# Use Case Development for Traffic Control in Emergency Situations for Smart Cities

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by

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# Author's declaration

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Stuttgart, September 2014

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**Abstract**

Smart Cities will be part of our future. The need for better interconnection of IT systems working at the city's veins will lead to a sum of different new opportunities inter alia emergency control systems. These systems are especially needed to avoid traffic congestions in emergency cases to ensure a rapid progress for emergency vehicles. New ways of guidance will be necessary to ensure the safety where the infrastructure is already at its limit and a higher utilization rate is still expected. To investigate the technical feasibility of a traffic control system it is necessary to consider different technologies. The designed control system is planned to be implemented using the infrastructure provided by a certain intelligent street lights solution.

**Abstrakt**

Smart Cities werden einen Teil unserer Zukunft darstellen. Das Bedürfnis nach besser integrierten und verrknüpften IT Systemen wird neue Chancen mit sich bringen. Darunter auch Kontrollsysteme für Notfallsituationen. Diese Systeme werden besonders dazu benötingt Staus nach Notsituationen zu vermeiden um eine zügiges vorankommen von Einsatzfahrzeugen zu ermöglichen. Neue Techniken der Verkehrsführung sind dort notwending wo das Verkehrsaufkommen hoch ist und ein weiterer Anstieg dieses erwartet wird, auch um Sicherheit zu gewährleißten. Um die technische Machbarkeit zu prüfen ist eine Betrachtung verschiedener Technologien notwendig. Das entworfene System soll auf Infrastruktur - gegeben von Intelligenten Straßenlaternen aufbauen.

# Contents

# 1 Introduction

Due to urbanization, urban road traffic congestion has become a common phenomena in the whole world [39]. Traffic accidents are a frequent congestion cause. Especially in urban areas they represent a challenge for the infrastructure management. The infrastructure of cities increasingly depends on smart decisions based on data generated by environmental recognition sensors and communication. Any Smart City could be considered as a large network of interacting nodes. Thus, the major goal of Smart Cities is to maximize the amount of interacting nodes for optimizing the communication and achieving a reduction of conflicts which are caused by lacks of information. The street network is one of the parts of the Smart City network where a high reliability is essential. Ongoing urbanization still leads to a dramatically increasing load factor of street networks [5]. This is especially critical in emergency cases. Intelligent Transportation Systems (ITS) could improve the street networks performance using new technologies available in Smart Cities. ITS inter alia support traffic safety and efficiency by providing information about the surrounding situation [26]. Therefore the development of an Urban Traffic Control System (UTCS) for Emergency Situations will be described in this paper. Seeing [7] Traffic Control Systems are a subset of Intelligent Transportation Systems. Considering this, the first steps of the ITS standard system engineering process will be applied (shown in Figure 1) for UTCS development. Further information can be found in [34].

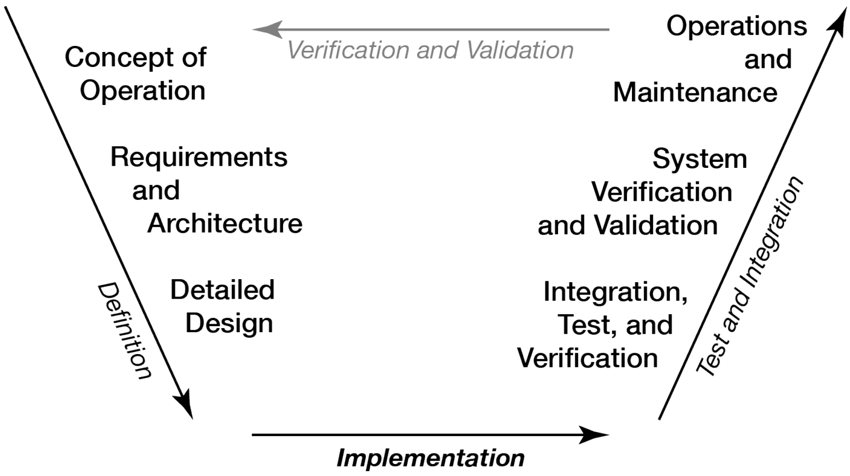


Figure 1: ITS Standards life cycle and System Engineering Process

There are two general use cases regarding UTCS in emergency situations. On the one hand there is a need for traffic control in case of traffic congestion caused by abrupt accidents including failure on nature disaster, failure on terrorist attacks and probability failure [40]. On the other hand traffic control can help emergency vehicles enhance their work routine by preventing delay [4]. Considering this the first case often triggers the second.

Case 1: A general approach to deal with emergency situations caused by abrupt accidents is rerouting the traffic by avoiding specific areas. This could be realized by advanced driver assistance systems (ADAS) that often promise to make the traffic systems more intelligent [24]. ADAS are capable of communicating with other vehicles and their environment. They i.a. include safety systems, comfort systems as well as navigation systems. Latest research indicates a focus on individual and dynamic navigation using residual capacities of the street network [38]. The first step in this direction is done by INRIX, NAVTEQ, Telenav, Apple, Google and others providing life traffic flow information in their maps [18], [13]. Although ADAS are able to communicate traffic and environmental related content and could provide a solution for our problem they are nowadays only included into a fraction of the total amount of cars. A majority of experts do not expect that more than 50% of the cars will be equipped with intelligent navigation systems until 2020 [24]. To reach all the road users another solution needs to be investigated.

Case 2: The siren is the most common medium for emergency vehicles to prevent delay but not always the most effective one. Even using sirens on congested roads emergency vehicles still have to deal with delays. Again there is an amount of road users where one cannot assume they all have ADAS with emergency vehicle announcement functions on-board. In Japan some Emergency Medical Service Vehicles are playing sounds like "The ambulance is turning right" or "We are going through the red light so please wait a moment" [14]. In the US an announcement system included into traffic lights at intersections was introduced by NASA [4]. So there are already established solutions on the market but not one of them is as flexible as it needs to be to involve all road users.

Thus, a new UTCS will be developed with the goal to reach all road users within the frame of the described cases. There should not be any need for additional technologies in the cars, even though the developed Urban Traffic Control System (UTCS) and the Advanced Driver Assistance System (ADAS) could later mutually improve each other's performance. For an independent UTCS Variable Message Signs (VMS) and traffic sensors are needed since they are essential components. The infrastructure provided by street lights will be discussed since intelligent street lighting (ISL) solutions are already optimized for movement detection i.a. using traffic sensors. Intelligent Street Lightning (ISL) itself can be seen as an improvement of dimmable street lightning including different features described in section 2.2. The most important use case nowadays is to make street lightning energy efficient through dimming if interconnected sensors do not detect any type of human movement [27].

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The overall goal is to provide a theoretical solution for a traffic control system in emergency situations as well as a visual demonstration. The theoretical solution includes a description of the used infrastructure, a solution to announce emergency vehicles and reroute the traffic, a discussion about a possible implementation and at last the network communication concept. The conditions for an effective traffic control system dealing with emergency situations as well as all requirements of the sensor network will be outlined. For a visual demonstration a simulation system will be developed which consist of different agents simulating the interacting parts like street lights, emergency management center, traffic management center and the emergency vehicles. Before having a deeper look into the network communication concepts and Intelligent Street Light Solutions the term Smart City will be described first, to set the necessary theoretical background.

# 2 Urban Traffic Control in Smart Cities

The context of Smart City is an important factor for the use case being realized as an UTCS. Smart City with all its attributes defines a place for innovative projects offering different solutions. To have a closer look on that context a definition of Smart City as well as a classification of traffic control follows.

## 2.1 Smart City

The term Smart City is used in relation to the utilization of technology in urban life during different innovative projects to achieve ecologic, social or economic goals [37] [15] [12] [22]. The motivation for Smart City projects is the urbanization that requires a more efficient, effective and reliable usage of the existing infrastructure [5]. This results in a need for intelligent linkage of existing products and processes. Areas affected by Smart City projects are:

- Mobility and Transport
- Information and Communication
- Production and Logistics
- Social Infrastructure (education, health, culture)
- Urban governance and policy development
- Energy
- Natural environment
- Security and protection
- Trade and services
- Urban development and planning (smart buildings, water, waste)

[12] [33].

The following definition (based on statements in [12], [37] and [33]) gives a new, generalized view of the term Smart City.

A Smart City is a settlement area where sustainable products, services, technologies, processes and infrastructures are developed with ecologic, social and economic aspects using highly integrated information and communication technologies.

Navigant Research - which is a market research and consulting team [31] - forecasted the annual revenue by region for Smart City technology. The worldwide forecast for 2023 is $27.5 billion USD of which $5 billion USD will fall under government related applications. The Asian Pacific Region represents the largest region by revenue followed by Europe and Northern America [25].

> [*Richard Martin* [25]] "One of the characteristics that all of the Smart City Applications share is the need for both, power and communication distributed around the city. And that is one of the key reasons why networked street lights are powerful drivers for a range of innovative smart city applications."

As stated by Richard Martin, one important aspect of the Smart City infrastructure for mobility and transport is the Intelligent Street Light - which is a government related application. This application is described hereinafter.

