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A Technical Concept for sensor-based Traffic Flow Optimization on connected real-world intersections via a SUMO Feature Gap Analysis

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Abstract: Traffic within cities has increased in the last decades due to increasing mobility, changing mobility behavior and new mobility offerings. These accelerating changes make it increasingly difficult for responsible authorities or other stakeholders to predict mobility behavior, to configure traffic rules or to size roads, bridges and parking lots. Traffic simulations are a powerful tool for estimating and evaluating current and future mobility, upcoming traffic services and automated functionalities in the domain of *traffic management*. For being able to simulate a complex real-world traffic environment and traffic incidents, the simulation environment needs to fulfill requirements from real-world scenarios related to sensor-based data processing. In addition, it must be possible to include latest advancements of technology in the simulation environment, for instance, (1) connected intersections that communicate with each other, (2) a complex and flexible set of rules for *traffic sign control* and *traffic management* or a well-defined data processing of relevant sensor data. In this paper we therefore define requirements for a traffic simulation based on a complex real-world scenario in Germany. The project addresses major urban challenges and aims at demonstrating the contribution that the upcoming 5G mobile generation can make to solving real-time traffic flow optimization. In a second step, we investigate in detail if the simulation environment SUMO (Simulation of Urban Mobility) fulfills the postulated requirements. Thirdly, we propose a *technical concept* to close the gap of the uncovered requirements for later implementation.

Keywords: Traffic flow optimization, connected intersections, traffic light systems

1 Introduction

In the last decade, traffic density has increased worldwide by the growing amount of vehicles making the management of the traffic more challenging [1], [2]. This leads to more traffic jams, accidents [3] or transportation problems such as costly delays [4]. Reasons for this are, e.g., the growing car ownership and the behaviour of road users [1], [5]. Thus, solutions for traffic flow optimization is important [4]. Especially with respect to multi-lane intersections [5], different traffic flows crossing each other and these crossings have to be regulated. The regulation can take place via traffic light systems and they thus have an effect on the traffic flow. Developing and testing such optimizations in the real world is time-consuming, expensive, hardly reproducible and a potential safety risk. Thus, traffic experiments should be performed in a virtual environment using traffic simulations [4]. Mapping the real world into a virtual environment and simulation which are also being studied intensively in the research community [2], [4] is of high priority for the traffic management [1]. Simulations require models which contains roads, buildings, traffic lights or traffic demands to reflect the reality in those aspects that are needed to find responses for posed research questions [6]. SUMO offers functions and tools for applying traffic simulations such as traffic lights or road data [6]. Traffic demand represents a basic information for running a SUMO simulation that is provided in different modes by SUMO [6]. Additionally, SUMO offers functionalities to understand the traffic state [6]. However, it has to be validated which requirements of the real-world scenario can be fulfilled with SUMO built-in features and which components have to be developed further. This paper addresses this issue by identifying project specific requirements, derived from a concrete real-world project called *5G-trAAffic* [1] supported by the German Federal Ministry of Transport and Digital Infrastructure, by comparing it with the current SUMO functionalities. One goal of the *5G-trAAffic* project is to optimize the *traffic flow* by tweaking the way traffic lights are managed at various multi-lane intersections. This is going to be realized by connected the intersections by a cooperative behaviour of the *traffic signal systems*.

The main goal of this work is to identify gaps between the project related requirements and the current SUMO functionalities ending up with a technical concept for a later implementation of new extensions or software plugins for SUMO. In the core, as Fig. 1 shows, we, firstly, analyze which requirements are demanded for SUMO to be able to closely represent the project reality within the virtual environment. Secondly, the concrete requirements are sorted within categories such as the geographical environment, the traffic logic such as a traffic management, and the data creation of relevant data sources such as traffic sensors as a traffic optimization is related to a sensor-based data processing. In addition, the identified gaps between the demanded requirements and the SUMO functionality resulted within a *gap analysis*, which transparently shows required SUMO enhancements to close the gaps. Thirdly, in the last step we use the gap analysis to suppose a *technical concept* which provides an overview of the solution approach.

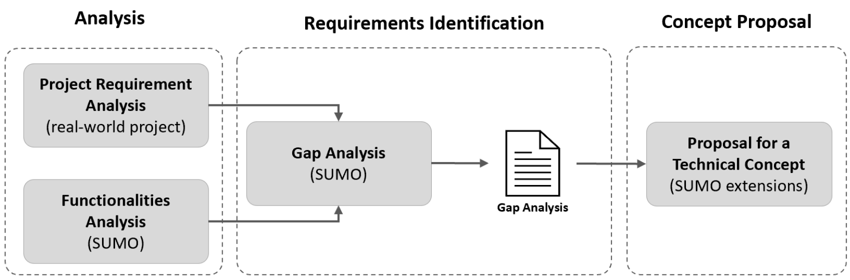

Figure 1. Overview over the work content

The structure of the paper is organized as follows: Section 2 provides a review of relevant literature. Section 3 presents an overview of the considered road intersections in the project and their specific conditions. It also includes the identified requirements on the simulation environment. In Section 4 there will be shown which requirements can already be fulfilled by SUMO and which requirements needs to be integrated to

[1] https://www.keim.iao.fraunhofer.de/de/projekte/5G.html

meet all requirements. Subsequently, Section 5 presents the technical concept with a diagram and description about the approach to extend SUMO. Finally, Section 6 provides an overall evaluation and reflection of the results.

