 are quite similar and reveals that the aim of Europe 2020 gets delivered by many Smart City initiatives [3]. The study shows, that not all Smart City initiatives and solutions are contributing to Europe 2020's targets. Smart City initiatives offer more than just economic benefits. The study also covers Smart City topics about traffic or for example social inclusion but it finally came clear that there is a general agreement that Smart Cities primary contribute to the achievement of Europe 2020's energy objectives.

To emphasise the impacts of common Smart City strategies on the goals of Europe 2020 (to build a "*smart, sustainable and inclusive economy*" [7]), the study listed some areas that can easily be implemented in most Smart Cities while impacting Europe 2020's goals. Table 2.1 gives an overview over those generic fields.

Relevance of Smart City topics are obvious for cities inside of the EU because they need to use those as an aid to reach Europe 2020's goals.

Investors

Fifth, investors may be able to maximize their investments by supporting Smart Cities. Washburn and Sindhu give Smart Computing an important role in their definition of Smart Cities 2.1.3. They claim Smart Computing to be the next major cycle of technology

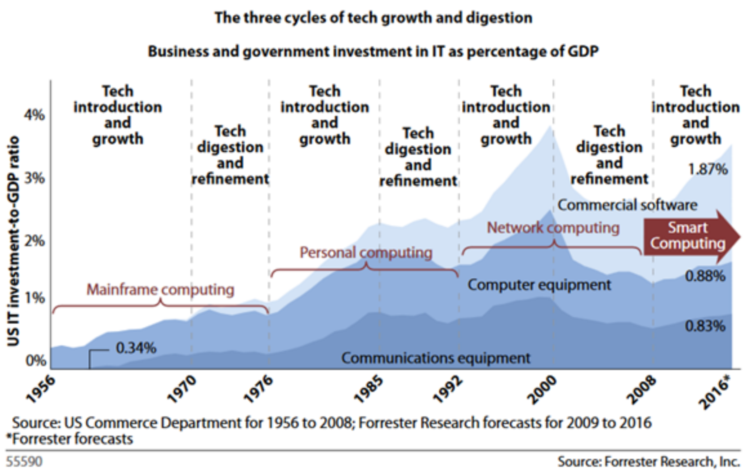

Figure 2.1: The Major Technology Adoption And Digestion Cycles Since The 1950s [5]

adoption and say that this cycle may last for the next seven years with high investment rates [5]. Figure 2.1 depicts this situation in comparison to other major technology and adoption cycles in the USA since 1950.

2.1.3 Definition

The study of the EU states, that most of the Smart City initiatives are still in the early phases of development [3]. That's why the next sub-section provides an analysis of different definitions. Most of them were defined in parallel because of many recent and independent Smart City initiatives. At the end of the following section a working definition of a Smart City will be given.

As outlined above, there are many topics which correlate with the term Smart City. The study of the EU emphasizes that a useful working definition of a Smart City needs to incorporate these mostly diverse definitions and requirements [3].

Due to the existence of many different definitions for a Smart City, it is not easy to find a common fitting approach. To get a common idea about Smart Cities and to form a good working definition it's important to compare different more or less common definitions that focus on different domains:

Focus on Six Key Fields

The "European Smart City Model", a research project of the Technical University of Vienna, defines a Smart City as "*a city well performing in 6 key fields of urban development, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens*" [2]. They associate each of the six key fields with some exemplary areas of application. Some will be listed below and will further be associated with some challenges of urbanization:

- Smart Economy faces the "*labor market, entrepreneurship, innovative spirit and international integration*" [2]. This field clearly correlates with the imbalance of the job markets and the required innovation that emerged by urbanization and higher population.

- Smart Mobility faces the "*local transport systems, sustainability of the transport systems, international accessibility, and ICT-infrastructure*" [2]. In relation to urbanization, this field is mainly connected to problems about traffic and transportation. Further, Smart Mobility also deals with "*environmental pollution and resource management*" which was also outlined as a significant problem of urbanization above.

- Smart Environment wraps topics about "*air pollution, ecological awareness and sustainable resource management*" [2]. Those fields of research are of high interest for planners of urbanized areas because they have a big impact in the citizens' quality of life and are important goals in different climate agreements. (e.g.: Paris Agreement - COP21) [8]

- Smart People faces the "*intellectual potential of a city's citizens*" [2]. As mentioned earlier in section 2.1.2, urbanized areas often have problems with transportation and a supply-demand gap between residential and business areas. Education faces the same problems but is urgent for further innovative power in the urban area. Lifelong learning and open-mindedness of the citizens is also an important factor for successful Smart Cities.

- Smart Living faces "*cultural and leisure facilities, health conditions, individual security, housing quality, education, touristic attractiveness, and social cohesion*" [2]. Many of these topics are harder to accomplish in more urbanized areas but can potentially be solved with new ICT-based solutions.

- Smart Governance faces "*political awareness, public and social services, and efficient and transparent administration*" [2] which gets more important for the successful handling of the same political processes in the bigger scale of increasing population.

Focus on Sustainability

One of the more broader definition approaches does not prioritise ICT-based connected services or networks: Schaffers et al. define a Smart City as a city that is gaining sustainable economic growth, a high quality of life, a wise management of natural resources and participatory governance by investments in human resources, social capital, and communication infrastructure [9]. This definition can be associated with a lot of cities, because it's very generic. Many definitions below give technology a more important role.

Focus on Smart Computing

Washburn and Sindhu define a Smart City as a city that uses Smart Computing to make its whole infrastructure more intelligent, interconnected, and efficient. They note that this includes city administration, education, healthcare, public safety, real estate, transportation, and utilities [5]. They further note, that for them Smart Computing means a whole new generation of integrated hardware, software, and network technologies including new IT systems with realtime interfaces and advanced analytic capabilities. As mentioned in section 2.1.2 Smart Computing could trigger a new technology cycle.

Focus on Systems of Systems

Another quite similar definition comes from the MIT. They have the vision that cities are systems of systems. According to them, those should use opportunities to introduce digital nervous systems and optimization at every level of system integration - from individual devices to whole regions [10].

Focus on ICT

The Smart City definitions above, obviously give ICT a quite important role. Due to fast growing cities, ICT is the only way to master many administrative tasks. The above mentioned study of the EU shows that the extension of existing city structures with the help of ICT generally enables a Smart City to accomplish multiple new things [3]:

- The collection of data could be more easy and costs for analysis or sharing can be reduced.
- Data analysis and (realtime) insights may bring new perceptions for authorities and citizens.
- More efficient processes and relationships between government, private sector companies, NGOs, communities and citizens could be made.
- Innovation could be supported.

The study further explains that ICT is the main factor to make Smart Cities possible. But they note that it's not enough to just deploy sensors, networks and analytic services. It could be insufficient to deploy the same systems over different cities because problems can be different from city to city. Before a city starts with the usage of ICT, the real problems of that specific city should be identified. The study recommends to compare those identified problems with other city's strategies to learn from each other [3].

Working Definition

After consideration of multiple common definitions and known assumptions of Smart Cities, the study of the EU advises a working definition for Smart Cities: A Smart City is "*a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership*" [3]. This means that challenges of a city that are addressed through ICT in a smart way for a specific reason are called smart. They also mention that a city can only be called smart if it solves those problems via ICT and includes at least one of the six key fields of the European Smart City Project, as listed on page 7 of this thesis [3].

2.2 Open Data and Open Transport Data

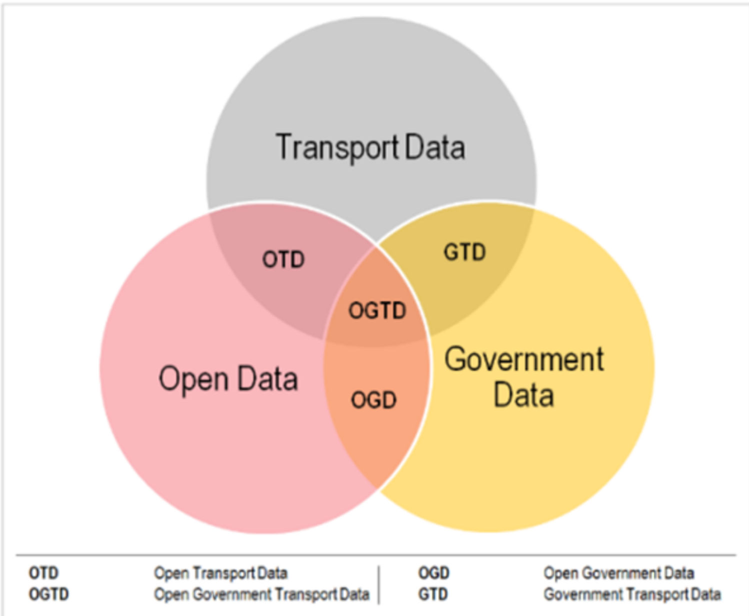

Figure 2.2: The Overlapping Of Different Types Of Open Data [11]

As already mentioned above, many Smart City projects use Open Data. A study of Deloite, about the value of public sector information in the United Kingdom, found that the direct approximate economic value of opening public sector information in the

UK was 1.8 billion pounds [12]. In concrete, they found a link between the disposal of public sector information and economic growth. A paper of a platform called Intelligent Transport Systems Austria (ITS) mentions that Open Transport Data and the process of opening data sources freely and with minimal restrictions recently gets discussed heavily, as well on Austrian as on European level [11].