## 2.2 Intelligent Street Lights (ISL)

Intelligent or Smart Street Lightning is a new illumination technology especially developed for saving energy. The street lights i.a. include motion and traffic sensors to detect human movement (cars, bikes, cycles, pedestrians), Light Emitting Diode (LED) lightning and wireless technology to communicate. The lights can be dimmed as long as no human movement is detected [28].

In Figure 2 the energy consumption of a regular Heigh Pressure Sodium (HPS) street light and a dimmed LED Street light is shown. At first the energy savings of the LED system about 70% compared with the HPS system can be observed. Additional the effect of dimming on the energy consumption can be observed for the LED system. At the moment motion sensors detect movement, the LED street light changes from dimming to full brightness. This significant differences in energy consumption between (dimmable) LED and HPS street lights is an important selling point [25].

According to Navigant Research [25] there will be a fast adoption of LED street lightning in the next years since 50% of new street light shipments are already LED based. The forecast of installed LED based street lights in the world indicates that by 2020 25% of the street lights will be LED based.

Eric Woods [**?** ] says that the shift to LED lightning is the perfect opportunity to switch to a smart city solution:

> [*Eric Woods* [**?** ]] "[...] Specifically the cost difference between an LED driver that can accommodate dimming and one that can not is becoming quite small so much so that some companies I talked to are not even charging a difference between those two. Wireless control is also becoming much cheaper."

Wireless communication between the street lights enables a self-management as well as a remote management without any additional underground cables. If an Intelligent Street

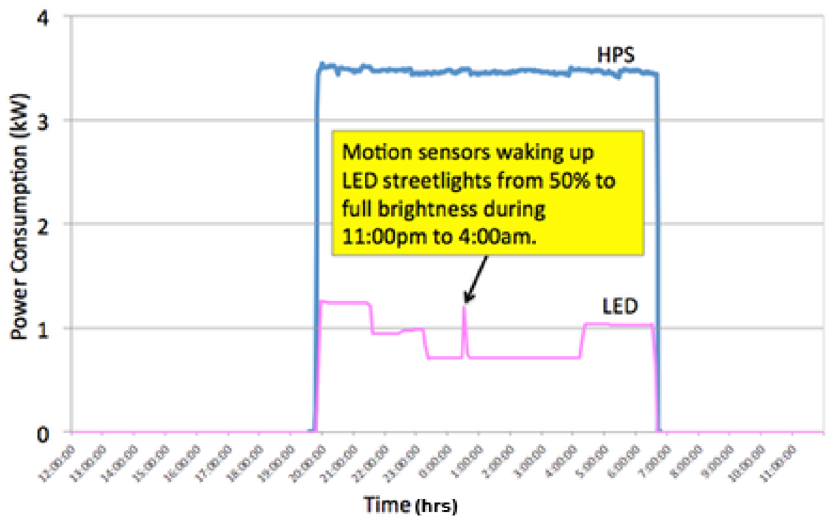



Figure 2: Comparison of electricity consumption of two street lighting systems (HPS vs LED) over the course of a day. Image Source: [32]

Lightning (ISL) solution is installed power and communications are available on poles distributed throughout the city. Sensors, cameras, and other devices can be implemented to provide information on traffic, parking, air quality, security etc. [31]. Some features of existing Intelligent Street Lightning products are listed below.

- Dimming
- Image Sensors
- Motion Sensors
- Traffic Sensors
- Weather Sensors
- Air Pollution Sensors
- Seismic Sensors
- Proximity Sensors
- Gas detectors
- Wireless Communication
- Remote on/off control
- Self Status Check
- Remote Status Check
- System Fault Detection
- Theft Detection
- Remote Monitoring
- Speaker
- Photovoltaic
- Notification Lights
- Digital Street Signs (Display)
- Digital Signal (Display - Controlable advertising panels)

[23], [28], [17], [35]

It can be assumed that not every new implementation of ISL includes all the features one is may be interested in future since every additional feature results in additional costs. Purchasing C136.41 street lights enables adding additional features after installing a minimized LED Street Lightning solution. The Caltech Center for Advanced Computing Research expects 6.8 million Control Node unit shipments in 2023 which are enabling Smart City functions for ISL. This is a growth of 20.4% [25]. The ANSI C136 Series are standards for Roadway and Area Lightning Equipment [3]. Relevant for the Intelligent Street Lightning Solutions are the C136.41 standard with title "For Roadway and Area Lighting Equipment—Dimming Control Between an External Locking Type Photocontrol and Ballast or Driver" and C136.46 "For Roadway and Area Lighting Equipment—Concrete Lighting Poles". Other C136 Standards are focussing for example on Induction Lighting (C136.38) and Solar Lightning (C136.40) [3].

**American National Standards Institute (ANSI) standard C136.41** describes methods of light level control between an external locking type light control system and a dimmable light system for street and area lighting equipment. Mechanical, electrical, and marking requirements are established for dimming and locking type light control systems [3].

**ANSI standard C136.46** applies to street lights used in roadway and area lighting equipment and includes nomenclature, performance criteria, marking and record keeping requirements and certain minimal material needs [3].

Since the developed UTCS will use especially the motion and the traffic sensor they are described next.

The **motion sensors** is used to detect human movement to provide the main functionality of the Intelligent Street Lightning system. The differentiation between movement being caused by plants or animals in relation to human movement is done through analyzing images being captured by a camera [28], [17], [35]. A **traffic Sensors** is in this paper defined as a sensor consisting of a proximity sensor and image analytic software to determine the traffic speed and volume.

To announce emergency vehicles in emergency situations and reroute the traffic in Smart Cities the developed UTCS will take advantage of Intelligent Street Lightning Solutions, however, the term traffic control will be introduced next.

## 2.3 Traffic Control

In the context of traffic control systems the distinction between traffic control and traffic guidance will be introduced. Traffic control is dealing with systems used to ensure the traffic flow under different circumstances. It is reactive to traffic congestion's or other traffic disruptions [39]. However, traffic guidance i.a. includes traffic signs, road surface markings and traffic lights which are basic systems to ensure the general traffic flow and safety[39]. By communicating traffic and environmental related content the performance of traffic control systems can be improved. Actual solutions are for example the ADASs from Apple or Google: CarPlay [18] and Auto [13].

Smart City as the context restricts traffic control to urban traffic control. Since urban traffic control is focusing on traffic control in urban areas the now developed solution is an Urban Traffic Control System (UTCS).

Vehicles are typically driven for 10, 15 or more years [34]. Information Technology and electronic life cycles are often much shorter [34]. Due to this facts working with defined standards is important. Therefore necessary communication standards will be discussed hereinafter.

# 3 Urban Traffic Control System Communication

The developed UTCS is - as already stated in the introduction - classified as ITS. In general ITS systems require connections between diverse entities which are listed below:

- Travelers
- Centers
  - Traffic Management Center
  - Emergency Management Center
  - Toll Administration
  - Commercial Vehicle Administration
  - Maintenance & Construction Management
  - Information Service Provider
  - Emission Management
  - ...
- Vehicles
  - Vehicles
  - Emergency Vehicle
  - ...
- Field
  - Roadway
  - Security Monitoring
  - Toll Collection
  - Parking Management

[34]

Considering the fact that the Intelligent Street Lights are placed along the roadway (which is a Field) for the development of the UTCS the ways of communication shown in

Figure 3 are important. These are *Field to Field communication (F2F)*, *Field to Vehicle communication*, *Field to Center communication (F2C*, *Vehicle to Center communication* and *Center to Center communication.*

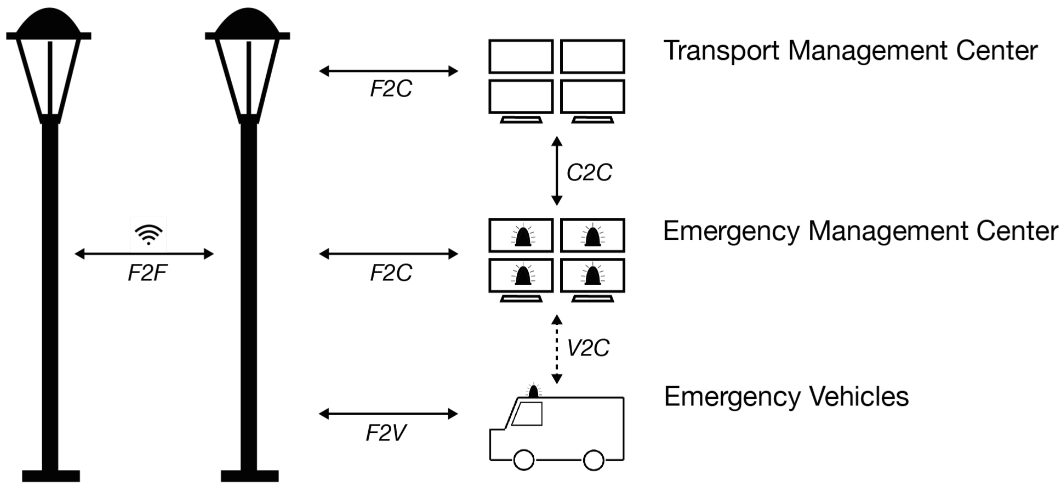



Figure 3: The ways of digital communication in the new UTCS

Before these communication types are now examined in detail a short look at the Open Systems Interconnection (OSI) Reference Model is taken.

