Concepts of Complex Road Information Systems in Urban Areas

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Abstract: The supervision and maintenance of public roads is a state and local government task. In short, it is a public duty. On the contrary, there is a few information about the main and the secondary road network. The special condition, quality and traffic information of the road network, with meter accuracy, is not known. Nowadays, most of the time, the basic data of the road network (state, traffic, restriction, speed limit) are not known and cannot be studied. In Europe, there are few places where a meter-accurate survey has been made, and there are many variable-based databases that would allow for further renovation, development and future planning. The developed concept, aims to provide solutions for these, which assesses the physical and traffic condition of the roads, and based on these, proposes the implementation of a complex road information system. The proposed system covers three areas, such as (a) Road condition monitoring, (b) Traffic monitoring and (c) Monitoring of parking lots. The key question of smart city concept is the enhancement and availability of difference services while exploitation of large-scale data. This article offers a concept for a realization for a road information system.

Keywords: Road condition monitoring; Traffic monitoring; Parking lot monitoring; Information system; Urban/state road-renovation; Data collection; Bus company

1 Introduction

If we look at the state of our roads, there is no accurate knowledge in the city information system concerning the current conditions of the roads. Additionally, if we consider another problem a lot of accidents happen every day and not much is done against these. Therefore, the importance of strengthening traffic safety, and the establishment of speed limits and traffic zones is raised. However, the basis for this can only be if we report with more information, if possible, with real-time information about the physical, traffic, and saturation conditions of the public roads.

The road assessment carried out so far partially supported and helped the information system that can be implemented on a complex basis. The authors designed a complex information system using engineering technologies that are in use today. Our scientific goal with this article is to prove that such a system can be built only with the use of previously existing elements. Thus, significantly reduces the operational cost of the system.

The implementable information system operated by a city covers 3 main areas, which are presented in the article. Compared to the existing systems this information system covers multiple fields of operation with only one (and affordable) data source. Furthermore, it allows a time series analysis of the data.

a) Dynamic road condition monitoring
b) Traffic monitoring in the intersections and zones
c) Parking space monitoring and parking surveillance system

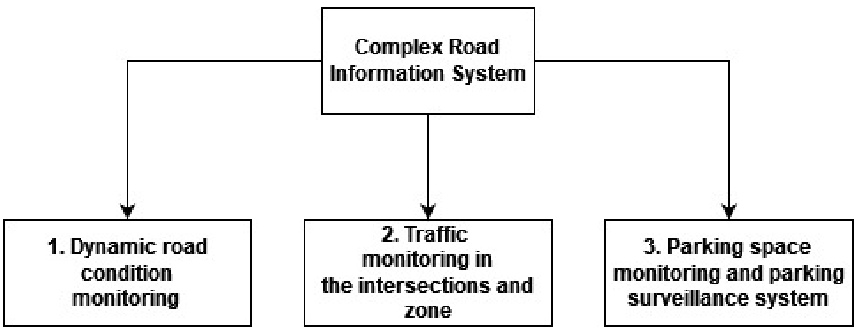

Figure 1
3 main areas of the Complex Road Information System

As a first step, these important road tasks could be implemented by integrating them into a common city information system. This common system with 3 areas could later be applied.

Since the low-cost implementation and the price sensitivity is important, therefore the system should be easy to build and affordable. For this reason, the size of the data set is more important than data accuracy. It is more important to have a large amount of data than to have a very accurate data set.

In addition to the posted specific road devices, data from surveillance/security cameras and urban weather sensors can be used with a great effect. It is necessary to use their road status data together with the devices to be installed. In this way, the total cost can be reduced, and the system integration can be increased. Furthermore, it is possible to run the system together with city information system. (e.g., surveillance camera data)

It is along these lines that the authors of this article have developed the pilot concept of Complex Road Information System to answer the following questions:

1) How can the condition of the entire road network of a given area (the administrative territory of a city) be sensed and a continuously updated database built from the data obtained?
2) How can this database and its analysis be made available to decision-makers through a management information system?
3) How to measure the traffic load on the road network and thus traffic management solutions based on real data?
4) How can the relationship between road condition and traffic load be analyzed, or other factors (e.g., weather) be included in the analysis?