In fact Open Data strategies provide multiple different data topics. Figure 2.2 shows a conjunction between three main topics: Open Data, Government Data and Transport Data. These categories result in intersections like Open Transport Data, Open Government Data or Open Government Transport Data. The following sections will give insights on those.

2.2.1 Definition of Open Data

Openness in the terms of Open Data can be summed up as "*Open means anyone can freely access, use, modify, and share for any purpose (subject, at most, to requirements that preserve provenance and openness)*" [13].

Open data may be used in multiple cities and could be the basis for further use cases. Today, most cities like for example Vienna, Paris or Amsterdam are opening public sector information to the web community. Open Data brings benefits for the whole society but Open Data does also come along with server costs and conversion problems: Most of the public sector authorities already have their own IT-infrastructure and generate digital information for their own use in their own software systems. It's not enough to just give citizens access to these sources, because the specific data structures and proprietary data may not always be usable for a bigger user group. Open standards are a good base for successful Open Data initiatives [14].

2.2.2 Definition of Open Government Data

Government Data includes all data items of the public sector, the state and the public administration authorities [15]. Governmental systems and data sets are not public by default. In 2011 the European Commission Vice President Neelie Kroes said that taxpayers do indirectly pay for the access to government data. He advises to give back the information to the people but further adds that this should at least happen for those taxpayers who want to use the information in new ways, to create jobs and economic growth [16].

The mentioned study of Deloite found that "*opening data sources of the public sector gives citizens and companies a solid base to build new products and innovations*" [12].

To push the availability of governmental data, the EU created a directive for Public Sector Information (PSI) which came into force on 17 July 2013 [17]. Member States had to implement the directive until July, 2015. The directive only focuses on economic aspects of reusable public information and not on concrete accessibility by the citizens. It encourages member states to make information that is held at any level in the public sector, or in organizations that were funded by or under control of public authorities, publicly available. It also handles conditions for the re-use. Available information should not be restricted and should be usable for everyone. The directive also prescribes that the information should be available as cheap as possible and that no authority should earn profits. If the data providing authorities have higher supply cost, they should limit the charges to the marginal costs of the individual request (reproduction, provision and dissemination costs) [17].

2.2.3 Definition of Open Transport Data

Transport Data includes all data sources of transport systems. A paper of Intelligent Transport Systems Austria (ITS) mentions that both public and private transport fits as Transport Data [11]. Transport Data does not only include information of the interactive parts of a transportation system. It also includes statistics and infrastructure details like time schedules, maps and stations.

In practice, the main focus of Open Transport Data often lies on data that gets published by public transportation authorities. By that, users are interested in the stop times and realtime-updates of buses, subways, trains, etc. Other kinds of Open Transport Data can also include individual transportation participants of a city. Singapore, as an example, is providing realtime insights about taxi availability over the whole city. Figure 2.3 shows a realtime map of free taxis over the city.

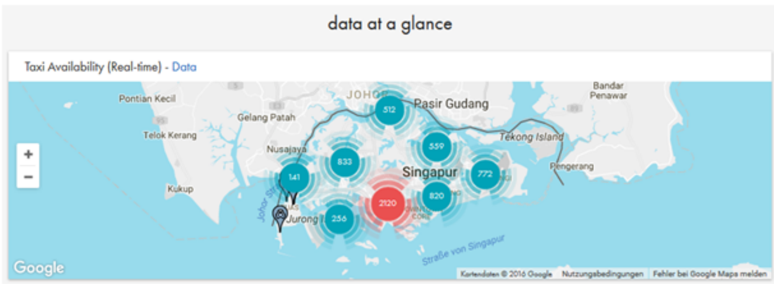

Figure 2.3: Available Taxis in Singapore, based on Open Transport Data [18]

Many European cities, even smaller ones like Linz or Freiburg im Breisgau are providing open access to Open Transport Data. As already mentioned in section 2.2.2, the EU created a directive regarding PSI which should support Open Government initiatives [17]. Open Transport Data is often applicable for the PSI directive and many European cities are providing Open Transport Data because of the PSI directive. But according to ITS Vienna, Transport Data should not always be considered as PSI because some member states of the EU are not running their own public transport companies in favour of private or semi-private companies [11]. ITS Vienna further notes that data which is not considered as PSI should also not be handled by the directive. If Open Transport Data is generated by a public sector body, it will automatically belong to the PSI directive for sure. But ITS Vienna further notes, that a private company that is fulfilling the task of public transportation in place of the country should also belong to PSI directive. And that's the case for many cities.

2.2.4 Overview on Open Transport Data Standards

Open Transport Data for public transportation agencies is provided through different file formats. Some just include static scheduling information while others are intended for realtime updates. There are two major combinations of international standards that cover static and realtime services: GTFS/GTFS-Realtime and NeTEx/Siri.

GTFS/GTFS-Realtime According to Sean J. Barbeau the General Transit Feed Specification, short GTFS, became the most popular data format to describe fixed and static transit services [19]. GTFS is a de-facto standard. It was first specified by Google as Google Transit Feed Specification and was used in Google Maps first in 2005. Because of the successful integration of the first public transport agency (TriMet from Portland, Oregon) Google offered their trip planner for free to all other agencies that wanted to provide schedules to Google Maps. Sean J. Barbeau further mentions that most agencies provided GTFS feeds primary to benefit from Google's free trip planner, but soon many other developers, that were not affiliated with Google, started to use the format [19]. Google decided to change one part of the specifications name from Google to General in 2010. Barbeau notes that nowadays GTFS is used for "*many different purposes, including trip planning, ridesharing, timetable creation, mobile data, visualization, accessibility, analysis tools for planning, realtime information and interactive voice response (IVR) systems*" [19]. He presents that in 2010, 49 of the top 50 largest transit agencies in the US have openly shared their GTFS data [19], which of course fits well into Open Data strategies in many cities: As mentioned in section 3.1.2 this promotes innovation in a good manner.

In 2011 GTFS first was extended with GTFS-Realtime. It's used to update the fixed schedules that were defined by GTFS with realtime-updates technically based on protocol buffers.

NeTEx/SIRI Another standard that may get more attention in the future is NeTEx by the European Committee for Standardization (CEN). NeTEx is a CEN Technical Standard for exchanging public transport data via XML. A W3C XML schema provides a formal technical description while there is also a data model available. It is possible to use the schema to exchange information about stops, routes, timetables, operational notes, schedule exceptions like holidays, composite journeys, operator-details, additional information about e.g.: duty crews and layover, accessibility information, metadata for handling updates in a distributed network, and as the CEN webpage about NeTEx notes: "*whilst there are a number of existing standards available for Timetables, NeTEx is the first systematically engineered standard that also covers multimodal fares*" [20]. NeTEx documents are common files that can be shared by a variety of existing protocols like FTP, HTTP and so on. "*NeTEx files can on one hand be used for the bulk exchange of big* *data sets like all the timetables for an operator and on the other hand there is a specified SIRI (Service Interface for Realtime Information / a CEN technical specification) based NeTEx protocol that can be used for smaller services*" [20]. The SIRI based service can handle requests and response messages and can also publish/subscribe messages for push distribution of NeTEx files. The CEN webpage about NeTEx further notes that there is a NeTEx-WSDL binding that can be used to implement services easily.

One country that is currently working on an implementation of NeTEx is Norway. The country wants to build a national standard for the whole public transport to replace the national RegTopp-format. As the CEN webpage about NeTEx further notes, Norway wants to make the whole collected database open to the public, both the raw data and an API and further wants to build a front-end for nationwide journey planning [20].

2.2.5 Distribution of Open Transport Data

To give an overview of file specifications in cities over the world, data of some main public transport operators of the 5 best smart cities of the world of 2016 [21] was taken and compared to each other in Table 2.2.

Table 2.2: File Formats in Top 5 Smart Cities 2016

City Transport Agency	Static Format	Real Time Format	Source
Singapore	XML	XML	[22]
Barcelona TMB	GTFS	Proprietary SOA	[23]
London TFL	XML, JSON	JSON	[24]
San Francisco SFMTA	GTFS	XML	[25] [26]
Oslo Ruter	GTFS	SIRI	[27]

First, all of the 5 top Smart Cities do provide Open Transport Data. But yet, not all use the same file specifications. GTFS is currently the most supported format for static transport schedules. For realtime updates there is no clearly leading format.

To get a feeling for the worldwide distribution of GTFS data, there is a project called Travic. Travic is powered by geOps and the University of Freiburg, Germany, and uses static GTFS files to interpolate the position of vehicles between stations. Figure 2.4 shows how the tool uses GTFS sources for many cities and countries.