2 Related Work

Our work strongly deals with several fields with respect to the traffic flow optimization. Jin et al. [7] generated an intelligent control system for traffic signal applications called Fuzzy Intelligent Traffic Signal (FITS) control. The system is designed to improve existing signal control systems without changing the fundamental traffic management infrastructure. It uses fuzzy logic for decision making and communicates with signal control hardware and simulated traffic environment through a M2M connectivity protocol.
Traffic monitoring is required to minimize traffic congestion and accidents and to develop *intelligent transportation systems* (ITS). Mega et al. [8] analyze a realistic simulation of vehicle mobility based on traffic surveys of a city using SUMO. The traffic information was obtained by integrating *OpenStreetMap* with request data and filtering with a Kalman Filter method. Muzamil et al. [9] designed an adaptive traffic signal control based on fuzzy logic with Webster and modified Webster's formula considering the average waiting time, average travel time, and average speed as performance indices. Data from three, four and five intersections were collected and by using SUMO it turned out that the two proposed adaptive traffic light control algorithms showed better results in terms of performance indices at a four-access intersection. In the *KI4LSA* project phase [10], a solution for real-time data-based traffic flow optimization of existing traffic light systems with artificial intelligence (AI) was proposed. They used SUMO and collected data from different sensors such as radar sensors or video-based sensors of the city of Lemgo. They showed a positive impact on the traffic flow by applying linear optimization. In comparison, our focus is on collecting other kinds of data like statistical and historical data sensor data, which later in the project will result in a set of rules that will provide the *traffic light systems* with suggestions for the next *traffic light* phase. Tomar et al. [11] address the problem to update traffic signal timing and synchronize the traffic signal at intersections based on real-time traffic information. They provide an overview of traffic light synchronization techniques for intelligent vehicles, a cutting-edge technology in ITS. They proposed a traffic signal synchronization framework which divides the system in two levels of synchronization to reduce the congestion, working with any technology to collect traffic density at intersection. Pandey and Jalan [12] use image and video processing to gather information on traffic density at an intersection and develop a strategy for allocating time periods for traffic signals. With their suggestion they want to reduce the waiting times for vehicles and reduce the average waiting queues.
The work of Lobo et al. shows the concept, model and validation to presents a realistic traffic scenario for *Ingolstadt*. For this purpose, observations from the real world were taken over, such as the average green phases at traffic intersections [13]. In contrast to our approach, we want to access the actual sensor data to provide an accurate representation of the traffic light phases and intersection situation in the simulation environment. In Luow at al. [14] the queue length at intersections is to be optimized. For this purpose, the two approaches of Machine Learning: Q-learning and policy optimization are faced. Here, the agents have access to the state of the traffic light as well as the number of vehicles. This approach excludes environmental factors to be considered in this work. Halbach and Erdmann [15] focus on the setup of intersections with SUMO and the implementation of traffic light codes of a manufacturer, which are

transmitted in a fixed interval. The transmission is realized by *Traffic Control Interface* (TraCI).

3 Requirements Analysis

Deriving requirements from the real-world project *5G-trAAffic* for virtualization, the real-world project needs to be analyzed in detail including the core characteristics such as the traffic flow or the logic of traffic management. Thus, in the following the project is described in detail followed by the the requirements analysis.

3.1 Overview of the 5G-trAAffic Project

The main goal of the *5G-trAAffic* project is to examine potential applications of the 5G mobile communications technology in cities. The project addresses major urban challenges and aims at demonstrating how the upcoming 5G mobile communications generation can contribute as a key technology to the solution of real-time *traffic flow optimization*.

The project is located in Aalen, Germany. Fig. 2 shows the three traffic intersections in Aalen that are taken as concrete scenario for the traffic flow optimization.