We know that there is technology where a camera and a programmed algorithm can be used to measure a stretch of road and map the defects on it. [1]

It is assumed that this system can effectively support decision makers (e.g., road maintenance, traffic controllers, local governments etc.) in their daily and strategic decision making

The main research gap covered by this article, is how the 3 different subsystems as area (a, Road condition monitoring; b, Traffic monitoring and c, Monitoring of parking lots) can synergistically form a common system and help the decision makers for the future interventions.

The system was tested, analytically calculated, methodologically justified. Furthermore, a project was set up, which reached the preparation stage. It could be further developed and implemented in a pilot location in the future.

As an achieved result, a proof of concept and a proof of analytical and experimental functions are elaborated. We have achieved this with documented analytical results (TRL 3) based on TRL 9 systems. Thus, significantly reduces the operational cost of the system.

In the following, in Section 2, the literature is reviewed. Section 3 presents the methodology based on evaluation of data of subsystems. The method is applied and verified based on data measured as a Case Study in Section 4. Following these, in the Section 5, the Data availability and the Case study company will be presented. The paper is completed with concluding remarks in Section 6, including future possible research directions.

2 Literature Review

Urban migration is a global trend that looks set to continue unabated in the coming years. This situation will force municipalities to step in and improve their services [2], while maintaining their roads at high costs. In our globalized society, there is substantial competition between nations and cities to develop and maintain smart services. For this reason, we present "City as a Service" for the first in our line in our literature review.

With the emergence of smart information and communication technologies and smart city architecture, transport and transportation, cities are making significant efforts to improve the quality of life and channel the citizens' attitudes. The majority of researchers have divided the smart city system into six main components: smart people, smart government, smart environment, smart transport, smart economy and smart life. Many people have tried to develop this model and to describe and develop different structures. [2-6]

Tran Thi Hoang and his team analyzed more than 600 articles to define this smart city structure, producing a general map of the different decision-making methods used at different levels. An important finding is that smart urban development projects do not take stakeholders into account at many points, and often lack supportive decision-making and advocacy methods and tools to facilitate negotiations. [7]

Among the research directions, an important topic is the description of the potential risks of the system and how to make it resilient to these risks (e.g., COVID-19) and how to make it efficient and sustainable. [3] In addition, compliance with central guidelines and the analysis of different future research directions and the description of development constraints is a very cardinal issue. [5]

The analysis of the relationship between the smart city and the smart grid is also a very relevant topic, in order to provide both useful and high-quality services within the city and to connect the different smart cities and systems (information technology and electrical energy systems). [4], [8-9] Without this, development by the article is also unthinkable. The existence of an information and energy structure is a basic structure, necessary and sufficient for the operation of the systems. [2]

Smart cities, in addition to the above, need to develop a framework of information and communication technologies that can apply technology and data-driven solutions to reduce the burden of population growth. [10] Joshi and his team call for the creation of even smarter systems that optimize the use of limited resources and can ensure sustainable development as meeting the needs of a growing population will soon become critical. [11]

Calzada, in addition to the evolution of technology, points out in his study that the learning process is equally important, and the attitude of policy makers is far from neutral in this situation that requires effective development. [12]

In addition to technology and smart cities, this article also addresses pavement quality and traffic volume and parking management in smart transport. Pothole and road defects detection algorithms have advantages, disadvantages and also limitations. In general, these systems are unstructured and dynamic. [13] Danilescu et al. used a pothole detection algorithm based on skeletonization for road segmentation, while Nienaber and his team built a model of potholes using an image library that combines neural network image processing techniques such as Canny filter and contour detection. This allows pothole detection with an accuracy of up to 80%. [14]

Information from traffic information systems is of great importance for traffic planning and for defining future research directions. [15-17]

Afrin and Yodo, as a researcher duo have conducted probabilistic congestion measurements, from which it has evaluated various probabilistic congestion measures that can be incorporated into future congestion prediction and mitigation plans. In addition, they have identified the current challenges of congestion measurement approaches and propose flexible traffic management for the long term. Zhang and his team explored the effects of congestion by proposing monetary compensation. [18]

Pun et al. present a systematic methodology for estimating traffic using three types of traffic data. Their study validated the performance of the system using an undirected graph without considering traffic constraints and a case study in Hong Kong. [17]

For urban parking, different approaches can be used to determine and estimate the occupancy status of parking spaces [25]. According to Di Mauro, if the configuration of a parking lot is not known, a method based on image segmentation should be used instead of a method based on object detection. [19] But in the future, other parking demand determination methods are possible, such as the drone images taken by Hsieh et al. [20]

The complete information technology infrastructure we use is based on the concept of a transport-specific combined architecture developed by Nagy and Csiszár. [21] The concept is a hybrid cloud architecture and a mix of mobile edge and cloud technology, with object-orientation being an important aspect. The concept they developed is applicable to vehicular network, 5G and IoT devices.