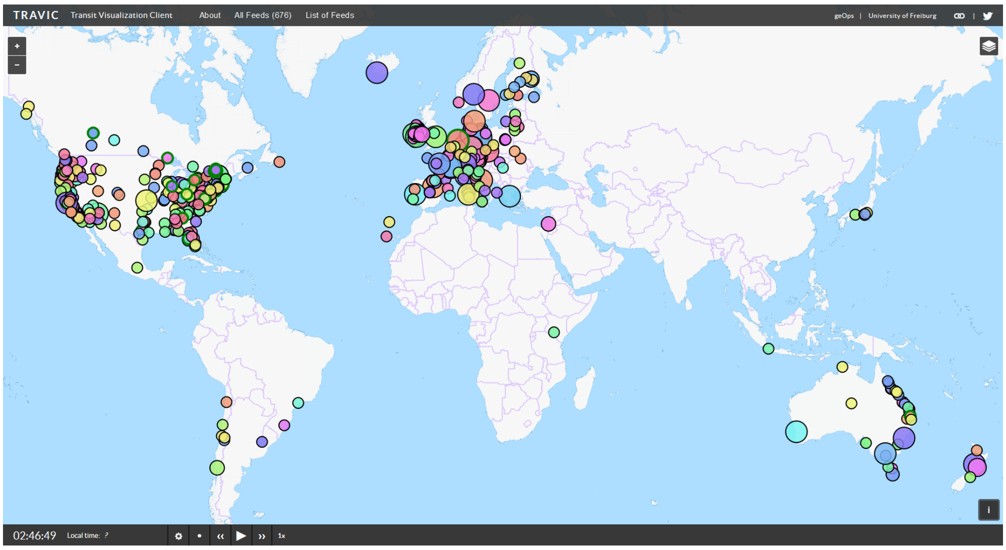

Figure 2.4: Areas that support to show moving vehicles based on GTFS data (here the vehicles are grouped due to the zoom level) [28]

CHAPTER 3

Nexus of Smart Cites and Open Data

This chapter analyzes existing Smart City and existing Open Data approaches. Afterwards, a comparison between both topics is given.

3.1 Related Work

3.1.1 Analysis of existing Smart City approaches

The study of the EU [3] depicts that there are many projects around the world that implement Smart City strategies. Washburn and Sindhu mention some real world example cities and infer that there are two types of Smart Cities: Those who already have existing IT-systems that now have to be rebuilt and newer cities that have the luxury of incorporating with Smart City visions from the beginning. They write that newer cities have the opportunity to deploy various information and communication technology components [5].

The authors further present some examples of those newer cities which can be seen in figure 3.1. The distribution of the cities around the world clearly shows that Smart Cities are a form of a global movement.

Planned Smart Cities

The following examples show some planned Smart Cities that also pursue Open Data initiatives:

Songdo International Business District One example for a Smart City that was initially constructed from scratch is Songdo International Business District. It's a

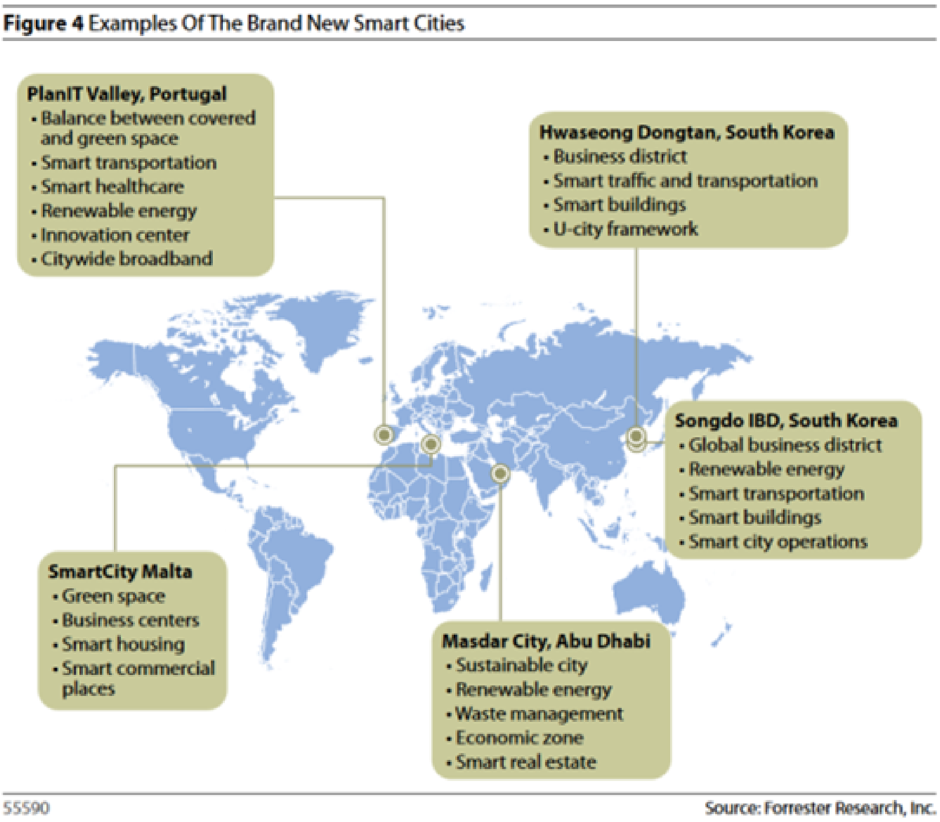

Figure 3.1: Examples Of The Brand New Smart Cities [5]

sustainable and smart project that is located in the bigger Metropolitan City Incheon which is near Seoul (56km). Further, Songdo is directly connected to Incheon airport via a 21km sea bridge from where one third of the world's population can be reached by plane in less than 3.5 hours. The planning of Songdo started in 2001 and was based on a basis of private-public partnerships. Since 2005 the planning was done and since 2009 the city is finally maturing because of the connection to the airport [29]. In cooperation with the main developer of the district, Gale International, many multinational technology companies, local service providers, and government organizations are partnering up in the last years [30]. One of those companies that joined the project is Cisco. In 2009 they started to build and alter Smart Homes to use Cisco's TelePresence videoconferencing system. It can be used to attend multiple activities like yoga classes or business meetings from the apartment. Cisco wants to deploy those systems over the whole city to enable a standardized platform for connected and Smart Homes. Anil Menon, president of the new business unit that will focus on "Smart and Connected Communities" at Cisco, describes that another vision is that: "*[They]'ll build the platform, then local entrepreneurs build the applications. A utility company could give cheaper rates to residents who agreed to let the company turn off their appliances during energy peaks; a car company could give* *drivers realtime traffic information and directions, automatically pay their tolls, and send emergency messages to the police and hospitals in the event of an accident*" [30]. He also mentions that Cisco will not be disappointed if some ideas will not work out well because Songdo is just a living lab of the 21st century for them and experiments in labs see both successes and failures [30]. The initiatives of Cisco in building a connected infrastructure is an important venture for many Open Data projects that could potentially be built on that base in the future.

PlanIt Valley Another Smart City that is built from scratch is called PlanIt Valley. It's located near Porto, and is with about 230.000 inhabitants the second largest city of Portugal. PlanIt Valley has already been partnering up with big companies like Cisco or Accenture. Furthermore Siemens was involved in the development of a new product that should combine data from various sensors of buildings, transport systems emergency services, environment and energy systems [31]. For the purpose of combining all these various input sources, a system called Urban Operating System (UOS), which collects this data from different subsystems, was created. UOS analyzes the sources in fraction of second and publishes the analysis to civic services to give them the strength of making better decisions. Beside the development of UOS, PlanIt Valley deployed many IoT-enabled sensors in the city. UOS acts similar to a normal PC operating system: it provides interfaces to abstract the software logic from the hardware. But UOS abstracts no direct hardware parts. It only abstracts the city's infrastructure systems by adding a layer over those IoT-sensors and other data sources. Besides the communication with various sources, UOS does also provide a control interface where integrated and aggregated data of own and external sources are shown. This control interface does also provide an API which enables 'apps' to interact with the platform [31].

Transforming into Smart Cities

According to Milind Naphade et al. existing, older cities often need to transform into Smart Cities [32]. The following cities used the concepts of the Smart City after facing problems with their existing city infrastructure. This can have many reasons like those listed in section 2.1.2. The following subsections will provide an overview on how some cities are changing:

Dubuque One of them is Dubuque, Iowa. After the resided wood-milling industry started to shut down more and more, Dubuque transformed into a hub for sustainable development and ICT-based optimizations for citizens and the city's governance. Milind Naphade et al. note that Dubuque is one of those cities that gives citizens an important role for a successful transformation into a Smart City, "*a vital aspect that is often ignored*" [32]. In partnership with IBM they created a dashboard that shows citizens information about their behaviour and impacts for the sustainability of the whole city. To achieve insights on water and electricity consumption, they deployed smart meters around the city. The city further provides citizens with a dashboard where they are able to see their actual water usage, their historic usage trends and comparisons of their data with other citizens [32].

Rio de Janeiro Another city that was willing to transform to a Smart City is Rio de Janeiro, Brazil. In every summer Rio is facing the consequences of intense rainfalls and experienced a particular heavy rain season in 2010. That's why they decided to implement advanced ICT capabilities to be able to manage situations like 2010 better. Rio has opened an operations centre that handles dynamic data from sensors, video surveillance and field personnel which allows multiple agencies to make coordinated and intelligent decisions. Milind Naphade et al. further mention that this system could also be extended to handle transport data of transportation systems, buildings or other systems like energy or water [32], quite similar as UOS does in PlanIt Valley.

Top Ranked Smart Cities

Background Boyd Cohen has done a Smart City ranking of the top 10 cities in the world [33].