**The OSI Reference Model** The reference model was developed by the International Standards Organization (ISO). IT was called Open System Interconnection (OSI] because it deals with connecting open systems. It consists of seven layers. Namely Physical (1), Data link (2), Network (3), Transport (4), Session (5), Presentation(6) and Application(7) Layer.

## 3.1 Field to Field Communication (F2F)

The Field to Field communication is provided by the ISL since they are used as field devices. Papers of some ISL solutions (listed in the Appendix 10.1) are describing different technologies. Tow solutions - both established as standards [10][1] - are outlined next.

ISO/IEC 14908 - also known as LonTalk - is a part of the LonWorks ® standard. LonTalk specifies a communication protocol for local area control networks covering OSI Layers 2 to 7 [10]. It supports peer-to-peer and master-slave control strategies as well as it includes approaches to exchange application and network management data [19]. LonTalk was developed by Echelon Cooperation [10]. Intelligent Street Lights working with this standard are developed for example by Echelon Flashnet, and ITOCHU.

Alternatively ZigBee is a standard being used for wireless communication between ISL. ZigBee is a low-cost, low-powerconsumption, two-way, wireless communication standard developed by the ZigBee alliance. ZigBee is based on IEEE 802.15.4 and working on distances between 10 and 100m [1]. The newest extension of ZigBee is defined in "ZigBee IP" which includes a simple implementation of ZigBee in sensor networks [2].**IEEE 802.15.4** describes a protocol working on the lowest two OSI layers for wireless personal area networks [30]. "ZigBee IP" covers the upper five layers. ZigBee is used for an ISL solution currently by Tvilight.

Other Wireless Personal Area Network technologies can be used for the development of ISL solutions as well until they form a stable network suitable for emergency use cases. Which types of topologies are suitable is explained next.

### 3.1.1 Network Topology

Networks can be of different topologies. The main topologies are known as bus, ring, star, tree or mesh. Combinations of these are hybrid typology. Suitable for the field network are all topologies able to form large scalable wireless networks not be prone to error. Scalability is the ability of the network to change its size without interrupting its service (QUELLE). The field (consisting of Intelligent Street Lights) needs to be scaleable because it should be easy to add more and more Intelligent Street Lights over the time as well as outages of single nodes (Street Lights) shouldn't have any impact on the network. The network is large since it connects Intelligent Street Lights around the whole city. The main topologies are discussed shortly. If there is one condition of the field network not fulfilled for a topology this topology is castaway. The bus topology is not the best one since it is not large scaleable. Since the traffic on the bus increases with every additional node. If the amount of connected nodes increases the network traffic increases. If the traffic increases the amount of collisions increases. If there are many collisions the reliability of the network decreases. This is what should be avoided in a network suitable for emergency use cases. The ring topology would not be prone to error since one node failure would result in a network failure. This can be seen in Figure 13. If there is an outage of one node the ring would not be a ring anymore. The star topology would not be easy to realize since all nodes had to connect to one single point. If the city has an area with bad connection the system could not installed at this area. Additionally the central node is a single point of failure which can be observed in Figure 13. The tree topology fulfills the requirements better than bus ring and star topologies. But it is still prone to errors since failure of the root or any other nodes except leafs affects other nodes. Mesh networks are scalable like tree networks but can simple work around errors using different routing paths. Thus it make scene to organize ISL in a mesh typology. A hybrid topology of tree and mesh could be considerable as well.(QUELLEN)

Both LonWorks and ZigBee can form networks of suitable topologies [20],[11]. A ZigBee network consists of two basic devices. The first is the Full-Function Device (FFD) the second the Reduced-Function Device (RFD). The FFD can operate as the Personal Area Network (PAN) coordinator (which needs to exist in every network once), as a router, or a end-node device. Since a RFD can only talk to a FFD it can only work as end-node device. Figure **??** shows ZigBee networks with star tree and mesh topology. [20]

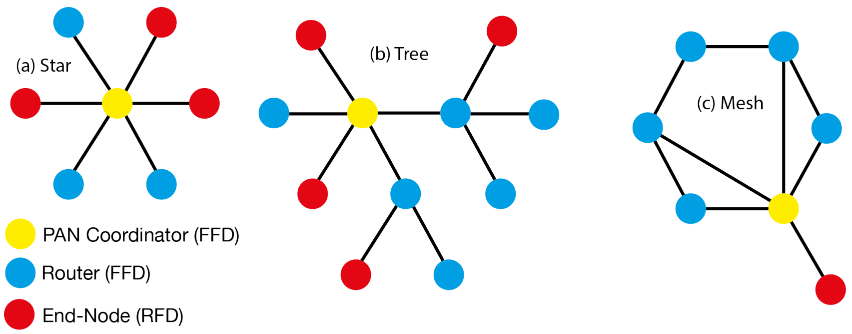



Figure 4: ZigBee networks in Star(a), Tree(b) and Mesh(c) topologies.

LonWorks uses a free topology (FT) twisted-pair technology which means that one can build networks of any type of networking topology. [11]

## 3.2 Field to Vehicle Communication (F2C)

The communication between field devices and vehicles is used for toll collection, driver alerts for critical safety situations etc. [19]. The F2C communication of the developed UTCS will be between **emergency vehicles and the field**. The problem to communicate digital content between a static field and a moving vehicle can be technically solved using the theory of Dedicated Short Range Communications (DSRC) [21]. DSRC technology is mainly developed by the automotive industry for use in vehicle to vehicle and vehicle to field communication. The already existing standards are IEEE 802.11p defining the lowest two OSI Layers for Wireless Access in Vehicular Environments (WAVE) (which itself is defined in IEEE 1609.0), the IEEE 1609.2, 1609.3, and 1609.4 defining Security, Network Services and Multi-Channel Operation (OSI Layer 2 to 6), the SAE J2735 Message Set Dictionary, and the emerging SAE J2945.1 Communication Minimum Performance Requirements (OSI Layer 7). [21]

## 3.3 Field to Center Communication (F2C)

For the communication TCP/IP and UDP/IP at the Transport Layer should is used [34]. For upper layer communication between center and field National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) standards are used in the US. These can be taken as blueprint for standards in other regions. For both **field to transport management center** and **field to emergency management center** the same standards can be applied. NTCIP 1103 defines a Transportation Management Protocol used for information exchange between the two parties. NTCIP 1203 contains messages for Dynamic Message Signs, NTCIP 1104 messages for Environmental Sensor Stations and NTCIP 1206 messages for data collection and monitoring.

## 3.4 Vehicle to Center Communication (V2C)

The vehicle to center communication is only necessary from the emergency vehicle to the emergency center. This communication could be done in two steps: From the vehicle to the field and from the field to the Emergency Management Centrer. Both communication ways have already been discussed. A direct communication could either be done mobile technologies like LTE or via other on board systems not discussed in this paper.

## 3.5 Center to Center Communication (C2C)

The center to center communication provides interfaces between transportation management centers for data archival, incident management, rail coordination, traffic management, transit management, etc. [34]. The standards defined are ITE TMDD for traffic management, APTA TCIP-S-001 for transit management, ASTM E2665 and ASTM E2468 for archived data management and IEEE 1512.x and IEEE P1512.4 for emergency management [34]. The layers are not discussed in more detail since it can be assumed that both centers are connected to the Internet. In this case only the communication between **emergency management and traffic management center** are affected by the UTCS. In IEEE 1512-2006 the common incident management message sets for use by emergency management centers are defined. This includes traffic incidents, public safety traffic incidents and hazardous material incidents. IEEE P1512.4 common incident management message sets for use in entities external to centers are standardized [34]. ITE TMDD is a Traffic Management Data Dictionary (TMDD) containing message sets for external traffic management center communication i.a. including sharing of route information like node list and route length [29].

For the sake of completeness the last communication type not explicitly shown in Figure 3 between the road users and the field is discussed next.

## 3.6 Field to Traveller

The first thing to note is that this is a one way communication between the field and the vehicle driver and not the vehicle itself, since the system should - at first - not end up in an ADAS. This communication is visual or acoustic and works though Variable Message Signs or displays and speaker mounted at the ISL. For Variable Message Signs NTCIP 1203 contains a specification of the logic interface between Variable Message Signs and the host System [34]. This should be considered during development of the API for displays installed at ISL to include these into the set of existing VMS. For acoustic signals no standards have been found.