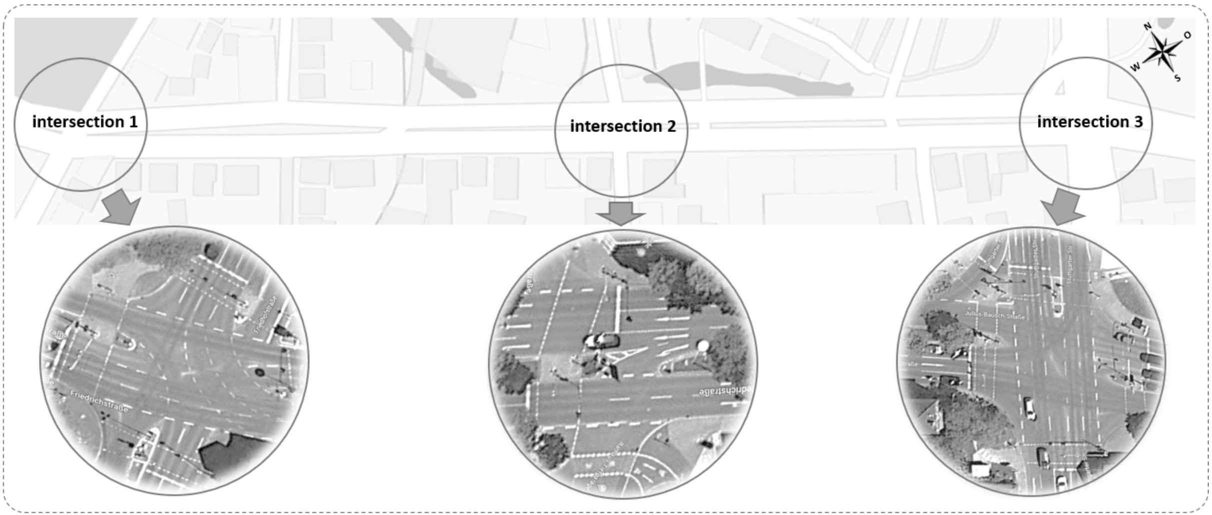

Figure 2. Overview about the intersections within the 5G-trAAffic project

The two streets *Friedrichsstraße* and *Friedhofstraße* represent *Intersection 1*. The middle intersection *Intersection 2* contains the both crossing streets *Gartenstraße* and *Friedrichstraße* and connects the *Intersection 1* and *Intersection 3*. The last intersection *Intersection 3* contains the *Stuttgarter Str.* and the *Julius-Bausch-Straße*. The intersections are connected by multi-lane roads and build major traffic axes. The traffic is characterized by motorized traffic including bicycle lanes, cars, trucks, buses or motorcycles. Pedestrians can request green phases via a request button on the traffic light pole. Induction loops and basic video detection to identify the amount of road users are provided at all intersections. The existing traffic light systems have a static traffic signal phasing program and have no knowledge about the current or next phase of the other intersections. The selection of the next traffic light phase can be influenced by the request buttons (pedestrians), induction loops and video detection. Several additional modern sensor devices will be added to the intersections and roads comprising, e.g., road-side units or weather sensors. These sensors can enable better optimization of traffic flow by providing additional relevant data for optimization. Furthermore, the driving areas will be equipped with modern AI assisted camera systems that can establish the fluctuation of the travel. This includes to detect the amount of vehicles per time as well as the class of vehicles (e.g., bus or car). Camera systems will enable tracking in which direction a vehicle is travelling. Thus, the camera systems will exchange data with each other. The current basic operating principle of the traffic light systems is to receive internal suggestions from the traffic system to decide which traffic light phase should be selected next. This should enable the traffic light system to react to local traffic conditions, but also to achieve macroscopic overall effects. Fig. 3 shows the *5G-trAAffic* project and its basic solution approach in order to optimize the traffic flow.

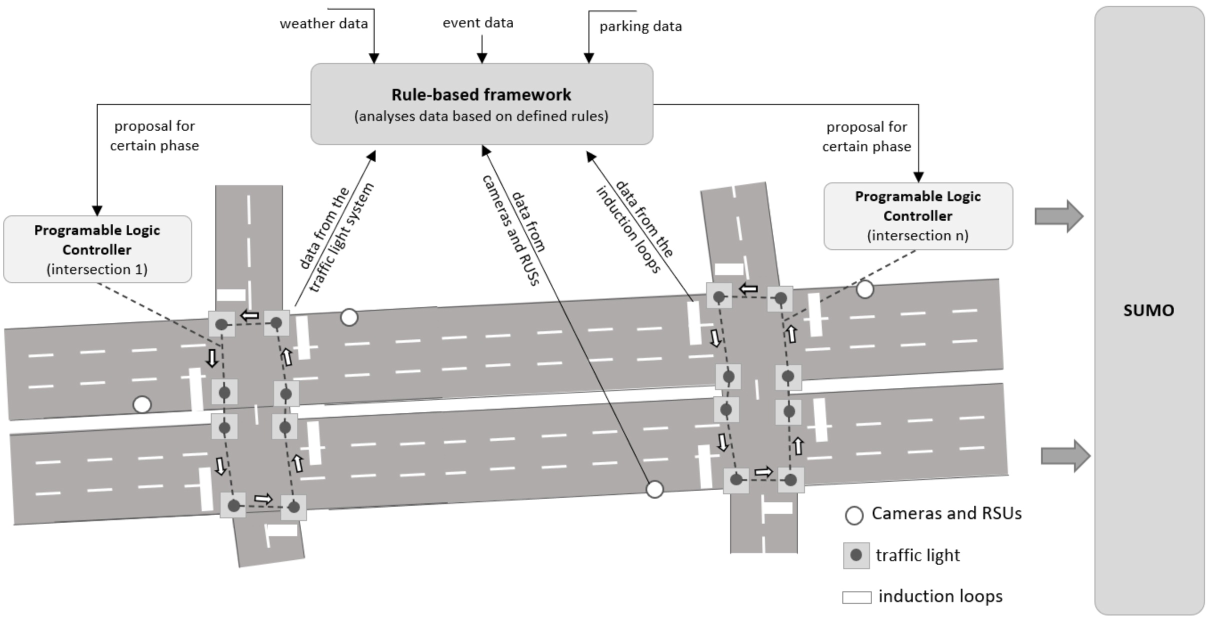

Figure 3. Overview over the traffic flow optimization using the rules based framework

The core of the traffic flow optimization are based on a *rules-based framework* which optimizes the traffic lights by sending a proposal for the next phases based on multiple data sources. Algorithms are being evaluated that calculate a recommendation for the next phase, based on the input signals from the sensors. The characteristics of the traffic light of the considered intersections *5G-trAAffic* is that they have a built-in logic to accept or reject the proposal. In real world this is performed by a hardware unit called a programmable logic controller (PLC). For simulation purpose in the running project *5G-trAAffic*, the PLC has to be emulated by a software module. This means that the behavior of the hardware unit (PLC) from the real world has to be modeled with a self developed software module. The PLC serves as an interface between the rule-based framework and the traffic signal system. The incoming proposal for the next traffic light phase is received and evaluated by the PLC. By accepting the suggestion, it sends the suggested phase to the traffic signal. Which requirements the SUMO environment needs to fulfill is part of this paper. In the next Section the requirements are identified that have to be fulfilled by the simulation environment.