These findings highlight the fragmented nature of prior research in the fields of smart cities and smart transportation, underscoring a lack of comprehensive synthesis. To address this, the domain and the proposed concept of the Complex Road Information System has been developed.

3 Methodology

The concept of the information system can be divided into three areas: determining the condition of the urban road, determining the traffic in the city, and determining parking and parking spaces. All these 3 areas are combined in the information and data model. These subsystems are presented in detail below.

3.1 Evaluation of Road Condition Data

Smart city concepts are about using data collected by sensors in a city to support decision making or to enable the provision of certain services or access to existing services. The services and support systems can be very diverse, ranging from driver information systems to systems supporting public transport or library services, road safety or environmental (emission reduction) systems.

However, the common basis of these solutions is clearly the collection of sensor data, and the automated provision of services based on this data. All smart city solutions are therefore based on data collected by some kind of tool without human intervention.

The road infrastructure's maintenance is a very important task and responsibility of the highway operator [22] and urban road network operator. [23] In the case of the road transport subsystem, for the "city", i.e., the state or municipal organization operating the infrastructure, the key data are the road surface and the traffic on it. Sensor-based collection of these data is therefore the basis of any intelligent transport system. If this data and the sensors to collect it are not available, there can be no smart city or smart transport.

The maintenance of road transport infrastructure requires that the maintenance contractor has up-to-date information on the condition of the road surface and the characteristics of the immediate environment of the road surface. In addition, it may be important to be able to predict the nature and extent of factors affecting the condition of the road surface, such as weather conditions or the effects of traffic diversion. In the 20th century, there were few methods of doing this other than the experience and local knowledge of the experts, but the development of digitalization and sensor data collection offers a solution to this problem.

In fact, the focus of the pilot concept we have started is on data, not on sensor development. The output of existing sensors is used as input to the developed concept. The aim of this area of the concept is to collect data on the state of the road surface, updated as frequently as possible for the proper road status prediction.

This will require designing a system that updates as frequently as possible and automatically detects upcoming road defects from the raw data collected:

a) Pavement breach

b) Chipping

c) Mosaic crack
d) Longitudinal crack
e) Horizontal crack
f) Peeling
g) Pothole
h) Treadmill
i) Mismatch
j) Delamination

The system should then divide the entire road network of the study area into short road section (e.g., 50 m) sections and categorize and display the status of each section on a map interface. By analyzing the historical data processed, it is also possible, after a certain period of time, to make predictions based on past and current conditions. (Figure 2)

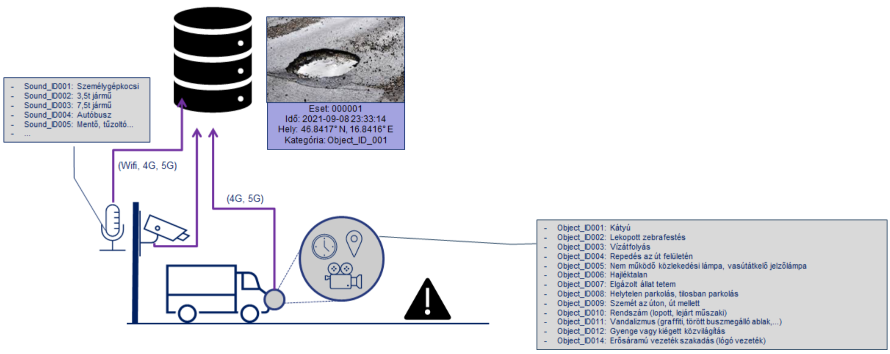

Figure 2
Monitoring of the road surface conditions

A dedicated vehicle could be set up for this purpose. In order to be cost-effective, it is therefore necessary to find a vehicle that is already running on the route to be studied, as the costs of purchasing and operating the vehicle will not be a burden extra cost. Optimally, these vehicles will already have a pre-installed recording camera capable of monitoring the road.

Logically, if the entire road network of a municipality or other well-defined area is to be monitored, the appropriate solution is to use garbage trucks, as they will cover all the routes in the area from which rubbish is to be collected.