In his ranking of 2014 the 3 best cities are from Europe, 4 out of the best 10 are so too. He published an excel sheet where he describes the criteria on which he is basing his rankings. Beside others he uses the already introduced six Smart City key fields to compare the cities. In more detail there are many indicators that influence his method. Some for example are: green area per 100.000m2, emissions, public transport trips, Open Data, education, crime rate or quality of life ratings [34]. Barcelona, Copenhagen and Helsinki lead the rating, followed by Singapore, Vancouver and Vienna. According to the study of the EU that was already introduced in section 2.1.2, "*Smart City initiatives can be considered a useful vehicle for cities to achieve their Europe 2020 targets*" [3]. The study further revealed that there is massive political attention of the European Commission that is not directly but collectively and independently involved in many Smart Cities [3]. Beside many initiatives, there is a project called European Innovation Partnership on Smart Cities and Communities (EIP-SCC) that brings cities, industry and citizens together to discuss and improve their common Smart City goals [35]. That's why European cities may have a significant advantage in the Smart City movement.

Barcelona Barcelona leads in the ranking of Boyd Cohen. Bakici, Almirall and Warham do also note that Barcelona becomes a leading Smart City among other cities by more and more improving its urban policies and reforms. Because of economic crisis and problems with the city layout and infrastructure back in 1980, city authorities already created a Smart City strategy in the 1990's [36]. Furthermore, the authors write that since then Barcelona is well known for their ambitious programmes of urban planning and regeneration. Bakicic, Almirall and Warham declare the main factor for success of Barcelona is the support and involvement of private and public organisations in their Smart City initiatives while as well cooperating with bigger knowledge institutions like Universities [36].

Barcelona recently started to provide Open Data to the citizens. They use a web-page to list all available sources As a city located in the EU, opening governmental data is covered by the PSI-directive of the EU that was already mentioned in section 2.2.2.

Amsterdam In February and March 2016 Amsterdam was part of IBM's Smarter Cities (R) challenge - "*the largest philanthropic initiative belonging to IBM, with contributions valued at more than $66 million to date*" [37]. IBM Smarter Cities (R) challenges already involved 132 cities around the world. According to the IBM Report about the challenge of Amsterdam, the city of Amsterdam houses about 800,000 people and is widely believed to be one of the most desirable European cities to live in. Anyhow, they discovered problems and solutions for rising problems. The report depicts that labor market shifts and changes in industry sectors are dangering the jobs opportunities of Amsterdams citizens. They predict that "*around 65% of children entering primary school today will work in job types that do not currently exist*" [37]. Key-findings of the challenge were, that the Amsterdam should create a culture of collaboration to improve future job opportunities in form of start-ups by giving Open Data a more important role. To do so, IBM recommends to establish Open Data and data driven tools for tracking and improving the start-up ecosystem.

Smart Cities in Austria

Many cities and countries provide some sort of governmental aid projects for Smart Cities. This section will focus on Austria. Since 2010 two funding initiatives are engaging in Smart City topics. The common goal of both is to improve quality of life and to strengthen economics. But each initiative focuses on another aspect of Smart Cities. The Smart City initiative of the Energy and Climate fund focuses on comprehensive top-level concepts, strategies and demonstrations about Smart Cities while the second initiative - by the BMVIT - focuses on sponsorship of concrete projects and technologies of technology actors and research establishments about Smart Cities [38].

Vienna Most of the cities that were presented in section 3.1.1 do all manage some special research fields to increase the quality of its citizens life. Vienna, the capital of Austria, is one city that will get more detailed attention in the further section. Vienna as the capital of Austria houses about 1,7 million inhabitants but is constantly growing [39]. In addition, Vienna has again been awarded as the world's top city in the quality of life index of Mercer in 2016 [40]. Vienna already got good results in "*housing, public transport and other infrastructure services (e.g. waste separation, spring water mains), education and universities as well as vast urban green spaces. All this contributes towards high quality of living*" [41]. Furthermore, Vienna is connected to international traffic and serves as a home for many international organizations. As shown in section 3.1.1, these factors get high weightings in Boyd Cohens Smart City rankings.

That's why Vienna - compared to other cities - already got a good base to reach typical Smart City goals and to get ranked high in the rankings. But the city's government does not rest on its success and also pursues a "*Smart City Framework Strategy*" that was first initiated in 2011 by the mayor of Vienna [41].

According to Homeier and Arzberger the speciality of Vienna's "*Smart City Framework Strategy*" is that they do not take technology as the key solution for problems of urbanization [42]. They take quality of life as the central point that should be improved. This of course needs the help and support of technical solutions but they note that those are no replacement for full consideration of social aspects, potentials and innovations. Based on this statement, the two initiatives of the Energy and Climate Fund and of the BMVIT invested in shaping first visions, goals and samples for the Smart City Vienna.

Until today, those initiatives resulted in multiple Smart City projects in Vienna. The city government is hosting a webpage that lists multiple currently running projects[1]. A selection of those follows next:

Seestadt Aspern One of the biggest projects that were listed on the website is Seestadt Aspern. With about 240 hectares it's one of the biggest urban development projects in Europe. The city government plans to build apartments for about 20.000 citizens. The whole district is intended to be multifunctional and to provide many working offices. Seestadt Aspern will give the citizens everything that modern work, business and private lifestyles should include. Vienna uses the project as a showcase to provide a test environment for combinations of intelligent ideas, concepts and technologies. Beside the good geographical location in terms of traffic, the project is placed in the middle of the growing economic region "CENTROPE" [43] [44]. Later on, this thesis will use a bus station at Seestadt Aspern as an example for the proof of concept in chapter 4.

LED-bulbs An older project is handling the update of street lights in public areas with LED-bulbs. LED-lights have a higher light output than conventional lights while having a better longevity and reduced energy consumption. The website notes that Vienna has already applied the updates in some areas. In one of Vienna's most famous local recreation areas, Donauinsel, the update was done in 2013. Conventional street lights used 89 watts each, while the new LED-lights only use 17,6 watts. The whole project reduced the yearly energy consumption by 370,000 kWh [45]. Further energy reduction may be possible by implementing our proof of concept which is presented in chapter 4.

Live App Another project listed on the web page is an app of the city government called "wien.at live-App". It provides mobile versions of conventional services like the governmental city maps or important phone numbers. The app does also provide push-notifications, that can be used for information about weather events, public traffic announcements, events or, new since September 2015, for invitations for urgent refugee aid. The app was downloaded about 40,000 times in September 2016 [46].

[1] `https://smartcity.wien.gv.at/site/projekte/`

AnachB "AnachB" is a project of the whole region around Vienna. It's a project that handles countrywide traffic routing including, traffic updates via multiple sensors, GPS-enabled cars, construction works and some others. Most information is based on the national project VAO which will be presented in section 3.1.2. Routing is based on CO2-emissions and travel times. The routing algorithm is not only looking for one mean of transport, it tries to combine different approaches as multi-modal transportation routes [47].

Salzburg Another Austrian city that is currently active in the field of Smart Cities is Salzburg [48]. The masterplan „Smart City Salzburg“ presents a vision for 2050. One primary goal is to be more energy efficient. They also want to involve people in their decisions and want to have a demand-oriented, intelligent transport system. One project that has already started is the rebuilding of a small district, "*Smart District Gnigl*" [49]. Around the area's of some educational institutions they are testing some concrete implementations. One of them is a Smart City lighting project that should save energy by dimming lights by clock or motion sensors. Those kind of projects are of interest for the prototype that will be discussed in chapter 4.

3.1.2 Analysis of existing Open Data initiatives

A nice and handy example about Open Data was recently published on the Open Data blog of Singapore, where the utilization of each gym in the city is shown on a visualization [50]. This gives citizens the opportunity to compare the occupancy with their needs. It clearly brings multiple economic advantages like an overall better mean occupancy over the whole city and probably a bigger cumulative output. Worldwide, there are many initiatives that provide Open Data. Especially countries and bigger cities started to provide a lot of Open Government Data. Many of them use similar ways to provide access to the Open Data files but some are also using their own approaches. This section will analyse the impacts and availability of Open Data via different platforms and then compares those with the current situation in Austria.

Open Data platforms

The common approach of many countries and bigger cities is to provide a web platform that lists all available sources of Open Data of the region. The graphical layout of most platforms do have some major similarities. Figure 3.2 shows the Open Data platform of Germany. Like many other data platforms the one in the figure lists categories for transport, environment, population and more. These categories do not only appear on the platform of Germany but can also be seen on platforms of many other cities and countries around the world too. Those will be characterized below. The similarities between the provided catalogues indicate that Open Government Data is a quite homogeneous global movement that currently gets established in similar ways.

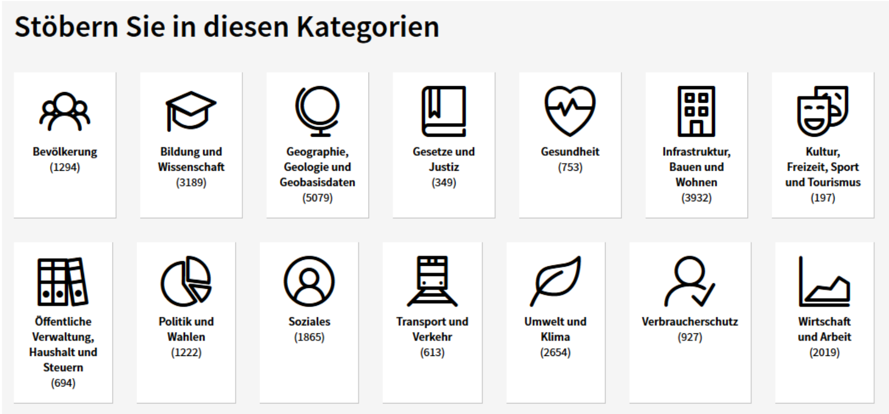

Figure 3.2: Different Topics of Germanys Open Government Data Webservice [51]

The platform of Germany[2] provides access to the datasets of its different provinces since 05.2014. On 28.09.2016 there were 16.164 data sets available. The platform gets advertised by writing that data will be the fuel of the 21. century and that opening data in the whole EU has an economic potential of about 40 billion Euro [51].