3.2 Requirements Analysis

The requirements for the *5G-trAAffic* project focus all on traffic flow optimization and not on traffic safety issues. Pedestrians will just be considered to represent how pedestrian requests affect the vehicle traffic flow. The requirements are structured in several groups. The first group addresses the requirements for the *traffic signal systems*. These are central to the objective of *traffic flow optimization*. The second requirement group is made up of the sensor systems which are used with the 5G technology, called the *5G sensor systems*. The described *5G-trAAffic* project uses already installed sensor systems such as induction loops or specific sensors (e.g., camera systems or 5G components) which provide the input sensor-data for the SUMO simulation. The third requirement group focuses the traffic simulation itself, which combine the *traffic signal systems* and the *5G sensor systems*. The fourth requirement group represents the *traffic flow optimization*. Table 1 shows the identified requirements for the *traffic light system*.

Table 1. Traffic Light System Requirements

Requirements - Traffic Light System	
RID	Description
1.1	Traffic signals need to be manageable via phase transitions.
1.2	Selecting the next phase, incoming signals from sensor devices need be considered.
1.3	An interface is needed to request the next phase based on the current input signals.
1.4	An interface is needed to change the current phase to the transmitted phase.
1.5	A PLC is needed to decide if a suggestion of the next phase is accepted or rejected.

Controlling traffic signals via phases within a traffic signal program is a standardized approach. Thus, the requirement *RID 1.1* is of particular importance. Furthermore, a traffic light program consists of multiple phases and its transitions. A 5G sensor system should deliver relevant information to determine the next phase (*RID 1.2*). For the development optimization of the traffic flow, the basic information about current state of the traffic light must be known by transmitting relevant data via a proper interface, defined in requirement *RID 1.3*. The traffic signal system requires an interface to change to another phase. This interface is necessary because the generated phase proposal of the rule-based framework need to to be transmit to the traffic light system.*RID 1.4*. PLC are installed in the traffic signal systems relevant to the project. The phase proposals are sent to the PLC. One task of the PLC is to check whether external signals such as the proposal for the next phase are accepted or not. The PLC decides on the basis of defined criteria whether a phase proposal is accepted or not. *RID 1.5*

In Table 2, the identified requirements for the *5G sensor system* are presented. In the project also pedestrians are considered and they can use request buttons at the intersections. Thus, the simulation needs to consider such functionality for the traffic flow optimization *RID 2.1*. In addition, the project requires detectors to distinguish between different types of vehicles such as cars, trucks of busses, which is set in *RID 2.2*. The used cameras must be connected with each other by a camera system, because they share information about the traffic comprising, etc, detected vehicles and their driving directions, described in *RID 2.3*. Finally, further information from vehicles such as speed or the destination lane is also required for the later optimization. Thus, road side units are installed which needs to be considered *RID 2.4*.

Table 3 shows the identified requirements for the *traffic simulation*. Creating a realistic model from real world data, it must be possible to reproduce the road layout as accurately as possible (i.e., *RID 3.1*). In addition, the traffic simulation needs to consider different road users for cars, buses and pedestrians *i.e., RID 3.2*. For the data collec-

Table 2. 5G Sensor System Requirements

Requirements - 5G Sensor System	
RID	Description
2.1	Request buttons need to be considered used by pedestrians influencing the next phase.
2.2	Induction loops need to be considered counting the traffic and making a distinction between cars, busses or trucks.
2.3	The traffic cameras need to be connected to an intelligent camera system to track each vehicle or pedestrian from entering until leaving the intersection.
2.4	Road side units needs to be included that can communicate with vehicles.

tion, 5G sensor systems need to be adaptable to the changing settings, meaning that properties of the sensor systems must be customizable (i.e., *RID 3.3*). During the simulation the behaviour of vehicles, the pedestrians and cyclists needs to be considered based on statistical information (i.e., *RID 3.4*).

Table 3. Traffic Simulation Requirements

Requirements - Traffic Simulation	
RID	Description
3.1	The intersections need to be modelled closely to the real-world project.
3.2	Different types of lanes need to be distinguished including, pedestrians, bicycles, cars/trucks and busses.
3.3	The 5G sensor systems need to be configurable within the traffic simulation in order to match the real-world project characteristics such as angle of the cameras.
3.4	Behavior pedestrians, cyclists or vehicles needs to be considered within the simulation.

Table 4 shows the identified requirements for the *traffic flow optimization*. The algorithm for determining the next traffic light phase requires the current status of all sensors. This is specified in requirement *RID 4.1*. Requirement *RID 4.2* states that an interface must exist at the traffic signal system for the transmission of a suggestion for the next traffic light phase. For the evaluation of the developed traffic flow optimization, a feedback from the traffic signal system is necessary to see if a proposal for the next phase has been accepted or rejected (i.e., *RID 4.3*). The identified requirements will be used in Section 4 to check which requirements can be fulfilled by SUMO and to identify the gaps.