However, if it is important to assess the condition of the roads and to look for road defects, in many cases only the roads with heavy traffic are relevant, but also those that connect settlements and carry heavy goods traffic. Their design and maintenance requirements are also very different from those for urban secondary roads. For example, they have to be designed to carry much heavier loads, yet they are more often subject to road defects (e.g., ruts, rises) that can compromise traffic safety. However, these roads are not typically used by refuse collection vehicles. Therefore, if the focus is on the condition of the main arterial roads, it is more logical to use regular buses to inspect the road surface. These buses tend to run more frequently than the garbage trucks, so the sampling frequency may be higher.

In both cases, it is essential to check whether the vehicles themselves are fit for purpose and whether the cameras installed on them are suitable for monitoring the road surface. In addition, it is essential to plan the data flow properly, i.e., how to read the recorded data from the recording equipment and on which platform this data can be analyzed while taking into account legal and technical aspects of data security.

3.2 Traffic Data Modelling, Traffic Zones

The traffic data originates from cameras and traffic counters at specific points in the city. With the collected data of the traffic counter units, the traffic in the different traffic zones can be determined. The given main entry points, at which measurement can be carried out, are located on the borders of the city (and traffic zones). By implementing all of these, the significant traffic of the zones can be determined with a high accuracy. Zones are assigned as in the following sequence.

1) Designation of current traffic measuring devices
2) Traffic counter designation at city border points on the given major access road to the city
3) Traffic counter designation at intersections of transit routes passing through the city
4) Traffic counter designation at main road intersections
5) Traffic counter designation at the main branching of the subordinated roads (which represents a larger boundary, e.g., geomorphological differences, branching at valley entrance)

Considering a city, the points at which traffic counting is already done must first be considered.

After that, it is necessary to mark the entry points of the major access roads to the city. These are the various access roads that enter the residential area of the city. (Figure 3) Thereafter, the intersections and intersections of the transit routes should be indicated, then it can be continued with the main roads, and finally the side subordinated road junctions can be marked, in which it is worth counting traffic.

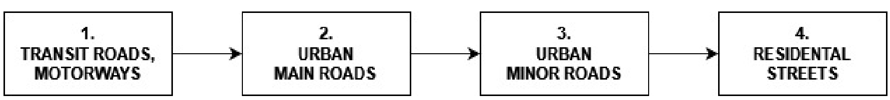

Figure 3
Sequence of examination of road types

In the case of a small town, 20-25 such measurement points are sufficient, in a medium-sized city there may be up to 40-50 measurement points, while in the case of large cities this may be 100-200 points.

This generalized methodology aims to describe traffic flow analysis for a system of zones. It introduces abstract notation that can be adapted for any number of zones and is independent of specific flow configurations.

1) Definition of Variables

The traffic in a system of n zones ($Z_1, Z_2, \dots, Z_n$) is modeled with the following variables:

- τ_x: Total traffic in zone x (per unit time)
- i_{xy}: Traffic flow entering zone x from zone y
- o_{xy}: Traffic flow exiting zone x to zone y
- γ_x: Intra-zone traffic generated within zone xx
- x, y: Zone indices, where $x, y \in \{1,2,\dots,n\}$

2) Zone-Specific Traffic Balance

For any zone x, the total traffic τ_x is defined as the sum of traffic entering the zone, the intra-zone traffic, and any additional sources or sinks of traffic. The general form is:

$$\tau_x = \sum_{y=1}^{n} i_{xy} + \gamma_x - \sum_{y=1}^{n} o_{xy}$$

Here:

- $\sum_{y=1}^{n} i_{xy}$: Total inflow to zone x from all other zones
- $\sum_{y=1}^{n} o_{xy}$: Total outflow from zone x to all other zones
- γ_x: Internal traffic generated within the zone

In the following, for simplification, the two-way flows are denoted by one i, but it refers to the in- and outflows.

3) Intra-city traffic

The intra-city traffic γ_x accounts for traffic that originates and terminates within the two differ zones of city, but within the city. It is calculated as:

$$\gamma_x = \sum_{p} p_{xy}$$

Where p_{xy} represents individual traffic segments or flows identified within the city, between zone x and y. The flow between zones, the inflow and outflow terms are specified trough the main intersections between two zones, as crossing points.