Another of these platforms is provided from the US government as the "*U.S. Government's Open Data platform*"[3]. By 28.09.2016 they provided access to over 186.847 datasets [52]. Similar to Germany they promote their initiative on a subpage of their platform: "*Open government data is important because the more accessible, discoverable, and usable data is, the more impact it can have. These impacts include, but are not limited to: cost savings, efficiency, fuel for business, improved civic services, informed policy, performance planning, research and scientific discoveries, transparency and accountability, and increased public participation in the democratic dialogue*" [52].

Switzerland joined the global movement in 2014 by creating a Open Government Data strategy and by launching a similar Open Data platform like Germany or the USA. Until today they published 1243 datasets via opendata.swiss[4] [53]. Their strategy uses Open Government Data not only to enable innovation and economic growth but further to create transparency and better participation in political activities of citizens, political parties and media groups. Switzerland further plans to boost efficiency in their own administration by using own Open Government Data to improve communication over the organizational and political borders of their own authorities. To reach these goals they are coordinating publication and accessibility of data by providing a free central infrastructure. As a longer-term goal they want to establish an open-data-culture by giving a continuous dialogue to spread the usage of Open Data across the country [53].

[2] http://www.govdata.de
[3] http://www.data.gov
[4] http://www.opendata.swiss

Open data in Austria

Austria does also provide access to a Open Government Data via their own web platform[5]. In July 2011 multiple larger cities of Austria, like Vienna, Linz and Salzburg, started to cooperate with Austria's federal chancellery to initiate a project called "*Cooperation Open Government Data Österreich*". The official website describes, that the goal is to get a better base for Open Government Data in the future by focusing on "*Communities, Science, Culture and Economics*" [54]. The website further notes that common standards should not only help all participating parties to work together efficiently, but should also encourage better cooperation in the D-A-CH area.

The available data categories are quite similar to those of figure 3.2, which show the categories of Germany. The big difference between Germany and Austria is the license of the provided files. Austria licenses most of the data sets by cc-by-at-3.0 while Germany uses the dl-de/by-2-0 and dl-de/zero-2-0 licenses. The mayor distinction between both is, that the German licenses are approved as conformant by an authority of Open Definition[6] [13] and Austrian licenses are not. The next two paragraphs will compare the licenses in detail.

cc-by-at-3.0 The cc-by-at-3.0 license allows to use the licensed object for any purposes, even for commercial ones. It allows to edit, remix and build upon the sources. It is also allowed to share the source in any format and with any medium as often as wanted.

Anyway, the cc-by-at-3.0 license also has a big restriction: At any place where the data is used in any kind (even in remixed cases) the name of the initial author must be clearly visible and therefore a valid link to the license text should always be included. This brings significant restrictions on design and usage of directly used or adapted versions of the data source. Another restriction is that the license is based on Austrian law which makes the usage for international companies more difficult.

dl-de/by-2-0 and dl-de/zero-2-0 The German licenses exist in two versions which can both be commercially used, edited or republished for any purposes. The zero version does not bring any further restrictions while the attribution version dl-de/by-2-0 is more similar to the Austrian license. Users must always link the license text and the authors name. Furthermore any changes that were made should be indicated in the source citation [51].

Transport Data in Austria

While there are multiple cities and organizations that provide Open Transport Data in Austria, there are also some institutions that do not (yet) or do in a proprietary way. This section gives an overview over the available sources and also gives critique on some

[5] `https://www.data.gv.at`
[6] `http://www.opendefnition.org`

providers that do not fully comply to Open Data definitions. Two cities that provide Open Transport Data at the Open Data portal of Austria[7], are taken as examples: Vienna and Linz.

Vienna Vienna's government runs their own webpage where they provide access and documentation of Open Data interfaces of many different sources, but they also replicate with the national Open Data platform mentioned in section 3.1.2. It's possible to filter for transportation and tech, which gives 79 results per 21.9.2016 [8]. Those results do not only contain Open Transport Data but also potential areas for energy production like windy areas or thermal earth regions. The data sets which can be called Open Transport Data include access to e.g. cycling statistics or a public traffic routing-API of the public transport agency of Vienna. Elevators, sources for handicapped people (like special parking areas), car sharing, taxi and City Bike stations are available too. Vienna does even provide access to a list of lowered pavements which may be useful for wheelchair users.

Vienna's public transportation agency provides access to Open Transport Data in form of static csv-files and multiple APIs. They host the files on their own servers but publish descriptions about the interfaces at Vienna's web platform. The static files cover information about stations, departures, lines and platforms. Two APIs provide a routing-service and a realtime-data-interface. Both APIs are only documented rudimentary in form of presentation slides[9]. Both interfaces appear to be developed by Mentz Datenverarbeitung GmbH [55]. Mentz provides software for the transport agencies of the Austrian areas Linz, Innsbruck, Salzburg, Steiermark, Vorarlberg and Vienna and the whole region around Vienna (VOR). While Mentz also has more than 40 customers in Germany, they also provide software for companies in Australia, USA, South Africa, United Arab Emirate, and multiple countries in Europe.

Linz Linz was one of Austrias pioneers in Open Transport Data. They use a very similar API as Vienna which does also appear to be made by Mentz Datenverarbeitung GmbH. Linz provides static schedules and live updates of their lines. One member of their public transportation provider was presenting their API to the Open Knowledge Foundation of Austria[10]. The member mentioned some benefits of their Open Data strategy. Due to multiple examples he assumes that Open Data results in more customers for their transportation services. Further benefits are the integration of public transportation info in trip guides or other apps. He also notes that one disadvantage of opening data is that their own webpage is mainly visited to query traffic schedules. The presentation shows, that Open Data may reduce the visitor count and that it will then be harder to influence customers with advertisements or other information that was placed on their

[7] https://www.data.gv.at/

[8] https://open.wien.gv.at/site/

[9] https://open.wien.gv.at/site/wiener-linien-routingservice-dokumentationen/

[10] http://transport.okfn.org/2013/12/02/open-knowledge-foundation-austria-meetup-on-open-transport-data-toc #more-73

own web-services in the past. Further, they experienced negative feedback on apps, that were considered to be theirs but were not made by them. Their API provides a lot of information but they do not publish the whole schedule as single files for the whole validly period. That is because they are afraid of miss-usage and loss of image. Furthermore, they do not publish the whole schedule because they want to guard the final customer of inconsistency due to special schedule updates, different routing algorithms or the overall quality of the experience like handling of changeover times correctly [56]. Due to the typical functionality of GTFS, the GTFS-archives include a longer time period, which may further mean, that Linz may never publish their information via GTFS then.

ÖBB: Hacon / HAFAS The national train services of Austria (ÖBB) do not yet (13.9.2016) provide Open Data [57]. Anyhow they provide branded apps and a website called Scotty to access train schedules. This system is powered by HAFAS[11]. Further they opened their data via GTFS for Google Maps in 2013 [58]. Offene-Oeffis, an Austrian platform that wants to inform about Open Data [59] criticizes that ÖBB is able to create GTFS files for Google Maps but does not give them away as Open Data. The ÖBB refers to VAO, a national traffic information system.

VAO - Verkehrsauskunft Österreich Sadly VAO cannot be seen as a Open Data provider as well. VAO is a german abbreviation for information system on traffic and transport in Austria. They aggregate traffic information of multiple data providers and are currently (22.9.2016) connecting multi-modal traffic information like car-routing, public transportation-routing bicycle-routing, Bike & Ride, Park & Ride, Bicyclesharing, Carsharing, and others [60]. They provide apps and online routing services that make use of all these sources but they do not open their data interfaces for public use.

3.2 Comparison and Similarities of Smart City and Open Data strategies

As already mentioned in section 2.1.2 major goals of most Smart City initiatives are approaches against the problems of urbanization and against energy ineffectiveness. Furthermore, in section 3.1 countries and cities that use Open Data for multiple Smart City projects were presented. Many of the given examples use sensors, data analysis or dashboards to support common Smart City goals. Smart City systems like UOS (PlanIt) do not only interact with its own sensors and its own servers but also with apps and other external systems via their own API, that can in fact be easily extended to Open Data. Cisco deploys systems in Songdo that should connect homes and people throughout the city and also supports an open platform and Open Data. Rio initiated a control centre that connects multiple agencies with dynamic data. They may extend this system with transport data in the future. Vienna is opening government data to be used by any

[11] http://www.hacon.de/

citizen. Further, Homeier and Arzberger note in Vienna's context that help and support of technological solutions are important for any Smart City projects [42].

Beside explicit Open Data usage in common Smart City projects, there are also many Open Data initiatives that provide citizens and companies with valuable information without any given use case. Section 3.1.2 made clear that many Open Data initiatives are focusing on economic improvements. Anyway, it also came clear that many initiatives also cover improvements of communities, administration, science and culture. Open Data of urban areas can be used for many Smart City projects but Open Data that covers even governments or whole countries could potentially power more wider "*Smart Projects*" - on national or even broader level.