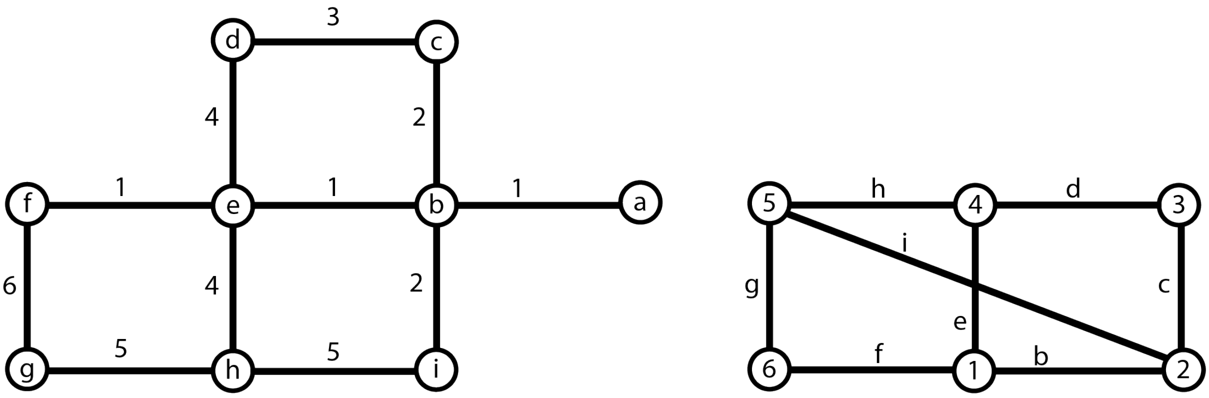
As a further step some basic cartography theory will be described to better understand the development conditions for the UTCS and to find some characteristics of street networks.

# 4 Cartography Theory

The first step is to derive a graph from a map, since a graph can be formalized and then analyzed by computer. For clarification a distinction between *Primal approach* and *Dual approach* will be explained. Both approaches are visualized in Figure 6 representing the map shown in Figure 5. Within the dual approach streets are represented as vertices $V$ and intersections as edges $E$ of the graph [16]. Using this approach a geographical portrayal is not possible anymore [16]. This could be seen in Figure 6 (b). However, within the primal approach intersections are represented as vertices $V$ and streets as edges $E$ [16].


Figure 5: The original map.

Since a geographical portrayal is useful to outline some analogies between the graph and the street network the primal approach is used further on.




(a) Primal approach (a) Dual approach

Figure 6: The primal approach(a) and the dual approach(b) representing the original map in a graph.

## 4.1 The adjacency matrix

The adjacency matrix can be derived from the graph. Since the graph represents the street network, the adjacency matrix represents the street network as well. In formula 1 the adjacency matrix for the (primal) graph in figure 6(a) is shown. Both columns and rows represent vertices. The content of the matrix indicates a connections between the vertices. Thus a 1 in row 1 and column 2 indicates the edge (street) from vertex $a$ to vertex $b$ ($A_{1,2} = 1$). The 0 in row 1 and column 3 indicates that there is no edge (street) from vertex $a$ to $c$ ($A_{1,3} = 0$).

$$A_{i,j} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix} \tag{1}$$

After a representation of the street network (easy to handle for a computer) was shown now a method to find routing paths with different goals is discussed. Both cases mentioned in the introduction need routing. The first to reroute general road users, for the second Intelligent Street Lights need to know the routes the emergency vehicles are driving to announce them correctly. How the routes are calculated is explained representative for both cases by the second.

## 4.2 The fastest path

Since emergency vehicles need to be fast we are interested in the fastest route. To find the fastest route the street network is considered as a directed (there are one-way streets) and weighted graph using the *Primal approach*. The weights are given by a function $Weight : E \to \mathbb{R}$ returning the expected traveling time (QUELLE FÜR MÖGLICHKEITEN WIEDERFINDEN) on an edge $e \in E$ while an edge can be defined as a connection between two vertices $V \times V \to E$. The function values could be based on the current network conditions given by the traffic sensors. Finding the fastest route can now be considered as a *shortest path problem* between the start $s \in V$ and the destination $d \in V$. The result is a sequence $P = (v_1 = s, v_2, ..., v_{n-1}, v_n = d) \in V \times V \times ... \times V$ [16]. Different algorithms to solve the *shortest path problem* are given in (QUELLE SUCHEN). One simple approach is Dijkstra's algorithm.

Taking a closer look at the street network it can be observed that there are main roads which should be favored against smaller roads in traffic-calmed areas. **Functional Road Classes** are - according to [36] - widely accepted for road prioritization. These classes are associated with different factors like traffic flow and road size. According to Hannes Koller these classifications need to be different for Emergency Vehicles since they are allowed to use some additional roads and have different average travel times on the roads. Expertenint

(IDEE Exestienenden INRIX Straßentypen gewichtungen für bestimmte fälle zuordnen wie beim Noronalen netz.)

Now a short excursus follows where a method to find central vertices is presented to make suggestions for areas the UTCS should be installed. Therefore the degree is introduced first.

## 4.3 The degree

The degree exists for every vertex and is the number of adjacent vertices [16]. Thus the degree is counting all streets (leading away) from an intersection. It is defined as follows:

$$d_j = \sum_{i \neq j} a_{ij} \tag{2}$$

For example if $j = 3$ formula 2 returns the degree of intersection $c$: $d_3 = 2$. This can be verified counting the edges connected to vertex $c$ at the primal graph. The degree in street networks is relatively small due to geographic constraints. In average it is around 3

[16]. Also stated in [16] is the fact that 90% of the streets have a degree less than the average while the rest has a degree greater than the average. Since the average degree of street networks is small we are talking about a Small-World Problem [16]. Knowing these characteristics we can not simply assume that areas containing verticies with a higher degree are important areas where the UTCS should be implemented. Therefore a second approach measuring the the importance of nodes is shown.

## 4.4 Central Analysis

The idea is to analyze the amount of shortest paths containing a vertex, concluding that a vertex is central if it lies on many shortest paths. The shortest paths are given as the shortest paths between every pair of vertices. concluding that a vertex is central if it lies on many shortest paths.

$$C_i = \frac{1}{(N-1)(N-2)} \sum \frac{n_{jk}(i)}{n_{jk}} \tag{3}$$

In formula 3 $n_{jk}$ is the number of shortest paths between $j$ and $k$ and $n_{jk}(i)$ is the number of shortest paths between $j$ and $k$ over $i$. $N$ is the total number of vertices and the term $(N-1)(N-2)$ is the total number of possible routes.

Since we have now suggestions where to install the UTCS and all communication partners are known and the basic conditions for the new UTCS are outlined and the most important aspects for the implementation of the system are considered in detail.

# 5 Concept of the Urban Traffic Control System

Applying the input-process-output (IPO) model to the UTCS the system can be split up into a *input unit* including the sensor network and other input sources, a *processing unit* working in the background and an *output unit* directly communicating with the road users. For a better understanding an overview of all used input, output and processing channels is given in Figure 7.

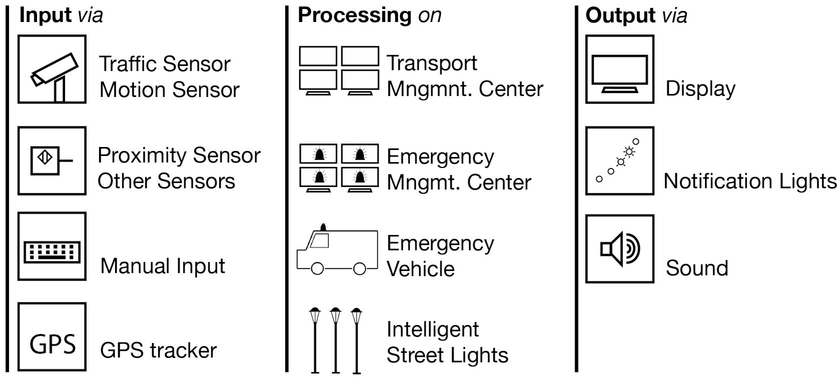



Figure 7: The *input unit* consists of different sensor types, manual input and GPS information, the *output unit* consists of visual and acoustic entities and the *processing unit* is divided into parts running on the Transport Management Center, the Emergency Management Center, the Emergency Vehicle and the Intelligent Street Lights.

As next step the *processing unit* - coordinating all the interacting parts of the UTCS - will be described for the announcement of emergency vehicles (introduced as case 2 in the introduction) and for the traffic control in case of abrupt accidents (introduced as case 1). Then the *input*, *processing* and *output unit* will be discussed for all communication partners individually. The communication partners are agents running on the Intelligent Street Lights, the Emergency Vehicles, the Emergency Management Center and the Transport Management Center.

## 5.1 Announcement of Emergency Vehicles

This part of the *processing unit* is coordinating the announcement of emergency vehicles at the correct time and place to the pedestrians using displays, notification lights and the sound system of ISL. The content communicated to the pedestrians depends on the traffic condition, the emergency light status, the route the emergency vehicle is driving, the actual position of the vehicle and the displays' positions. The displays' are fixed at the ISL and therefore the positions are known. The traffic conditions are given by the Transport Management Center and sensors directly implemented at the ISL. These traffic conditions are mapped to all edges in the *primal* graph. This is visualized in figure 8 for the traffic flow. For example $Weight_{Flow}(edge(a,b))$ would return 42 as time in seconds needed to pass the street and $Weight_{Flow}(edge(b,a)) = 30$. It can be observed that the graph is now considered as a directed one. For this UTCS it is defined that the function $Weight_{Flow} : E \rightarrow \mathbb{R}$ returns $\infty$ if the street (edge) is empty for a longer time and otherwise the average speed of the last detected vehicles. If $Weight_{Flow}(e)$ with $e \in E$ returns $\infty$ the information if the road is locked down or not is also part of the traffic condition. If it is not, the traveling time is assumed to be the edge length in m divided by the allowed speed in m/s. Alternative measurements for the traffic flow are for example average delay per vehicle, maximum individual delay, percentage of cars that are stopped and the average number of stops [**?** ].