Table 4. Traffic Flow Optimization Requirements

Requirements - Traffic Flow Optimization	
RID	Description
4.1	The simulation need to request the current state of each sensor via an interface.
4.2	Suggestions or next phases of traffic light systems need to be interface-requestable.
4.3	A feedback mechanism is needed to get information of the suggested phase acceptance.

4 The SUMO Traffic Simulation Environment

In this Section, the requirements from Section 3.2 are compared to the available features in SUMO by performing a gap analysis based on the official documentation of SUMO [2] as well on Lopez et al. [6]. The results of the gap analysis are presented and discussed in Section 4.2. By mentioning SUMO, the whole SUMO package, including all official components, which is available at the official SUMO webpage[3] is meant. By mentioning TraCI, which stands for Traffic Control Interface, the Python[4] based TraCI library[5] is meant. TraCI is an interface to interact with a running simulation, to retrieve current values and to modify simulation parameters and properties of simulated objects. This allows to implement highly customizable traffic simulation models.

4.1 Existing built-in Features

4.1.1 Traffic Light Systems

SUMO offers sophisticated standard functionalities for traffic light system controls, such as fixed-timing control and adaptive traffic control based on detected time gaps [16]. The integration of *traffic light systems* (TLS) into SUMO models can be realized by the following SUMO tools: *netconvert* [17] or the OSMWebWizard[18] to work with real world maps and *netgenerate* [19] to work with generic traffic networks (e.g., grid or spider web shaped). These tools automatically create *traffic light systems* and *traffic light programs* with default settings, which are both represented in XML files. The cycle length is by default 90 seconds and the green time is equally split between the main phases. The created XML files can be customized, by modifying, adding or removing parameters, *traffic light programs* or whole *traffic light systems* to the corresponding XML files. By default, the latest assigned program will be used. Switching between predefined programs can be performed by TraCI or by WAUT switches [16], which can switch between different traffic light programs for different timestamps [16]. To simplify the import of TLS programs from real world TLS, SUMO provides Python scripts such as *tls_csv2SUMO.py* and *tls_csvSignalGroup.py* [16]. Furthermore, it is possible to model induction loop detectors to detect time gaps between vehicles, which affects the phase duration of TLS. Customizing different behaviour for traffic light systems can be implemented with TraCI, which provides various TLS functions [20] like *setPhase*, *setPhaseDuration*, *setProgram* or *setProgramLogic*.

4.1.2 5G Sensor Systems

5G Sensor Systems can be modeled by the offered types of detectors provided by SUMO. There are different types of detectors to retrieve data from intersections, which can be used to optimize traffic light programs. They comprise the induction loop detector (named as E1 [16]), lane-area detectors (named as E2 [16]) as well as the multi-entry-exit detectors (named as E3 [16]). The induction loop detectors are simple detectors to retrieve the number of passed vehicles, the time gap between vehicles, the length and the speed of the passed vehicles. Lane-area detectors represent vehicle tracking cameras for certain areas. Compared to simple induction loop detectors, lane-area detectors track each vehicle that enters the supervised area and measures queues of jammed vehicles, jam length and halting duration. This information can be

[2] https://sumo.dlr.de/docs/index.html
[3] https://www.eclipse.org/sumo/
[4] https://www.python.org/
[5] https://sumo.dlr.de/docs/TraCI/Interfacing_TraCI_from_Python.html

coupled with *traffic light systems* to optimize their programs. With multi-entry-exit detectors (named as E3 [16]) the entering vehicles and exit positions can be supervised and the information can be processed via TraCI [21].

4.1.3 Traffic Simulation

SUMO provides various tools like the OSMWebWizard[18] and the netconvert[17] to create simulation models from real-world map data including road networks that consist of different lane types for cars, trucks, buses, bicycles and pedestrians. The infrastructure, the vehicles, the pedestrians, the routes, the traffic light programs and other relevant information and parameters like simulation time, speed limits and overtake behaviour are defined with a set of XML files. The traffic simulation can be performed in two possible modes: a static mode and a dynamic mode. The static mode uses static settings based on XML files including, e.g., fixed defined routes or speeds. The dynamic mode enables interactive behaviour during the runtime based on TraCI. Additionally, TraCI provides data for each entity of the simulation and the associated parameters can be modified. This allows, e.g., changing routes, speed limits and vehicle parameters during the runtime.

4.1.4 Traffic Flow Optimization

Using TraCI allows the implementation of highly customizable traffic flow optimization modules, which allows to retrieve different kinds of detector data. Furthermore, that modules can also switch between traffic light phases and evaluate traffic flow data (e.g., number of vehicles per lane or number of entering and exiting vehicles per lane). The core task of the a traffic flow optimization is to find an optimized next phase for the traffic light system, for example to reduce waiting times. This information about the next traffic light phase need to be sent as a proposal to the traffic light system by the *rule-based framework*. Also further data sources, like weather data or event data can be taken into account to adjust the simulation parameters according to the real traffic behaviour.

4.2 Gap Analysis

In the following, a gap analysis is performed and presented in Table 5. It shows the requirements, described in Section 3.2, and its degree of fulfillment by SUMO to model the real world scenario described in Section 3.1. The fulfillment differs between completely fulfilled, partly fulfilled, and not fulfilled. The requirements are structured in Table 5 and in the description by the aforementioned topics, comprising traffic light system, 5G sensor system, traffic simulation and traffic flow optimization.