Summing up, there are many indicators that the exchange of data is an essential part of the strategies that Smart Cities need for their transformation. Many Open Data initiatives are linked with Smart City initiatives and vice-versa. The examples of related work in section 3.1 also make clear that Smart Cities do not only include Open Data initiatives and that not all Open Data initiatives are only linked to Smart Cities. Both topics cover a wider area of application but support their common goals in exceptionally good ways. A study of Ojo, Curry and Zeleti comes to a similar conclusion and notes that linking Open Data and Smart Cities enables open innovation in cities [61]. Innovation in Smart Cities was also depicted as an important factor in section 3.1.2.

CHAPTER 4

Proof Of Concept

This chapter will introduce a practical implementation of the presented concepts and ideas. It focuses on a Smart City application that is powered by Open Transport Data.

4.1 Introduction

The main purpose of this thesis is to demonstrate a useful Open Transport Data example in the context of a Smart City. Therefore, a proof of concept was designed that uses Open Transport Data of the Public Transport Agency of Vienna to influence the brightness of street lights near bus stations. A server component provides access to traffic schedules and the application logic inside of the street lights downloads and stores the information about the traffic tables. Furthermore, the street light receives realtime updates of delayed vehicles. Section 4.2 will describe the requirements and design decisions for the chosen use case.

During the planning and implementation of the example, multiple problems had to be solved. According to section 2.2.4, there is a significant difference between the standards NeTEx/SIRI and GTFS/GTFS-realtime and initially it was not clear which one fits best. Further, there are multiple parts of the API of the public transport agency of Vienna which are not documented well. Section 4.3.4 describes why the street lights are not directly using the file specifications of Vienna's public transport agency and why it is feasible to convert the traffic schedule to GTFS first. The distribution of the GTFS archives will be done via HTTP. Section 4.3.1 and section 4.3.5 describe why the communication for realtime traffic updates is done via MQTT instead of HTTP.

4.2 Technical Concept

There are many requirements that should be met by the implementation. The following section will define the requirements of the implementation and section 4.2.2 will discuss the design decisions that are based on these requirements later on.

4.2.1 Requirements

1. Smart Control: The brightness of street lights should be dimmed according to the schedule. Therefore traffic lights at least need to interpret static traffic schedules. A more advanced control strategy could also use realtime updates of the schedule to not dim the light to a lower level if a vehicle is delayed.

2. Energy Effectiveness: The implementation should reduce the overall energy consumption of the street lights. Therefore, the whole system needs to incorporate that by at least using an energy effective network stack.

3. Offline Behaviour: A requirement that is considered to be important for practical reasons is the offline behaviour of street lights. Internet connection may not be stable at all stations or may not even be available at some more segregated areas. Due to that, street lights need to have the ability to cache traffic information to bridge connection issues and also need to provide a configuration-interface for an overall offline case of application.

4. Portability & Extendibility: The major goal of many Smart City implementations is to not limit the shown concepts to one city or system and to consider appropriate portability. Portability regards two parts of the implementation. On one hand, the individual components of the street lights should be loosely coupled to ensure that further upgrades, like for example additional sensors, can be done easily. On the other hand, the network communication should be based on standardized file formats and components should be easy to provide.

5. Converter for Vienna: As mentioned in section 3.1.2, the public transportation agency of Vienna already provides Open Transport Data. Unfortunately, they do not use a common file format but rather a closed and mostly proprietary format. Because of that, the information of Vienna's public transport agency needs to be converted to a common standard to fulfil requirement 4. Using a common standard will result in portability of the street lights and will allow implementations in other cities.

4.2.2 Design decisions

To simulate a representative environment, the implementation should be usable in multiple cities. Due to requirement 4, the street lights should also not only work as closed entities.

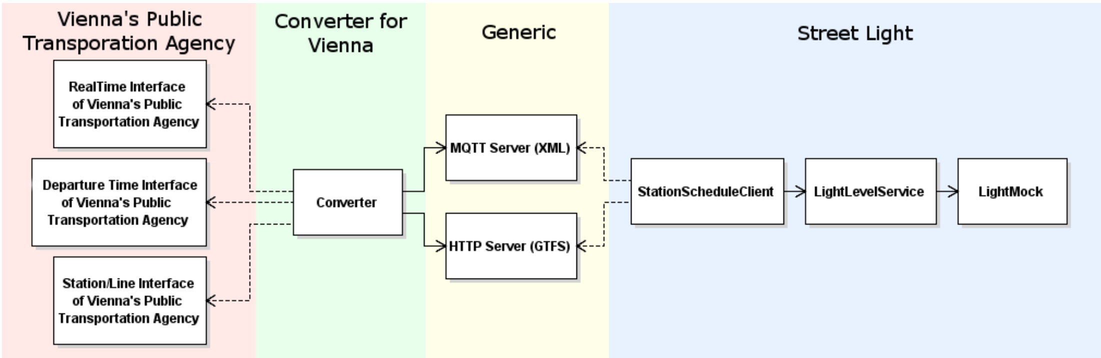

Figure 4.1: A diagram that shows the several network borders and components of the system

Because of that, the components of the systems are separated to multiple parts. Figure 4.1 shows an overview of the whole system. The background colours indicate the network borders between the components. The existing servers of the Public Transport Agency of Vienna (red in Figure 4.1) provide three interfaces to query information of their grid, planned departure times and realtime updates. The converter (green) regularly pulls these files via HTTP, even the realtime updates, because there is no documented method to subscribe to certain events. According to requirement 5 the input needs to be converted, which results in two output files: a long-term schedule as a GTFS-archive and live updates as XML files. These files will be published via HTTP and MQTT (yellow). HTTP will only be used for the exchange of bigger files like the whole GTFS-archive. MQTT will be used to transfer realtime updates. MQTT is way more energy efficient

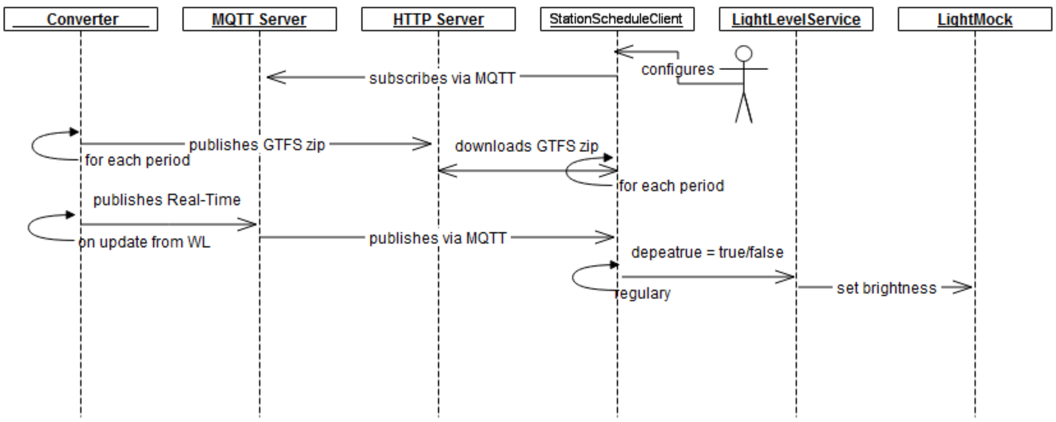

Figure 4.2: A sequence diagram of the information flow

than HTTP and fits requirement 2. The street lights (blue) will initially pull the traffic schedule via HTTP and subscribes to realtime updates via MQTT. If the street lights have no Internet connection, they will rely on offline GTFS-files. Therefore, the street lights could also be configured with an initial copy of a GTFS-archive. The street lights themselves are separated into tree modules. All of them are running on the same JVM but are separated into classes due to requirements 3 and 4. The task of the street lights is to regulate the brightness according to current public traffic information.

Figure 4.2 shows a sequence diagram of the top level view of the implementation. The communication between the components is shown with the indicated arrows. The arrows are annotated to show their meaning. The implementation of each component will then be introduced in section 4.3.

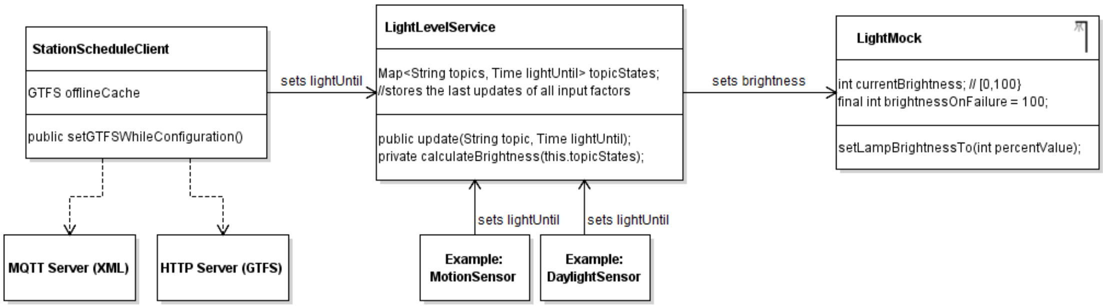

Figure 4.3: A class diagram showing the street light in detail

Figure 4.3 describes the design decisions for the software components of the street lights in a more detailed view. An HTTP Server and an MQTT Server will be located outside of the street lights and will provide access to traffic schedules. The street lights themselves will have three components that have different responsibilities. The most specific one is called StationScheduleClient and is responsible to load and combine traffic schedules via HTTP and MQTT. Another component is called LightLevelService and was introduced to abstract the traffic schedule component from the rest of the application. The LightLevelService may also be used for other purposes than only the light control of the street lights. The LightLevelService can handle input of various sensors and combines the information. The information is then used to set the brightness of a generic LightMock. The LightMock provides an interface to the LightLevelService of a street lamp and can be adapted to any hardware in different cities. In our case, the LightMock will only print the current brightness of the light to a log file.