3.3 Evaluation and Utilization of Traffic Data

The data can be collected at specific urban district where the traffic can be calculated with a good approximation for the given zones based on traffic data measured at predefined entry points. Based on the traffic data, the zone traffic loads can be determined. Although mentioned car-focused traffic measurement was mentioned, the installed complex sound- and image-based traffic measurement units can be suitable for measuring the number of pedestrians and cyclists, and for determining road traffic noise levels.

Besides that, there is a great need for dynamic forecasting of vehicle traffic and vehicle congestion during a traffic diversion or road renovation. In a case of large, drastic increase in the number of passenger traffic, transport experts can recommend the development of public transport on the main routes, while in the case of heavy transit traffic (i.e., freight traffic), the construction of the bypass ring can also be based on the measured data.

Data collection can be more accurate if traffic data is collected for different vehicle types. In addition, today's modern camera sensors are also suitable for measuring speed, and thus high-speed drivers can be filtered out by installing the system.

These data can be used by road traffic experts, traffic planners, and city managers for decision preparation and foundation.

3.4 Evaluation and Utilization of Parking Data

Considering a very frequented small town, 15-25 parking zones can be separated in the inner district(s) of the town. If the city did not deal with the analysis of parking data before, then usually the parking lots are characterized by a rising tariff from the suburbs towards the city center. While in the suburbs the parking fee is 0.5-1 EUR per hour, in the inner-city core can be the tariff much higher (2-5 EUR/h). It is not customary to review these tariffs frequently, and ticket prices are increased by the rate of inflation at most after 2-3 years.

Public buses can also be used to check parked cars by a camera mounted in front of the dashboard This is useful because these vehicles can travel and control the road sections with the greatest parking difficulties. No data processing takes place in the vehicles, image transmission takes place, image processing takes place in the central system. Based on this, the toll service provider and supervisor authority can later carry out the checks. For this reason, no one can access sensitive data (number plates, car types).

If a data-based parking can be implemented, in which the various traffic patterns are also observed in the previous period, the price of parking lot really changes accordingly, since when people are doing their task and business in the morning, the price of a parking space is worth more than when no shops are open in the evening.

By raising and decreasing the parking tariff, the need for downtown parking can be reduced (people don't even leave by car/park further outside) or enlarged (vice versa). By increasing the tariff, given areas can be easily freed up in preparation for a specific event (e.g., major sports/cultural event, holiday). On the other hand, by reducing the tariff, the parking revenue can also be increased, since the demand will also increase.

Overall, it can be said that the secondary role of the parking policy is to generate income, the primary role is to displace vehicles in the city center, to reduce long-term lingering, so that the city center is accessible to everyone by public road, and thus everyone can reach the central offices, hospital, and municipality and so on.

3.5 Information- and Data Model

The data model of the system is a complex information technology infrastructure (ITI) capable of processing data, platform technology, network and communication technology. Instead of the traditional infrastructure running on physical servers used in the past, we envision the interconnection of subsystems as a cloud-based infrastructure development. Cloud-based infrastructure can provide on-demand storage and computing capacity, is scalable at will, and is more widely available. With this structure, the joint operation, monitoring and data transport of vehicular network, 5G and IoT devices can be implemented. This ITI system follows the principles of Industry 4.0. [24]

The proposed technology was published in a previous paper by Nagy and Csiszár. [21] The advancement is a combined architecture to achieve two important things: cross-organizational information technology integration through a hybrid cloud architecture and integration of edge devices through a combination of mobile cloud and mobile edge computing networks. This technology is used to connect not only end-user devices but also vehicles to the IT network.

In the system, the infrastructure can connect to the vehicles at the edge cloud layer and the vehicles can interact with each other. This layer also facilitates the development of vehicle networks and IoT applications. Computing capacity sharing, V2V and V2I communication can also be implemented at these connected points.

In the edge cloud layer, mobile devices, vehicle cameras, roadside cameras, traffic counting sensors, and parking sensors can be connected to various smart phones and mobile devices to form a complete, extensive IoT network.

So far, transport companies and organizations have stored data on traditional, robust servers and only collected the target data, on an ad hoc, incidental basis. The new technology collects all possible data from mobile devices and transmits it to the cloud, providing large amounts of dynamic big data that can support further development processes. Examples include multimodal route planning, detour planning, road reconstruction forecasting.

Using this combined information ITI, the system can serve the purposes of the Complex Road Information System.