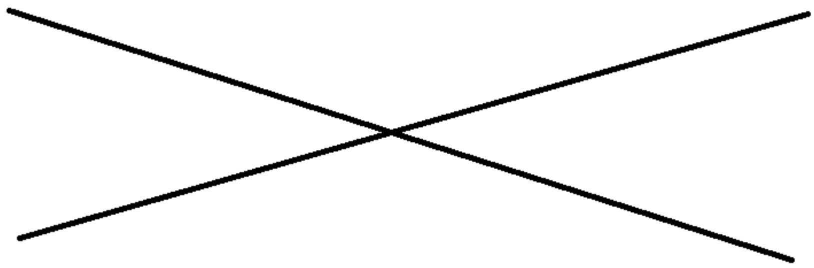


Figure 8: A weighted graph containing the average speed of the last detected vehicles in km/h on every edge.

Knowing the traffic condition and the displays position, the emergency light status, the emergency vehicles position and the route the emergency vehicle is driving are still missing. The emergency light status, and the emergency vehicles position are provided by the emergency vehicle itself directly to the field. It is assumed that the announcement of the arriving vehicle is currently not important if the emergency vehicle has not turned the blue lights on. Using the emergency vehicles position the area where it is announced is is defined as the area the emergency vehicle would drive through in the next 30 seconds. The route is important since the emergency vehicle should not be announced in all streets reachable by the emergency vehicle in the next 30 seconds. The announcement should took place only at the streets being part of the route. Since the emergency vehicle can use roads other vehicles can't a special routing graph for emergency vehicles is needed. This was already described in 4.2. The route calculation will take place at the Emergency Management Center. Now a look at the possible output messages is follows. For the announcement of Emergency Vehicles, displays, speaker and notification lights will be used. The notification lights (one at each street light) are blinking in a coordinated timing to announce a direction on the street, if this direction is not clear intuitively. This is the case if the emergency vehicle is driving in opposite direction on an one-way-street.

The speaker could transmit voice messages or signal tones. Voice Messages are critical since it can not be assumed that foreigners are always able to understand messages in the country's official language. Signal tones again have the problem that the message content is very limited. For the announcement system the signal tones will be used to intensify the displays content, if the system do not detect any positive reaction of the environment until 10 seconds before arrival time. Voice Messages are only used in the pedestrian area counting on effects of swarming. The display will provide very situation specific the messages. A collection of images can be found in the Appendix . The situations considered for this theoretical solution are: Announcement on . . .

(MESSAGE DEFINITION IMAGES)

1. a straight road in direction of the emergency vehicle.
2. a straight road in opposite direction of the emergency vehicle, if it the road users there are is affected.
3. a intersection at the street leading to the intersection on perspective of the emergency vehicle.
4. a intersection at all other streets leading to the intersection.
5. a roundabout at the street leading to the intersection on perspective of the emergency vehicle.
6. a roundabout at all other streets leading to the intersection.
7. a one-way-road in direction of the street, if the emergency vehicle is diving in opposite direction. (If the emergency vehicle is driving in correct direction the first listed situation is given.)
8. a pedestrian area in all directions.

After the main conditions for the Emergency Vehicle announcement have been outlined now the processing unit for abrupt accidents follows.

## 5.2 Traffic Control in Case of Abrupt Accidents

This part of the *processing unit* is coordinating rerouting of road users around an operation area if the street network is affected. In case of an abrupt accident, intersections (vertices) or streets (edges) are affected. They are blocked partly or completely. Considering this the traffic should be controlled automatically based on the analysis of the current network conditions. As output only the displays of ISL are used. The content communicated to the pedestrians depends on the operation area, the traffic condition and the displays' positions. For both - the traffic condition and the displays' positions - the same conditions are given as described in section 5.1. The operation area is provided by the Emergency Management Center. The displays are providing information about the area to be avoided and first steps to find alternative routes. Providing completely dynamic road signage is problematic due to the fact that the provided information would be inconsistent to existing road signage. Additionally the road signage is ignored often, believing the navigation system. (QUELLE)However, also the announcement of first steps to find alternative routes should be explained to the road users showing a short description of the causing event like shown in Figure (BILD "Accident on " ). After the attention of the road users is caught by the ISL the rerouting information is shown. This is based on the traffic conditions. The problem to solve is, that there is no start or destination point given. This problem could be solved by looking for all

EINFALL KOMME - graph traversal? The first step to provide rerouting messages is to find the areas which should be avoided. They could be identified by traffic sensors and self-analysis of the sensor network or the traffic management center.

After the whole system was specified in general we will take a look at the concrete processing from input to the output.

## 5.3 Centralized and Decentralized calculation

In the next step there is a decision to make between a centralized management of the whole system or a decentralized management by many running agents. To make this decision we take a look at the general structure. There are many street lights placed at the roadside. These street lights are connected using mesh, tree or a hybrid of these two as discussed in section **??**. In figure (BILD BAUN mit laternen auf straßennetz und netwerkverbindungen). There are emergency vehicles driving inside the street network and there is one Transoprt Management Center and one Emergency Management center. **Centralized management** from the Transport or the Emergency Management Center lead to a lot of network traffic since all messages would travel from one point to all others. This causes problems since the network has - due to geographical concerns - the property that virtual connections are between physical neighbors. Thus there are bottlenecks at the access points between the center and the field. However, **decentralized management** from agents running on the street lights, the emergency vehicles and the centers would eliminate the bottlenecks and reduce the network traffic. To understand the concepts of agents better a short digression for a definition follows.

> **Agents** According to [**?** ] there is no universally accepted definition of the term agent. But there is a general consensus that autonomy is

> central. In [? ] agents are defined as individual actors or basic entities of actions in a complex adaptive system. Depending on the phenomena of interest, agents can represent a wide variety of entities such as human beings, organizations, objects or concepts. Each agent is is described by attributes and behavior rules.
> This definition is very general but contains already the main idea. Another more specified definition is presented in [? ]: An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives.
> This definition is now used for this paper since it describes very well what the agents of the UTCS are doing.

The agents are autonomous elements working in the "Smart City" environment. The content transmitted to other agents is reduced since every agent is aware of its own content. Still missing content will be requested. But this would be less than if the whole content would send always through the network. But using decentralization would increase the difficulty of monitoring. The first idea to realize the system will be a combination of both explained approaches. There will be agents running on the Intelligent Street Lights, in the emergency vehicles, the Traffic Management Center and the Emergency Management Center. The Emergency and Traffic Management Centers agents will be a "central agents" including administration functionality and providing functionality like network analysis.

For the following description of the agents a short formal concept is given in analogy to [? ] and [? ]. The introduced agents are split up into a *see* function which maps the input of the agent to a perception. The *next* function then maps the current state and the perception to the next state. And as last step the state is mapped to an action using the *action* function. This is visualized in figure 9

The see function is defined as $see : S \to P$ where $S$ is the set of states and $P$ is a set of perceptions. The next function is defined as $next : I \times P \to I$, where $I$ is a set of states, and the action function as $action : I \to A$ where $A$ is a set of Actions.

## 5.4 The Emergency Vehicle Agent

As shown in figure 14 the emergency vehicle is only communicating directly with the field and has a GPS tracker on board. The variables of the emergency vehicle are the route $r$, a timer $t$ and a wireless connection status $c$ . These variables are considered as boolean for the logical operation. If $r = 1$ a route and all meta information's are given, if $t = 1$ the timer is expired and if $c = 1$ there exist a connection to the field.

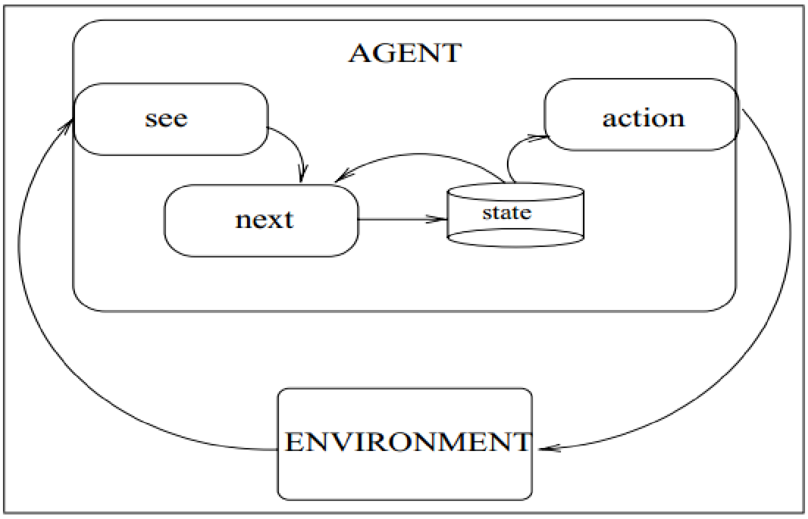



Figure 9: An Agent split up into a see, next and action function using states. Source: [? ]

The set of states is defined as the power set of all variables $S = 2^V = \{s_1 = \{\neg r, \neg t, \neg c\}, s_2 = \{\neg r, \neg t, c\}, s_3 = \{\neg r, t, \neg c\}, s_4 = \{\neg r, t, c\}, s_5 = \{r, \neg t, \neg c\}, s_6 = \{r, \neg t, c\}, s_7 = \{r, t, \neg c\}, s_8 = \{r, t, c\}\}$.