4.3 Details and Findings of the Implementation

This section provides details of the software components and used libraries and also lists findings that occurred based on the implementation.

4.3.1 Description of the Software Components

Converter

To achieve requirement 4 and portability of the street lights, the networking part should depend on standards. The most used standard for Open Transport Data should therefore be used for this implementation. GTFS and NeTEx could both potentially have been used as a file specification for this project. Section 2.2.4 notes that NeTEx covers a wider range of possible information than GTFS. This implementation would yet not need these features of NeTEx because the only valuable information are departure times. Users at a discussion group of Google expect that governments may continue to develop and use complex but standardized standards like NeTEx while others should maybe just use the de-facto-standards for simplicity [19]. Section 2.2.5 established that GTFS is supported by 3 of the 5 highest ranked Smart Cities. GTFS is also used by many transport agencies around the world and there are also a lot of community driven projects that convert or directly produce GTFS data. GTFS, as a de-facto-standard, suits better for the use case of this implementation and will be used as a baseline for that reason. Street lights will only be able to interpret GTFS in favour of better portability to multiple other cities. Still, Vienna's public transport agency does not provide GTFS directly. To ensure the provision of GTFS for the public transport agency of Vienna, their proprietary format needs to be converted beforehand. Their files are licensed as cc-by-at-30. Fortunately, the license was introduced in section 3.1.2 and allows the required transformations. This component therefore fetches the schedule for one station for the whole week, converts it to GTFS and then publishes the resulting files to an HTTP-server. Realtime updates will also be fetched regularly and will be published as XML instead of GTFS. The converter will only publish the updates to the corresponding topic of each station via MQTT. Details on why we restrict the GTFS files to a span of one week and why XML is used in favour of GTFS-Realtime are given in section 4.3.4.

HTTP Server

The converter from section 4.3.1 provides static GTFS-archives that will be hosted by this component. Street lights will access the files via HTTP.

The majority of the traffic agencies in a list of worldwide GTFS providers at Google Code [1] use HTTP to publish their archives. This implementation uses an HTTP server in favour of compatibility of the street lights to those other Open Data strategies. As described in section 3.1.2, Vienna does not provide GTFS yet. That's why a converter and an internal HTTP Server are used to mimic the behaviour of the majority of the other GTFS providers. Other cities may not need to run this component again if they already publish GTFS via their existing HTTP interfaces. As it will be seen down below, the StationScheduleClient is able to use any HTTP-GTFS-provider.

[1] `https://code.google.com/archive/p/googletransitdatafeed/wikis/PublicFeeds.wiki`

MQTT Server

This component handles the exchange of realtime-updates for stations. MQTT is a very efficient communication protocol for IP and is required for requirement 2. In comparison to HTTP, an MQTT-service works with the publish-subscribe-pattern. Many IoT-Systems handle use cases where an event can occur at any time, on non regular intervals. With HTTP, the device would regularly poll the server for updates, which is more network and CPU-intensive and consequentially uses more power. In this prototype, the MQTT-realtime updates are published on demand. If Vienna's transport agency provides realtime updates, the converter from section 4.3.1 will first check if the updates were already sent and will only publish them if the information is new.

Realtime updates are published to an MQTT-topic that is named equally to the ID of the station. The updates contain delay information as JSON. Listing 4.1 shows a snippet that was published by the converter to the topic of a specific station. It contains two updates, which both contain the planed departure time 'p' and the estimated departure time 'r'. The station ID has no need to be included because each topic is associated with the ID of only one station anyway.

Listing 4.1: Realtime traffic updates as JSON

```
[
  [
    {
      "p": "2016-11-13T23:43:00.000+0100"
    },{
      "r": "2016-11-13T23:43:18.000+0100"
    }
  ],
  [
    {
      "p": "2016-11-13T23:58:00.000+0100"
    },{
      "r": "2016-11-13T23:58:30.000+0100"
    }
  ]
]
```

StationScheduleClient

The StationScheduleClient will be located inside of the street lights. This component is responsible for handling the Open Transport Data aquisition and processing. On startup the StationScheduleClient will lookup for a static traffic schedule via HTTP. To provide offline availability for requirement 3 the client should also be configurable by a configuration expert. Therefore, a prepared GTFS-archive can be placed on the local disk. If the StationScheduleClient finds no valid GTFS-archive on the disk it will try to download the archive via HTTP. On success the downloaded file will be placed at the same disk location as where the configured one would be expected. The file will then be used until the timestamps of the departures in the Stop_Times.txt file expire. The Stop_Times.txt file is part of the GTFS specification and includes departures at stations for the whole network of the operator. Listing 4.2 shows a few entries of the file that is provided by the converter above.

Besides the static GTFS schedule, the StationScheduleClient will also subscribe to an MQTT-topic that is named corresponding its own station ID.

Listing 4.2: GTFS - Stop_Times.txt containing entries for Hannah-Arendt-Platz at Vienna's Smart City Project Seestadt Aspern from section 3.1.1

```
trip_id,arrival_time,departure_time,stop_id,stop_sequence
friday-215096034,00:06:00,00:06:00,219364361,1
friday-215096034,00:14:00,00:14:00,219364361,1
friday-215096034,00:21:00,00:21:00,219364361,1
friday-215096034,00:29:00,00:29:00,219364361,1
friday-215096034,00:36:00,00:36:00,219364361,1
friday-215096034,00:44:00,00:44:00,219364361,1
friday-215096034,00:56:00,00:56:00,219364361,1
friday-215096034,01:08:00,01:08:00,219364361,1
friday-215096034,04:41:00,04:41:00,219364361,1
```

The StationScheduleClient will always call the LightLevelService if there is a departure in a time interval of 0-10 minutes. If the converter component publishes a realtime update, the MQTT listener of the StationScheduleClient will be informed and forwards a corresponding update to the LightLevelService which then will handle that the light stays on for a longer time.

LightLevelService

In practise a street lights may not only depend on traffic schedules but also on various other inputs or sensors. Motion sensors, video cameras, push-buttons or even light sensors may be included. Therefore, the LightLevelService holds a list of components that independently talk to the LightLevelService. The service then calculates the total brightness corresponding to all input sensors. Figure 4.3 shows some exemplary sensors that can be connected with this component. Generally speaking, the LightLevelService is used to abstract the GTFS-logic from the LightMock to meet requirement 4.

LightMock

This component is also introduced due to the required modularity of requirement 4. Street lights of different manufacturers may provide different hardware interfaces. Listing 4.3 shows that the LightMock technically is an interface that provides a method which should be used to set the brightness of the street lights. This interface must be implemented for each supported street light model to be used by the LightLevelService on the next hand.

Listing 4.3: Complete code of LightMock.java

```java
package at.pazourek.michael.tuwien.bachelor.thesis.streetlight;
```

```java
/*
* should be implemented for concrete hardware
*/
public interface LightMock {

	/**
	* updates the brightness of the lamp to a corresponding
	*         percent value between 0 and 100. 0 means off.
	*
	* @param  percent the new brightness in percent.
	*                  Between inclusive 0 and inclusive 100.
	*
	* @return the old brightness as int
	*/
	public int setBrightness(int percent);

}
```

4.3.2 Hardware Limitations

To run the components of the street lights, the shown implementation uses Java on a Raspberry Pi to make the discussed concepts easily demonstrable. To accelerate the prototyping, a Raspberry Pi is a favourable solution but applications in real scenarios should better use a more energy efficient platform to save costs.

Aside from that, the implementation does not use the hardware of real street lights but only provides a concrete implementation of the LightMock-Interface. The "hardwareClass" is not controlling the brightness of real hardware but only saves the instructions to a log-file.

4.3.3 Used Java Libraries

To accelerate the development of the implementation, multiple Java libraries were used. The most integral one is an MqttClient by Eclipse Paho [2] because the library is used to connect both the converter and the StationScheduleClient to the MQTT server. The MQTT sever itself does also make use of a Java based library to run an MQTT broker. The library is called Moquette MQTT by Eclipse IoT. [3] Both used libraries are licensed under the Eclipse Public License 1.0.

Another library that is used both in the converter and at the StationScheduleClient is OpenCsv [4]. By definition, GTFS files are stored as comma separated files. Therefore, this library helps to read, write and map GTFS-files to Java instances. Listing 4.4 shows important parts of an annotated Java class that uses OpenCsv to map a GTFS-file.