4.2.1 Traffic Light System

RIDs 1.1 to 1.4: The requirements for modeling traffic light systems are completely fulfilled. SUMO provides sophisticated functions to define the phase transitions via different TLS Programs, to retrieve signals from traffic sensors and to change between predefined TLS programs during runtime.
RID 1.5: The requirement is not fulfilled, because the programmable logic controller to accept or reject proposals, which are sent to the traffic light systems for changing their current traffic light program is not part of the SUMO standard functionality and must be

Table 5. Overview of the gap analysis.

Gap Analysis - Traffic Light System Requirements		
RID	Fulfilled	Description
1.1	Yes	SUMO provides customizable TLS-Programs
1.2	Yes	The TLS can be actuated by detectors
1.3	Yes	TLS phases can be switched with TraCI
1.4	Yes	For one TLS several interchangeable Programs can be defined
1.5	No	PLCs are not represented in SUMO
Gap Analysis - 5G Sensor Systems Requirements		
RID	Fulfilled	Description
2.1	No	There is no TLS request button, but this can be emulated
2.2	Yes	E1 Induction Loop Detectors count and measures time gaps
2.3	Partly	Camera interaction can be modeled with TraCI
2.4	No	But 5G Sensors can be represented with TraCI
Gap Analysis - Traffic Simulation Requirements		
RID	Fulfilled	Description
3.1	Yes	SUMO provides tools to import OpenStreetMap data
3.2	Yes	SUMO allows to model different lane types
3.3	Yes	The Sensor Types E1, E2 and E3 are customizable
3.4	Yes	Each vehicle / person can be accessed individually
Gap Analysis - Traffic Flow Optimization Requirements		
RID	Fulfilled	Description
4.1	Yes	TraCI allows sensor value retrieval
4.2	Yes	TLS phases can be changed by TraCI
4.3	Partly	A feedback mechanism can be implemented

extended by a custom implementation. For the integration into the SUMO environment, TraCI can be utilized.

4.2.2 5G Sensor Systems

RID 2.1: This requirement is not fulfilled, because SUMO does not provide traffic light request buttons for pedestrians, but such buttons can be emulated via a custom software implementation by interacting with the simulation by TraCI according to an already existing tutorial[22].
RID 2.2: This requirement is completely fulfilled, because induction loops can be modeled with induction loop detectors (names as E1[16]) and customized with a set of parameters.
RID 2.3: This requirement is partly fulfilled, because traffic camera behaviour can be modeled with multi-entry-exit detectors (named as E3 [16]) to detect source sink relations for each lane, but not for tracking individual vehicles over a wider range (e.g., several intersections). Therefore the behaviour of the AI assisted cameras, described in section 3.1 needs to be implemented, by connecting several multi-entry-exit detectors (named as E3 [16]) via TraCI.
RID 2.4: This requirement for 5G Sensor Systems is not fulfilled. The reason for this can be found in the very specialized use case described in Section 3.1 and in the fact that 5G sensors are not in the scope of the SUMO environment. But their behaviour can be emulated and integrated via TraCI.

4.2.3 Traffic Simulation

RIDs 3.1 to 3.4: The requirements for the traffic simulation are completely fulfilled. SUMO provides all required functions and tools to set up simulation models and to perform sophisticated traffic simulations. The OpenStreetMap[6] Data is imported, processed and a set of XML files are created as output, as shown in Table 6. Additionally to the predefined definitions from the XML files, TraCI allows clients to interact with the simulation during runtime, e.g., to adjust parameters (like routes, traffic light states and speed limits), track entities and retrieve detector values. When the simulation is finished, SUMO retrieves the overall simulation results and writes result files as configured in the *osm.sumocfg* file.

Table 6. Overview of basic XML files for SUMO

Overview of basic XML files for SUMO	
xml file	Description
osm.net.xml	street network with edges lanes and traffic lights
osm.[x].trips.xml	predefined trips for different vehicles / pedestrians
routes.xml	route definition for the vehicles / pedestrians
osm.sumocfg	master file which imports all the other files
osm.view.xml	GUI view settings
osm.poly	polygons (areas and buildings) and points of interest

4.2.4 Traffic Flow Optimization

RID 4.1 and RID 4.2: The requirements on performing traffic flow optimizations are completely fulfilled. The current state of the sensors can be queried and simulation-parameters can be modified at each time-step during the run-time of the simulation via TraCI. **RID 4.3**: The light signal channel does not have a feedback mechanism, but this can be modelled via the PLC. Thus, the rule-based framework initially communicates with the PLC, which serves as the interface to the traffic light system.

5 Concept for SUMO Extension

in the next Section, the *technical concept* is presented that meets the described requirements of the *5G-trAAffic* project. The concept comprises components and interfaces that are required to transfer the reality from the real world project to the virtuality of SUMO. Figure 4 shows the *technical concept*, which is divided into three perspectives: the *reality*, the *modeling* and the *virtuality*. Finally, for rounding off, the fulfilled or not fulfilled requirements are mapped to the technical concept.