With the following perceptions (again boolean variables) all cases of interest are identified. $p_o \widehat{=}$ "operation", $p_e \widehat{=}$ "operation ended". $p_c \widehat{=}$ "connection missing", and $p_r \widehat{=}$ "route information missing".

Now the see function is given in equation 4

$$see(s) = \begin{cases} p_o & \text{if } s_6 \\ p_e & \text{if } s_8 \\ p_c & \text{if } s_1 \vee s_3 \vee s_5 \vee s_7 \\ p_r & \text{if } s_2 \vee s_4 \end{cases} \tag{4}$$

The states of the emergency vehicle are: $i_o \widehat{=}$ "operation", $i_r \widehat{=}$ "wait for route information", and $i_c \widehat{=}$ "search connection".

Knowing them gives the ability to define the next function. the next function took the current state and perception to evaluate the next state. Therefore the start state is defined as $i_0 = i_r$ and the *next* function is defined in equation 5.

$$next(i,p) = \begin{cases} i_o & \text{if } p = p_o \\ i_r & \text{if } p = \{p_r \vee p_e\} \\ i_c & \text{if } p = p_c \end{cases} \tag{5}$$

It could be observed that the next state depends only on the perception and not on the previous state. Thus we are dealing with a verry simple agent. As last step the action function $action(i) i \in I$ is defined literally. If $i = i_o$ send the route ID , the vehicle ID and the GPS position every second to the field. Then check whether the position has changed the last timer duration (for example 15 minutes). If this is the case reset timer, if not send a signal to the Emergency Management Center and the Intelligent Street Lights that the operation ended. If $i = i_r$ noting is done actively, the agent waits for information. If $i = i_c$ is is searched for a connection.

Now the role of the Intelligent Street Lights follows.

## 5.5 The Role of the Intelligent Street Lights

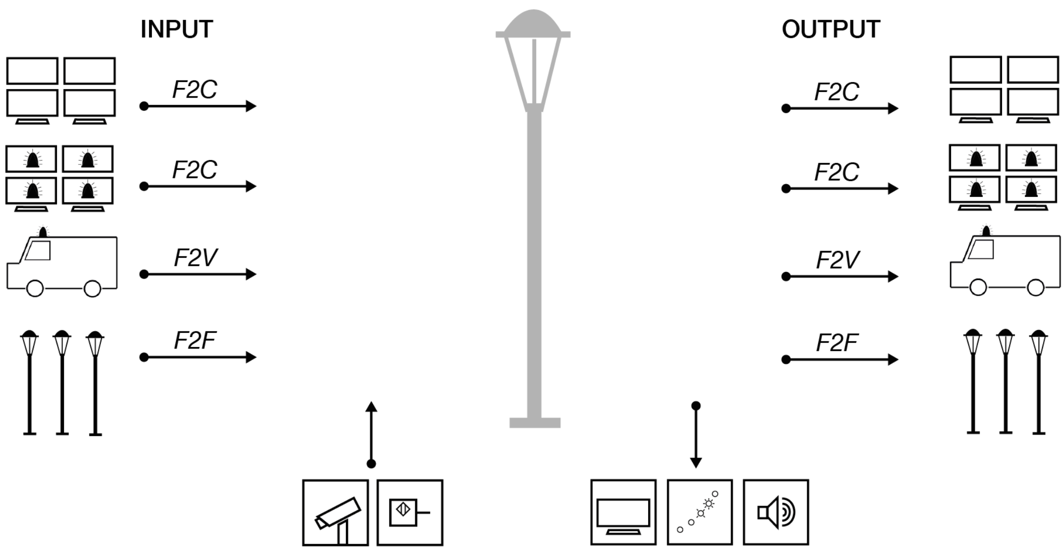



Figure 10: Intelligent Street Light agent overview

The static input of the street light is the information of the environment List with adjacent street lights, i

The dynamic input of the Intelligent Street Lights consist of a motion sensor, a traffic sensor, additional traffic information from the transport management center including traffic flow information and the information if a street is locked down or not route information with associated vehicles,

The combination of Floating Car Data (FCD) and traffic sensors should give precise states of the traffic. For later use four states of traffic will be defined: 'free', 'flowing', 'partially congested' and 'heavily congested'.

Configuration Input: Map with all Street lights. The Own street lights and stati. Connection to the Access point.

Live Input: Emergency Vehicle id input. Emergency Vehicle Signal from other street lights. Emergency Vehicles route.

Processing:

Output: Display, Notification Lights Sound After a while connection to TMC or after a status change.

The information gathered by the sensors are communicated to all adjacent Street Lights to avoid wrong decisions about congested roads. Only if the adjacent sensors provide the same information about the traffic the flag 'high traffic density' will come up. Open parameters are the distance on which a road needs to be congested and the duration in which all sensors on the interval have to provide the same information. These parameters could be defined more exactly after additional research. The time $t$ is assumed as the average waiting time at the upcoming intersection. This could be the typical cycle of the traffic lights at the next intersection.

Intelligent Street Lights, the Emergency Vehicle, the Emergency Management Center and the Traffic Management Center

The route of the Emergency Vehicle need also be known by the ISL since they are announcing vehicles based on this data. This is done using Field to Center communication 3.3. The Emergency Vehicle sends then at least its own ID and the exact GPS Position as well as its Route ID to the ISL to show its presence.

If an emergency Vehicle is announced the default message will be "Emergency Vehicle arriving soon". At intersections is could be an advantage to announce the possible next directions. However each display need to display content dependent from the next displays position.

The exact time when the display should switch content could be defined by an experiment. As estimate 25 seconds before the emergency vehicle arrives on congested roads and 15 seconds before it arrives in partially congested situations.

Open parameters are the distance on which a road needs to be congested and the duration in which all sensors on the interval have to provide the same information. These parameters could be defined more exactly after additional research. Until then the distance $d$ is assumed as the length $l$ of the street (edge) minus a tolerance $d = l \pm 20m$. The time

$t$ is assumed as the average waiting time at the upcoming intersection. This could be the typical cycle of the traffic lights (Ranging between 80 and 180 seconds [**?** ]). As minimum $t = 60s$ are assumed. Quelle raus- suchen

Message Signs $M$ are placed onto edges or vertices. Therefore every node and every edge has a set of Message Signs. As mentioned before the real world messages are represented by displays. For simplicity only displays at ISL are discussed now. VMS and billboards could later be included into the routing system as well as messages in on broad navigation systems. As already mentioned above also the sensor network is provided by ISL.

The displays content is changing from regular content (i.e. advertising) to announce an emergency vehicle if

1. it is an urgent emergency case and
2. the displays position is on the route of the vehicle and
3. the displays direction is opposed to the emergency vehicles travelling direction and
4. the traffic density is to heigh that the siren would be enough to ensure a fast pass through and
5. the emergency vehicle is not to far away (a defined travelling time).

These five conditions are now discussed in detail. An emergency case is defined as urgent if the emergency lights are switched on. If they are turned of the emergency vehicle is considered as a usual traffic participant. A sensor detecting the state of the traffic light is not to complicated to implement into an emergency vehicle.

It is obvious that it would be a big problem if all displays are switching their content if only one emergency vehicle is driving inside the area of one system. Thus the system need to be aware of the position of the display on the street network graph. These are long term informations and defined during the installation and configuration of the system.

Since there is no need to inform anyone travelling the opposite direction as the emergency vehicle the displays direction is relevant to the system. This information is also already given during runtime.

It is expected that only if the traffic density is 'partially congested' or 'heavily congested' the emergency vehicles average speed could be increased significant using the early warning system compared to the siren. Additionally the car drivers are slow enough to imagine the additional signs.

Only traffic participants affected by the pass through need to be informed. This is the case if the emergency vehicle is close and it is coming along a road or intersection the road user is driving on. Now it is observable that the position of the emergency vehicle is relevant.

The displayed messages are composite by a characteristic symbol for the passing emergency vehicle and an arrow showing its direction.

Speaker could provide additional information in special cases. Only in quiet areas there is a sense to use the speakers to get attention. In case of partial failure like blackout battery powered notification lights could be the last backup for an evacuation system

## 5.6 The Role of the Emergency Management Center

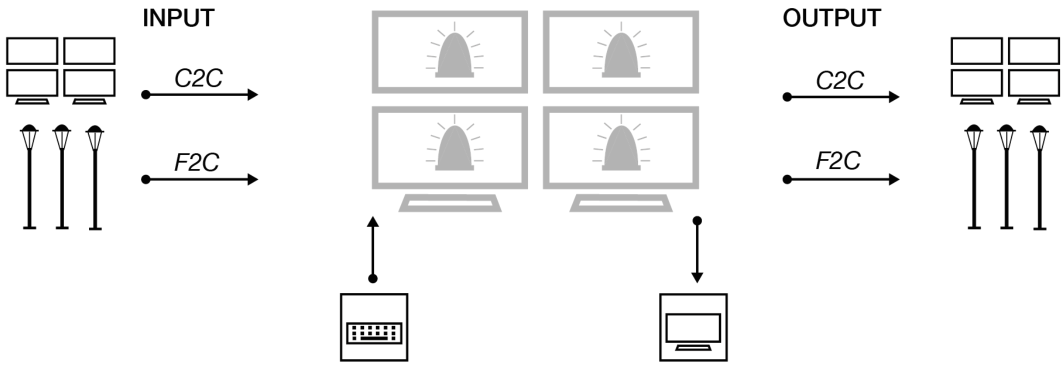



Figure 11: Emergency Management Center agent overview

The Emergency Management Center is connected with the traffic management center and the field. The variables bolean variables of this agent are.