[2] https://eclipse.org/paho/clients/java/
[3] https://projects.eclipse.org/projects/iot.moquette
[4] http://opencsv.sourceforge.net/

Listing 4.5 shows important lines of the GTFS converter that uses OpenCsv to create a csv file on the disk. OpenCsv is licensed under a Apache 2 license. [5]

Listing 4.4: A class that is annotated with OpenCsv-Annotations

```
public class Stop_Time {
        @CsvBindByName(required=true)
        private String trip_id;

        @CsvBindByName(required=true)
        private String arrival_time;

        ...
```

Listing 4.5: Procedure to write a CSV-file with OpenCsv

```
//define the columns that should be saved to the csv file
String[] cols = new String[]{"trip_id","arrival_time","departure_time",
    "stop_id","stop_sequence"};

//use OpenCsv to store the java.util.list finalResult that contains
    converted Stop_Time instances to a file on the disk.
CsvUtils.persistToCsv(finalResult, Stop_Time.class,
    Config.diskFolderPath+"stop_times.txt", cols);
```

To parse the JSON-based updates of the realtime interface of Vienna's public transportation agency, org.json is used. The license allows any usage as long as the license text is included to all copies of the software.

4.3.4 API of the Public Transport Agency of Vienna

The API of Vienna's public transportation agency provides access to multiple interfaces:

- On one hand there are multiple csv-files that contain information about the infrastructure grid like stations, lines and platforms. One is called "*Halte.csv*" and contains multiple columns like name, location or type of the stations. There is no documentation about the meaning of each column but the title of the columns is self-explanatory in most cases. Unfortunately, there are also errors in the provided files where station names are only described as "*xxxxx*". Due to the not existing documentation it is not clear how those stations should be interpreted.

- There is also an HTTP based API that provides access to routing information. A request for departures of a specific station results in an XML-file with mostly undocumented fields. Some fields are self-explanatory which makes the API usable. But anyway there is a significant lack of professional documentation. To query the departures of a whole week, the user needs to establish an HTTP-session to furthermore iterate the whole week in small parts via the HTTP-Get command

[5] http://opencsv.sourceforge.net/license.html

"*dmNext*" [6]. Furthermore, the API provides no XML-tags to guess the regular weekly schedule that is the base for each daily departure time. GTFS can only map weekly schedules which are not available in Vienna. Therefore, the converter of section 4.3.1 will only convert one future week to GTFS. To build a better GTFS converter, an algorithm that compares departures between weeks could be implemented but this exceeds the scope of this thesis.

- Another HTTP interface provides realtime information for departures. The response contains a JSON structure with the estimations of the next 70 minutes. The API is rudimentarily documented at the webpage of Vienna's transport agency[7] in form of a list of available fields, but the description of the fields is meaningless in most of the cases.

4.3.5 Realtime Updates

After evaluating SIRI and GTFS-Realtime as file formats for realtime updates, it became clear that both concepts are in early development stages and that an implementation is not really straightforward. SIRI involves a whole new XML schema while GTFS-Realtime requires Protocol Buffers for proper serialization. Both formats include a lot of functionality that is not needed for this implementation and would bring a lot of unjustified work. A simple JSON representation fits the scope of this thesis and is therefore used to describe realtime updates. Further versions of the implementation may reorganize the realtime update procedure to be based on a broader used standard.

Furthermore, this implementation only covers information about delays of planned departures for one whole station. Further updates could consider also single platforms, extra tours or complete cancellations.

4.3.6 Offline Availiability

This section will describe the offline behaviour of the implementation. We distinguish between two cases: There are stations with no connection to the Internet at all and there are stations that normally can access the Internet but could potentially lose the connection at any time.

No connection at all

Due to basic design decisions this implementation can be used for any GTFS providing traffic operator. Anyway, not all traffic operators may provide GTFS via HTTP services. Furthermore not all street lights may have Internet access. Mobile broadband is mostly available in urban areas, for example the city of Vienna has a proper coverage of mobile broadband access. But this implementation could also be used in more rural areas, as

[6] www.wienerlinien.at/ogd_routing/XML_DM_REQUEST?sessionID=sessionRequired&dmLineSelectionAll=1&command=dmNext

[7] http://data.wien.gv.at/pdf/wienerlinien-echtzeitdaten-dokumentation.pdf

many parts of Austria are located in alpine regions. Due to that, not all parts of the country are covered with mobile broadband access. Figure 4.4 shows some under-supplied areas of Austria's one of the biggest mobile providers Drei[8].

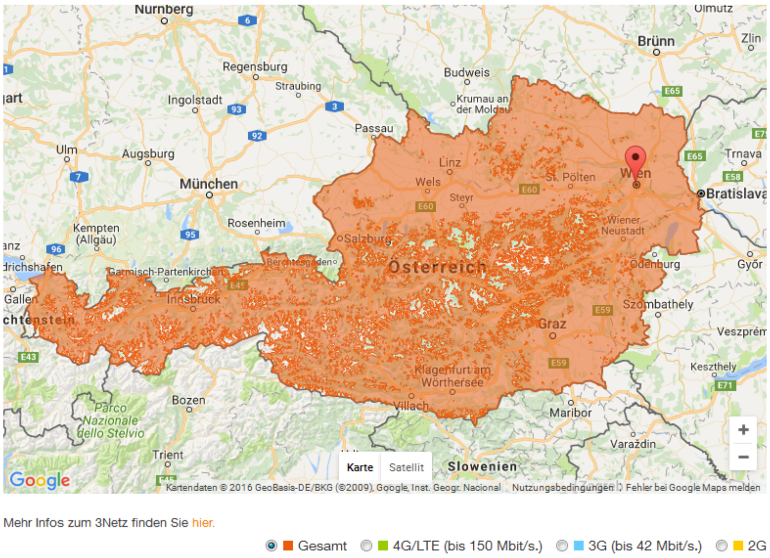

Figure 4.4: Moblie Broadband of the Operator Drei [62]

To not limit the implementation to areas with Internet access or agencies with suitable web services, the StationScheduleClient can also be configured for offline access. Besides an entry in the config files, the StationScheduleClient will behave similar to the normal use case but will not try to pull the GTFS files via HTTP and will also not subscribe to MQTT for updates. Instead, the client will require a ZIP archive containing the GTFS files at a given path on the local disk. Installation teams then need to copy the up-to-date GTFS archives to the device to initialize the StationScheduleClient.

Temporary loss of connection

Another offline behaviour that is supported by the implementation regards the temporary loss of Internet access while normal operation. The StationClient normally tries to download the GTFS schedule when the validity of the schedule comes to its end. On success, the files are stored on the local disk and will also be available if the Internet connection fails. Realtime updates will only be available with working Internet access and will stop working on connection loss but will start to work if the connection comes up again.

If there is a fatal failure and no schedules are available at all, the implementation always sets the brightness of the street lights to a safe level. As described in section 4.3.1 the

[8] `https://www.drei.at/portal/de/bottomnavi/kontakt-und-hilfe/netzabdeckung/`

LightLevelService may also have other sensors to rely on if no schedule is available.

CHAPTER 5

Conclusion and Outlook

5.1 Summary

Chapter 2 first gave an overview over Smart Cities and then discussed the relevance of them. Afterwards different common definitions and a working definition for Smart Cities were formulated. Furthermore, chapter 2 presented definitions of Open Data, Open Government Data and Open Transport Data and showed an overview over international standards and the worldwide distribution of them. Chapter 3 then provided examples of existing Smart City and Open Data approaches and an excursus to different projects around the world. In Section 3.2, explanations on the context between Smart Cities and Open Data were presented. Finally, chapter 4 presented the implementation of an Open Transport Data based street lighting project and discussed the technical details of the implementation.

In retrospective, the thesis discussed multiple definitions of Open Data and Smart Cities and not surprisingly found a nexus between both topics. It was shown that projects around the world tend to implement similar concepts as the sample implementation of this work. The practical implementation gave some interesting insights in the bigger challenges of the work with data interfaces. Developers of portable Smart City implementations are fully depending on standardized interfaces. The work also showed, that the conversion of non-standard interfaces is of course possible and may seem easy in the first place. But in the end, this thesis also shows that, at least for Vienna, a complete conversion to a standardized format would be very time and cost intensive. Therefore, the big lessons learnt of this thesis are that Open Data provides a huge amount of new opportunities for new applications on the one hand. But on the other hand it also came clear that files in non-standardized formats have a significant negative impact on the success or failure of Open Data initiatives. To simplify the process in the future, Open Data providers could even more focus on the usage of common standards.

5.2 Future Work

The presented concepts of Smart Cities and Open Data cover a lot of theory. To extend research on the given topics, more detailed investigation on the link between successful Smart City and Open Data initiatives could be done. Furthermore, this thesis names multiple sources for the economic value of Open Data. Evaluations on the fulfilment of predicted economic impacts of implemented Open Data projects, that are already running for a few years, could be given. Regarding the presented file specifications in section 2.2.4 a more detailed comparison between NeTEx and GTFS can be made. Realtime formats like GTFS-realtime and SIRI could also be discussed hereafter because they were mostly left aside due to the immersive technical specifications that would exceed the scope of this thesis.

Future work for the prototype can also be done for multiple components. Currently, the information flow from the transport agencies to the street lights is unidirectional. But street lights could not only consume but also publish information in the future. The integration of an MQTT server easily enables the components to communicate in any direction. Street lights may be coupled with motion sensors or video cameras that may publish statistics or motion updates to the MQTT server. The GTFS-converter of section 4.3.1 currently only works for one station of Vienna and for one week at a time. Further work could convert a whole year of the dataset of Vienna's public transportation agency to GTFS. As mentioned in section 4.3.4, this can only be done by a more complex algorithm. A clock synchronization between the server and the street lights may also be useful to improve the precision of realtime updates and to enable autonomous time-based control logic (e.g. scheduled on-off cycles) for the street lights.

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