The data used for the concept can be provided by the specific city where the system can be introduced. Given that the raw data are basically in image and video format, their use is subject to several laws that may affect privacy rights. An analysis of these could be the subject of a separate legal publication, but it is sufficient to note that the raw data are available to the municipality, but the IT system used for the concept must be designed in such a way that it does not contain any images or videos that could affect personal rights.

Accordingly, the system must be designed in such a way that, once the recordings have been analyzed by machine vision, the system stores only the result of the analysis and not the recording itself. Given that the analysis is entirely based on machine vision, which only recognizes vehicle categories and road defect categories, it is possible to avoid that the system identifies individuals or that the recordings can be viewed later by a user or operator or municipal employees.

4 Case Study

4.1 Application Case

While designing the project, the first designated test site of the application case was planned in Zalaegerszeg, Hungary, where this system was planned to be first implemented. The city is located in Western Hungary, in the Zala county, and has 55,000 inhabitants.

Figure 5

Zalaegerszeg area and its international relations

At the regional level, it is placed between Győr (HU), Veszprém (HU), Maribor (SI), Graz (AT), Wiener Neustadt (AT). Two important directions in the city are decisive, the North-South direction, in which significant passing traffic passes through the city center between Nagykanizsa (HU) and Vasvár (HU), and the East-West direction, which connects Keszthely on the Balaton with the national border (Szentgotthárd, HU) and Graz across the town. (Figure 5)

4.2 Dynamic Monitoring of Road Conditions

Based on Figure 6 the currently installed recording cameras are monitoring the road at the right angle and resolution, so the images seem suitable for analysis. The city of Zalaegerszeg, which was chosen as the location for the pilot concept, has a total of about 200 km of roads, of which 180 km are operated by the city. A complete weekly record of this road network represents about 2 TB of data with a resolution of 1080p * 30fps. This is the amount of data that the system needs to scan and analyze in one go. It is an important professional and business decision whether the client wishes to keep all the recordings or whether only the analyses and map conditions based on them will be relevant as historical data.

To save costs, it was decided to store frames taken at selected locations on certain important road sections, but once analyzed, the video footage can be deleted. In this way, the storage requirements of the system are a fraction of those of storing all the footage.

Figure 6

Recording image from the garbage truck dashboard

Although the planned system is experimental, it can perform all the final functions for the municipality of the test city when it is in operation. The most important element of the system is the software environment that can be extended with additional functions or combined with other smart city solutions.

Other elements of the system are the hardware devices through which the sensor data collection is implemented. These are essentially cameras that can be mounted on vehicles to monitor the road and installed at traffic junctions to monitor passing traffic. Of course, there are two different types of sensors: those installed on vehicles as a box solution and those installed at intersections as partly box sensors and partly sensors individually designed and built within the project.

As this is a pilot project, the budget should also take into account the possibility that not all solutions will work immediately, so a significant margin should be built into both hardware and software design. At the same time, in a pilot project, the main focus is on proving the scientific hypothesis and testing the system successfully in operation, so the availability and reliability of the system in the first version does not need to be guaranteed to the same extent as in a live accounting or telecommunications system. Accordingly, security features can be developed after live testing.