5.1 Extension Points

There are two possible extension points in SUMO shown in Figure 5. The first extension point is to use self-provided applications by SUMO and the second extension point is to connect self-developed components via *TraCI*. The two applications *osmWebWizard* and *netconvert* are provided by SUMO. Both can be used to import map materials into SUMO and fulfills *RID 1*. In the progress of the project it may turn out that other applications can be useful, this is represented by the three dots in *Applications*. For importing the map material *osmWebWizard* will be used in the *technical concept* to

[6] https://www.openstreetmap.org

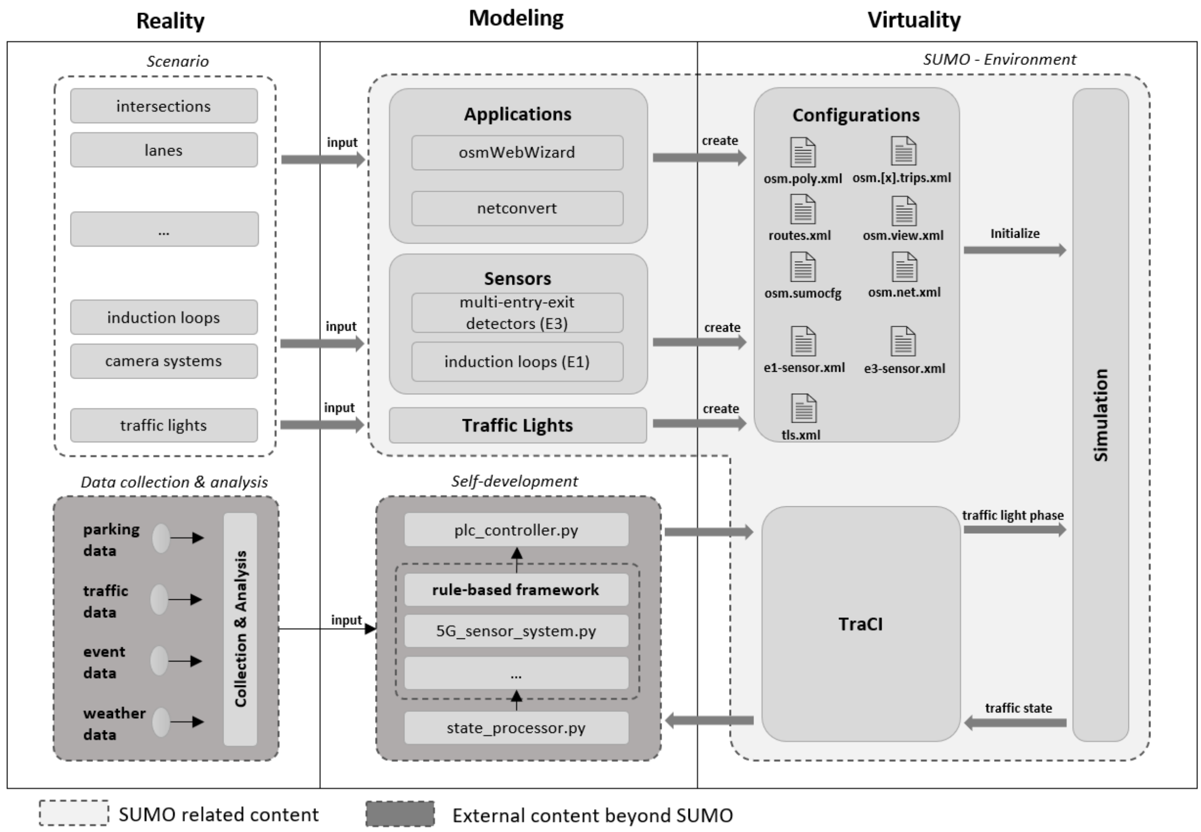

Figure 4. Technical Concept

import, e.g., streets or intersections. The second extension point TraCI which is provided by SUMO is to integrate third-party (external) applications. With respect to TraCI, it allows to interact with a traffic simulation at runtime via programming scripts. Python scripts, for example, can be used to emulate a PLC or the 5G sensor system. The PLC from the real intersection environment is not linked so an own implementation is needed. Furthermore, also states of traffic intersections can be retrieved and suggestions of a rule-based framework can be send back to a traffic light system within the simulation.

5.2 Technical Concept

The two extension points are used to close the identified gaps from chapter 4.2 and convert them to a technical concept.

With reference to Figure 4, for understanding an existing real scenario which needs to be modelled, the *reality* perspective helps to analyse the real-world with its infras-

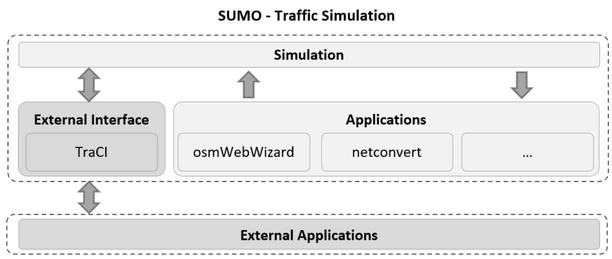

Figure 5. Overview of SUMO's extension points

tructure such as streets, intersections and sensor systems (e.g, traffic signals or other detectors). Furthermore, this perspective gives also insights into relevant data that can be collected from different sources such as vehicles, pedestrians, parking sensors or weather sensors.