The actions are start operation, send route and vehicle ID, stop operation (delete route at vehicle), send operation area to isl,

These variables are again considered as boolean for the logical operation. If $r = 1$ a route and all meta information's are given, if $t = 1$ the timer is expired and if $c = 1$ there exist a connection to the field.

The Emergency Management center is communicating with the Emergency Vehicles (as Server) and the (as Client) Transportation Management Center.

Live Input: The Emergency Vehicles are sending a state like "free" or "in Operation" and the current position.

Processing: After there is one emergency vehicle connected (mobile internet or other connection in real life (RECHERCE) the Emergency Management Center is randomly sending routes to free vehicles.

Output: Status Logs and Sending the ongoing operations to the Traffic Management Center. The positions of the emergency vehicles are transmitted further to the TMC if it is in operation.

Monitoring View. Information provided by TMC

## 5.7 The Role of the Transportation Management Center

Route inclusive street light list

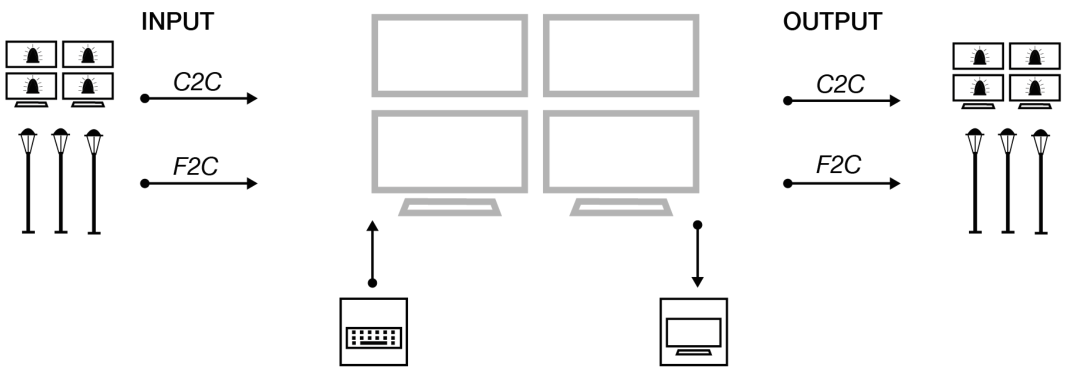



Figure 12: Transportation Management Center agent overview

The traffic management center will administrate the installed ISL and the whole network. Thus the emergency area detection 10.1.1 will run at the traffic management center as well as collect Floating Car Data from the traffic and motion sensors. Thus a Field to Center Communication 3.3 is used. The detected areas will be forwarded to the Emergency Management Center. The Floating Car Data (FCD) could be compared and combined with other FCD collections like INRIX. The combined data could be send back to the ISL and forwarded to the FCD Collections. In addition ISL positioned on streets which are completely locked down as described in 5.1 will be informed by the traffic management center. For administration purposes the traffic management center can request the whole network status to generate the network adjacency matrix as well as physical position, traffic sensor information, motion sensor information, display content, notification light status and speaker message. For monitoring purpose the Emergency Vehicle positions also known by the Field is received. The TMC has the ability to monitor the whole system and influence it in many ways.

timestamps

Klassisch IoT

The information sources about the traffic flow are different. The first source are the traffic sensors included into the Intelligent Street Lights. Then a database like INRIX provides. A third source could be statistical or live Floating car Data from the Traffic Management Center. The information, if the road is locked down or not, could either be

INRIX erläutern

given by the emergency management center in case of an abrupt accident or by the traffic management center in case of construction sites.

Either the route or the address of the emergency case is also given by the emergency management center. In the second case the fastest route is calculated using an on board computer.4.2.

To calculate the optimal route the actual traffic conditions are taken into account. The graph to solve this problem described in 4.2 has to be considered as extended graph including the information if a street is locked down or not.

(kann genutzt werden zur frühwarnung.

# 6 Demonstration Software

Noch komplett zu überarbeiten! Einiges schon wieder komplett verworfen

## 6.1 Processing and Input Simulation

For the simulation some threads are started. These Threads are communicating via Lists. The real world communication is mapped to the communication via lists. Although the Routing is discussed it is part of the lower ISO OSI layers and not of essential importance for the general realization of the Use Case. Considering Intelligent Street Lights which are connected to each other and an access point to the TMC can in the simulation write on the data exchange Lists at to their adjacent ISL and directly to the TMC list. Reaching the TMC is in real world only via Hop to Hop Communication possible. After the Configuration file is loaded, lists for all objects are created: These are the Message Lists for the simulated Communication. Every Emergency Vehicle gets a list with all street lights and its position – by calculating their own position and searching for all street lights in an defined radius. The Emergency Vehicle is then always connecting to the "reachable" streetlights. This simulates in an simple way the reachability.

Let's consider a given path through a Graph. The Goal is to change the state of all nodes on the path. Any node has a function which maps a path to true or false. This is the graph of the street network.

Since there is a abstract graph for the street network the path is given for, but the hardware network consists of street lights placed on the edges of the abstract graph there is a second step needed.

In this step all nodes on the edges of the abstract graph need to change their states. Their state includes a message, a direction and a time for execution.

The intelligence is only placed into the underlying graph of the street lights. The street network graph is virtualized by them to interpret the input in the right way.

Simplest way to virtualize the street network graph. No guaranty for optimized communication. Every street light is part of one edge and maybe one node. Each street light is aware of the two nodes it is between.

For every path that is given a broadcast could be send out. Every node know decides if it has to change the state, and sends the broadcast further. No double broadcasts where send (ID) - inefficient.

If no broadcast is send out the initiator and the path from initiator to start of the path should be given al well. Due to scaleability and outages of

## 6.2 Output Simulation via Visualisation

Comet Programming Overall three tools! One Webpage.(comet programming, osm map, data received from TMC) One TMC (Since this is the Management Tool) providing WEB API ECM API AC API.

And the Simulation Tool running EMC, AC, ISL

For the demonstration a tool including different agents is developed. The tool loads at first configuration files which are containing all the information to setup a simulation environment. The output is a log about all state changes and different .geojson files. These files can be loaded into the Visualization displaying snapshots during runtime.

For simulation four agent types are defined: 1. Emergency Vehicle 2. Emergency Management Center 3. Traffic Management Center and 4. the streetlights. Since the above discussed functions are all playing its role in ISO OSI Application and Presentation layer these are the Layers being simulated. The Networking related Theory is already discussed. None of the agents functionality should be influenced by the lover five OSI.

# 7 Changes in the Infrastructure and Driver Acceptance

This UTCS will be additional infrastructure in an urban area. Visible for all citizens are the changed behavior of the street lights and the new devices installed at every street light. The devices installed at the street lights are namely in this case displays, speaker, notification lights and sensors i.a. including a camera. With changed behavior dimming and the announcement of information is meant. For all changed behaviors it needs to be ensured that the traffic safety is guaranteed. Another key success factor for the future implementation of the UTCS is in understanding how the citizen will experience and respond to this changes. Since - as almost every new ITS has - this UTCS has to deal with the challenge of driver acceptance. For a success of the UTCS it should be ensured that the system is widely accepted. To ensure this the system design of implementation and support need to be done considering some acceptance indicators. To not exceed the limit of this paper only a collection of social indicators from [**?** ] and [**?** ] follows. Studies on the expected acceptance need to follow later on.

- Social norms
- Personal aims
- Responsibility awareness
- Problem perception
- Information and knowledge about the problem
- Perceived efficiency
- Perceived effectiveness
- Perceived usability
- Perceived usefulness
- Satisfaction

was ist die beste technologie für das system 1. Call mit durchbesprechen mit ait besprechen - parameter auf den tisch legen -> daraus folgt eine präsentation -> country manager mit presentation - > dann brainstorming für aktuellen kunden

PreSales Leistung! PreSales Projekt -> SOAR Prozess (ES) Opportunity allesment SOAR Gesetze

Some presuppositions for a higher acceptance of the system are that messages displayed should not give any room for misrepresentation and a high reliability is guaranteed. Even if this should be analyzed in detail later one critical aspect has to be outlined now. This is the *"Big Brother effect"* the system can have. The user may feel uncomfortable being watched by an citywide sensor network individually.

# 8 The Result

Referenz auf the Prozess am anfang - echte implementation mit welchem system?