4.3 Traffic Monitoring

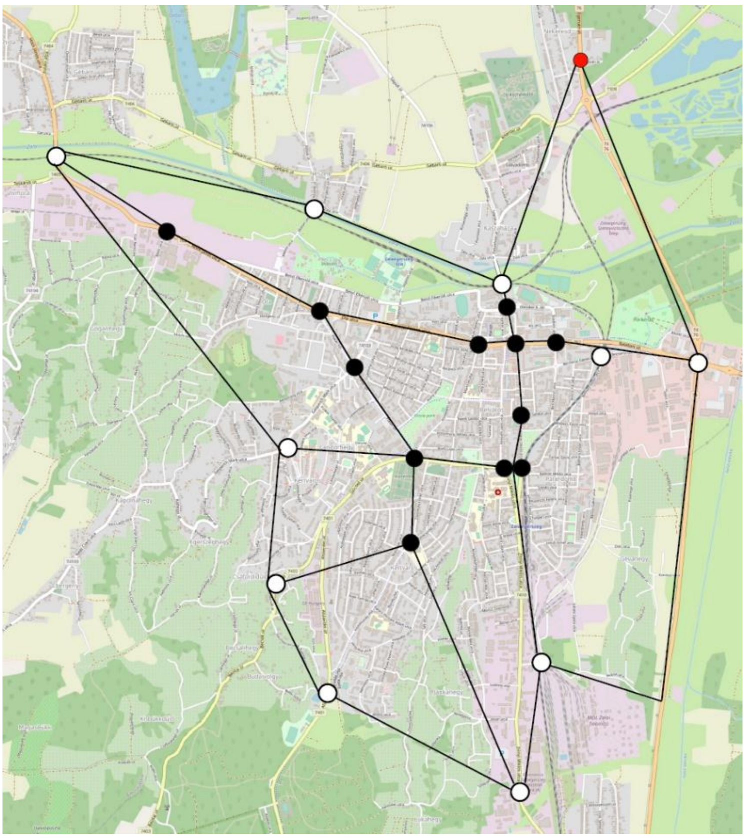

Figure 7

Traffic measurement points, and urban traffic zones of Zalaegerszeg

The traffic zones of the test site are shown in Figure 3 based on entry and important nodes of the city. In Figure 7, one of the devices of the currently operating Intelligent Road Camera Network can be seen in red, in white are the external (city border) measuring points, while in black are the inner-city measuring points.

Let's consider the case of a small town, because the calculation method of concept can be presented here quite well. In the case of a larger city, the previous method can be followed with a larger extent. In the case of the city of Zalaegerszeg, Hungary, there is no built-up highway/expressway ring, so the city's road network handles transit, intercity, regional and local traffic. This provides a completely basic case of zoning traffic. In the case of the example city also shown in Figure 4, there are 9 entry points at which measurements are made, in addition, there are 12 internal traffic measurement points, from which data the flow between zones can be estimated with sufficient accuracy.

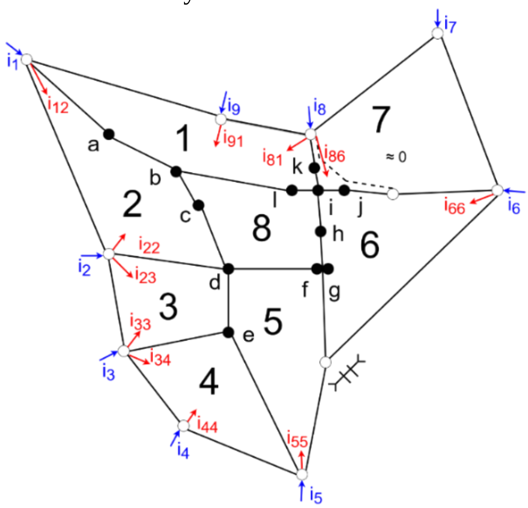

Figure 4

Example traffic network - Traffic zones of the investigated network

The investigated case gives 8 traffic zones, in which the traffic can be approximated by the traffic values per unit vehicle in the traffic zones. The traffic of zone 7 can be taken as zero, because it does not contain residential areas, and the traffic passes on the zone border. The traffic per hour in the given zones was designated with τ_i. Based on these, the zone traffic for zones 1-8. (Eq. (1)-(8)):

$$\tau_1 = [i_{81} + i_{91}] + \gamma_{k1} \quad (1)$$

$$\tau_2 = [i_{12} + i_{21}] + \gamma_{k2} \quad (2)$$

$$\tau_3 = [i_{23} + i_{33}] + \gamma_{k3} \quad (3)$$

$$\tau_4 = [i_{34} + i_{44}] + \gamma_{k4} \quad (4)$$

$$\tau_5 = i_{55} + \gamma_{k5} \quad (5)$$

$$\tau_6 = [i_{66} + i_{86}] + \gamma_{k6} \quad (6)$$

$$\tau_7 \approx 0 \quad (7)$$

$$\tau_8 = \sum_i \gamma_{kx} \quad (8)$$

Continuing the traffic determination, the flow between the zones must be examined through the given internal measuring points. Notation is:

τ_x – total traffic in the zone

i_x – in the zone entering traffic

γ_x – intra-zone traffic

x – serial number of a zone

From this traffic directions, the traffic entering the zone can be determined.