After the analysis of the reality, it is possible to create a model from the reality. For this, the *modeling* perspective offers different possibilities to map the reality into the virtual world using different applications or SUMO build-in detectors. This perspective shows two different areas for possible modeling approaches that are necessary to meet our defined requirements of the real-world scenario. The first area refers to the build-in applications, like sensors and the traffic lights that SUMO offers for modelling. To meet the defined requirements, we used the following different modeling approaches. Beside the *osmWebWizard* to integrate roads or intersections, we modelled different lanes and induction loops by using the *multi-entry-exit detectors* and *induction loops*. The existing project's related traffic light programs are, finally, modelled by the SUMO *Traffic Lights* tool including the traffic light programs itself, the traffic light phases, and the state transitions. The second area is related to the *Self-development* of external components which are not or partly included within SUMO.

Finally, the *virtuality* perspective represents the virtual area where different configuration files map the reality and TraCI provides to interact with the the simulation during runtime via an interface between the *Self-Development* and the *Simulation*. The configuration files contain the modeling aspects from the perspecitve *modeling* that arise from the individual applications such as *osmWebWizard*. For instance, they describe the traffic light programs, phases and state transitions for the *Traffic Lights*. The configuration files are XML files that are imported when the simulation is generated.

5.3 Mapped Requirements

In the following, it is summarized which and how the defined requirements are mapped and assigned to the presented technical concept which need to be implemented into the *5G-trAAffic* project.
Traffic Light System Requirements: The requirements RID 1.1 - 1.4 are already fulfilled by SUMO by default. By configuring the XML file, the traffic light programs and phase transitions can be modeled. At runtime, phase changes can be modified via *TraCI*. For the fulfillment of the requirement RID 1.5 an own development is planned. For this purpose, a *plc_controller.py* will be developed to interface the *rule-based framework* and interact with the simulation via *TraCI*.
5G Sensor Systems Requirements: The *Request Button* from the RID 2.1 requirement must be emulated by a self-development, based on an already existing tutorial[22], which shows in detail, how this emulation is performed with *TraCI*. The requirement RID 2.2 is fulfilled and all relevant functions for the induction loop are available. The camera system, which is described in RID 2.3, can on the one hand be mapped via the *multi-entry-exit detectors*, but must be extended by the in-house development. The emulation of the extension is located in the *Self-Development* block in *5G_sensor_system.py*. In addition, the RID 2.4 requirement is fulfilled here, the emulation of the *road side units* as well as the communication between the vehicles.
Traffic Simulation Requirements: The applications provided by *SUMO* meet the requirements RID 3.1 and 3.2. Via *osmWebWizard* the map material can be imported and provided to the simulation as a configuration file to initialize the environment. Requirement RID 3.3 is represented by the *multi-entry-exit detector*, but the extended functionality is represented in the file *5G_sensor_system.py*.

Traffic Flow Optimization Requirements: With *TraCI* the requirements RID 4.1 to 4.3 can be fulfilled. This allows the current state to be retrieved in each time step and individual states to be manipulated.

Traffic Flow Optimization - Planned Process: Starting from the *rule-based framework*, the generated data from the *reality* is included and additionally the emulated data from the *5G_sensor_system.py*. Based on this data a proposal for the next traffic light phase is generated. This proposal is forwarded to the *plc_controller.py*. Here it is decided whether the proposal is accepted or rejected. If the proposal is accepted, the new traffic light phase is sent to the *Simulation* via *TraCI*. The *Simulation* sends via *TraCI* the state of the simulation, which is passed to the *state_processor.py*. The received state is processed and serves as additional input for the *rule-based framework*.

6 Conclusion

In this work, a technical concept was shown that represents an approach how to transfer a running real-world project comprising different types of complex traffic questions into SUMO in order to implement a later traffic flow optimization using a rule-based framework. The described real-world project comprises sensor systems, roads, intersections, lanes and a traffic light system. Based on this, concrete project-based requirements were derived and compared with the current available functions and tools of SUMO. This requirement analysis was based on the official SUMO documentation. It revealed some gaps which need to be closed in order to make the project a success regarding the traffic optimization goals. The result of the gap analysis was then used as input to define a technical concept showing how SUMO can be extended by self-developed extension in order to meet the unfulfilled or only partly fulfilled requirements. The technical concept reveals different perspectives (i.e., reality, modeling and virtuality) with different aspects that are relevant to meet the defined project requirements. The technical concept combines the usage of SUMO's built-in applications as well as the integration of self-developed programs by using TraCI. At the beginning of the work, we expected a higher demand of self-development. We intensively studied the available features of the SUMO environment and were positively surprised that most of the requirements are already fulfilled by SUMO. In our future work we are going to implement the described concept. A later implementation will show how the integration of the self-developed components works in combination with the processing of real-time data from the real-world scenario. A functional and evaluated rule-based framework will be created in the running project *5G-trAAffic* and the results will be presented as follow-up. To complete the picture, SUMO already offers different tools and applications to model many aspects with respect to traffic flow optimization. Therefore, many derived requirements from the real-world scenario were already covered by SUMO. Additional features that include current and future developments of technologies that include new protocols (e.g., a MQTT), more complex traffic logic, or more complex communication functions or associated logic (e.g., Vehicle-to-X) should be considered. However, this work has shown that SUMO enables and makes it possible to model and simulate complex traffic aspects and offers TraCI to apply and integrate self-developed traffic logic, functions and tools.

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