# 9 Summary

# 10 Further Developments

In the future this Use Case will be implemented at first in a test environment and then in real cities. Until then some ... taking a look at the ITS Standards live Cycle and System Engeneering Process It can be said that the concept of Operations as well as the Requirements and Architecture are developed now!

Since many ITS are in development right now there will be a lot interesting developments in this area. To see what could be done to integrate them all and what could be done following the Smart City approach some Ideas are listed below. For a first step FCD systems could be included into this System and vies versa for more precise informations in both systems.

The Field to vehicle communication could be used to communicate with regular vehicles using ADAS to extend the output system. The car is now able to include this information into the internal navigation system or in systems for autonomous driving. Replace traffic light systems and prepredict cars at edges by intelligent street lights - In you car nobody can hear you scream [9]

Neuronales Netz.

City evacuation informations could be provided using the *Output Unit* of the System. This could improve crowd control and would make evacuation more dynamic. Using image sensors Intelligent Street Lights could also detect crowds of people and their emotion. Thus they could provide a early warning system for emergency cases.

Other Systems on the backbone of Intelligent Street Lights could be notifications for available parking spots or electrical vehicle charging stations. According to Mark Carter [8] Light sensor-based adaptive tunnel lighting can reduce glare and accidents. Light sensing at the entrance and exit of tunnels and controllable lights would be everything needed. That is close to the statement in the Study [6] that proper light control strategies at the intersections can reduce night crashes by 12% Source.

## 10.1 Additional Output Units

To provide the necessary information to the road users up-to-date UTCS systems take advantage of VMS placed into the street network [41] as well as displays in cars and smart phones. In emergency situations even more displays could used for the UTCS System. Displays included into ISL are expected to be appropriate for the early warning system since they are placed on every road in short distances. Including Speaker and Notification Lights these features completely represent the *output unit* for the announcement of emergency vehicles. The *output unit* for rerouteing could use VMS and displays of intelligent street lights.

# List of Figures

# List of Tables

# Listings

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# Acronyms

**ADAS** advanced driver assistance systems.

**ANSI** American National Standards Institute.

**DSRC** Dedicated Short Range Communications.

**FCD** Floating Car Data.

**FFD** Full-Function Device.

**GPS** Global Positioning System.

**HPS** Heigh Pressure Sodium.

**ISL** intelligent street lighting.

**ISO** International Standards Organization.

**ITS** Intelligent Transportation Systems.

**LED** Light Emitting Diode.

**MAC** Medium Access Control.

**NTCIP** National Transportation Communications for Intelligent Transportation System Protocol.

**OSI** Open Systems Interconnection.

**PAN** Personal Area Network.

**RFD** Reduced-Function Device.

**UTCS** Urban Traffic Control System.

**VMS** Variable Message Signs.

**WAVE** Wireless Access in Vehicular Environments.

# Glossary

### locking type

photo-sensor....

# Appendix

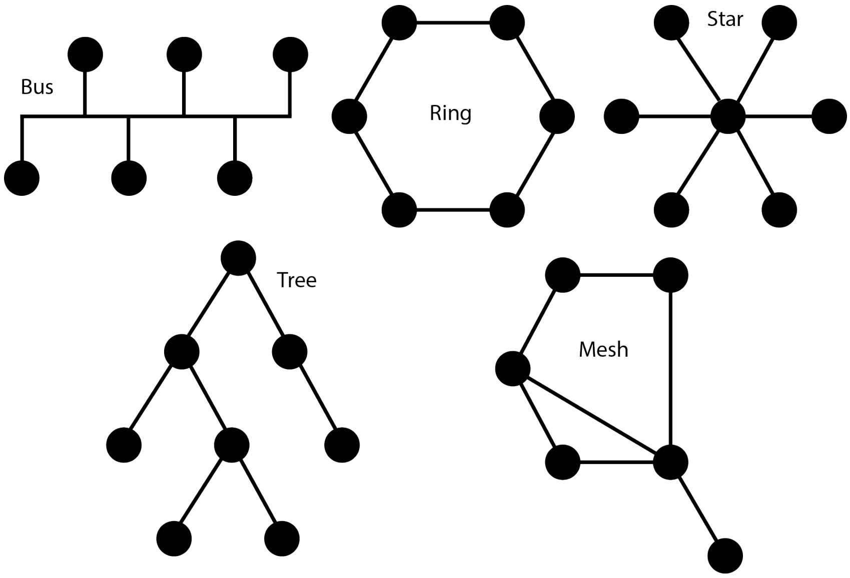


Figure 13: Network Topologies; Bus, Ring, Star, Tree and Mesh

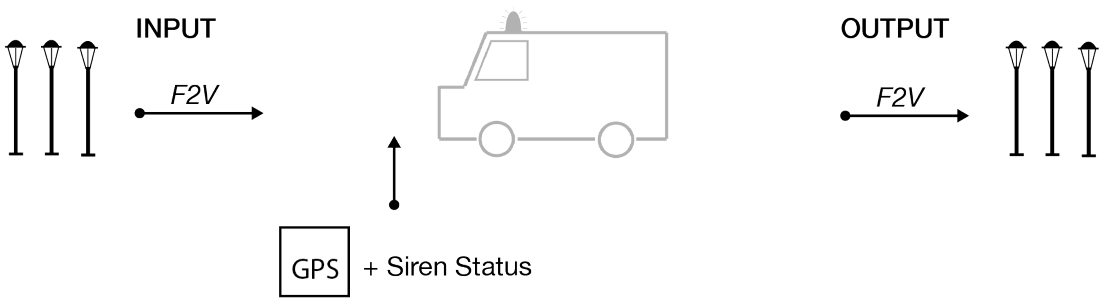


Figure 14: Emergency Vehicle agent overview

## Key Industrial Players

### Lamp and LED Vendors

- Bridgelux

- Cree
- GE
- Lighting
- OSRAM
- Philips

**Luminaire Vendors**

- Acuity Brands
- Eaton Corp.
- Electrical Group/Cooper Lighting
- Hubbell Lighting
- Panasonic
- Sol
- Thorn Lighting/Zumtobel Group
- Swarko

**Controls Vendors**

- Echelon Flashnet
- Illuminating Concepts
- ITOCHU
- Schneider Electric
- SELC
- Sensus Streetlight
- Vision Silver Spring Networks
- Tvilight

Source: Navigant Research
DSRC standards are listed below.

- **ASTM E2213** is a standard specification for telecommunications and information exchange between roadside and vehicle systems working with 5 GHz band including DSRC Medium Access Control (MAC) and Physical Layer Specifications.
- **IEEE 802.11p** also describes an information exchange standard for local and metropolitan area networks including MAC and Physical Layer (PHY) Specifications.
- **IEEE 1455** contains standard message sets for vehicle communications.
- **IEEE P1609.0** introduces the WAVE architecture working from OSI Transportation to Application Layers
- **IEEE P1609.1** describes resource management for WAVE.
- **IEEE P1609.2** is currently being developed and will define security service and management messages for WAVE.
- **IEEE P1609.3** defines networking services at the Transportation Layer for WAVE.
- **IEEE P1609.4** standardizes multi-channel operations for WAVE.
- **IEEE P1609.11** defines a Over-the-Air Data Exchange Protocol for WAVE in ITS.
- **SAE J2735** is a dictionary containing Message Sets for DSRC.

[34]

## The Shortest Path Problem

### 10.1.1 Emergency Area Detection

System fault detection could be used to find disaster situations automatically. The basic idea is to search for areas where a sum of nodes in a small area change their states in a short time period. Assuming that there is something unusual happening these areas should be checked for an emergency case since the probability for a disaster is increased. This change could be caused by a sensor or a complete outage of a node. If the analysis of the sensor status changes is done statistical data can teach the algorithm to not detect queues at traffic lights. Complete outages should be rare, thus areas where status changes of many nodes in a small area in a short time period and a self learning algorithm would not be necessary. At first the analysis for complete outages is discussed before the second case is derived from it.

Assuming that the network status - showing all the connections between the nodes (Intelligent Street Lights) - can be considered as graph with an adjacency matrix like the matrix in 1. If one node fails all connections to this node would be lost and the matrix would contain a zero-row and a zero-column. Like 6 for the node $b$ and $c$ has. If more than one node fails there are as many zero-rows/columns as nodes failed in the matrix. Assuming that the network typology is a mesh the connections between the nodes are related to physical position of the nodes. Thus if in regular a network connection between these failed nodes exists they are inside a small area. To determine if there is in regular a relation between the failed nodes exists it is searched for traversals inside a graph on basis of a adjacency matrix containing the regular network status but only the nodes with zero-rows/columns in the live matrix.

$$B_{i,j} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \tag{6}$$

In 7 the original matrix oly for $b$ and $c$ is shown. It can be observed that they had a connection and are close since there is a traversal of size two possible.

$$C_{i,j} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \tag{7}$$

If a connection failure happenes to all adjacent nodes of one other, this node is not reachable anymore and therefore defined as failed. Assuming that lost connections would be reported to a monitoring node the analysis could ran always when a defined number of nodes failed in a defined time period.

Nach dem Prizip eines Überlaufabflusses... analyse wird gestartet wenn es überläuft.

This method could also be used for sensor status evaluation if limits are defined for special situations and then a matrix like the adjacency matrix is created.