a) 2→2

b) 2→2 1→2 2→1 2→8 8→2

c) 2→2 2→8 8→2

d) 2→3 2→5 3→2 3→5 3→8 5→2 5→3 5→8

e) 3→4 3→5 4→3 4→5 5→3 5→4

f) 5→5 5→6 8→6

g) 6→6 6→5

h) 6→8 8→6

i) 6→8 8→6 8→8

j) 6→6

k) 1→6 6→1 6→6

l) 1→8 8→1 8→8

After that, the traffic volume between the given zones (γ_i) can be specified, which are generated between the internal measurement points. By adding the external incoming traffic to these, the entire total zone traffic (τ_i) can be obtained. (Eq. (9)-(16)):

$$\gamma_1 = b_{21} + k_{61} + l_{81} \quad (9)$$

$$\gamma_2 = b_{12} + b_{82} + c_{82} + d_{32} + d_{52} \quad (10)$$

$$\gamma_3 = d_{23} + d_{53} + e_{43} + e_{53} \quad (11)$$

$$\gamma_4 = e_{34} + e_{54} \quad (12)$$

$$\gamma_5 = d_{25} + d_{35} + e_{35} + e_{45} + g_{65} \quad (13)$$

$$\gamma_6 = f_{56} + f_{86} + h_{86} + i_{86} + k_{16} \quad (14)$$

$$\gamma_7 = 0 \quad (15)$$

$$\gamma_8 = b_{28} + c_{28} + d_{38} + d_{58} + h_{68} + i_{68} + l_{18} \quad (16)$$

4.4 Parking Space Monitoring

All three areas, roadway monitoring, traffic monitoring and parking monitoring can be implemented in a case study of Zalaegerszeg, or for the first time in any significant small town of 50,000-150,000 inhabitants. (Figure 4) By linking these subsystems into a common system, using the complex information technology infrastructure, the Complex Road Information System can be implemented. The parking zones are shown in Figure 7. The zones are marked with different colors. In the gray and pink (P01-P03) zones the tariff is HUF 240, in the yellow (Y01) and green zones (G01-G05) HUF 300, in the red zone (R01-R09) HUF 320, in the lilac zone (L01) HUF 400, while in the blue zone (B01) the parking fee is HUF 520/hour in August 2022. In September 2023, the euro exchange rate is 1 EUR is 390 HUF.

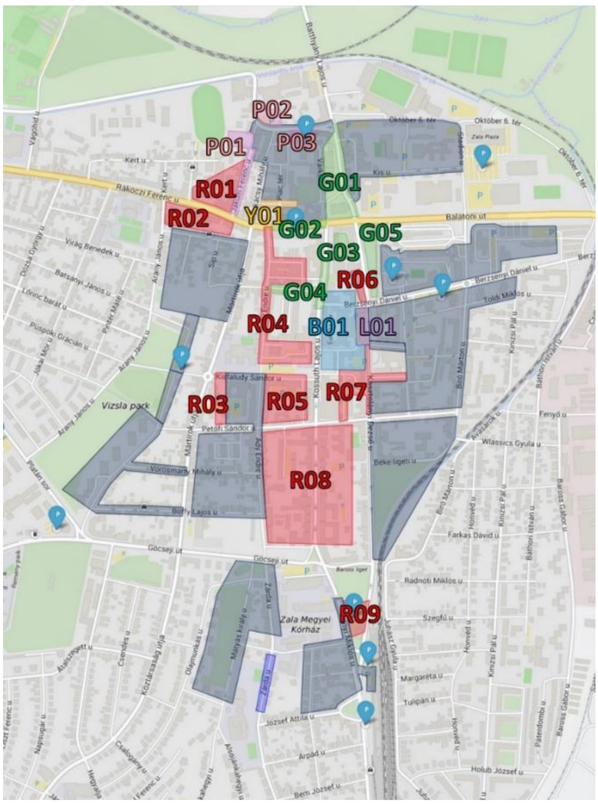

Figure 7

Traffic measurement points, and urban traffic zones of Zalaegerszeg

5 Data Availability and Case Study Company

The data used for the pilot project can be provided by the specific city where the system is introduced. Given that the raw data are basically in image and video formats, their use is subject to a number of laws that may affect privacy rights. An analysis of these could be the subject of a separate legal publication, but it is sufficient to note, that the raw data are available to the municipality, but the IT system used for the project must be designed in such a way that it does not contain any images or videos that could affect personal rights.

Accordingly, the system must be designed in such a way that, once the recordings have been analyzed by machine vision, the system stores only the result of the analysis and not the recording itself. Given that the analysis is entirely based on machine vision, which only recognizes vehicle categories and road defect categories, it is possible to avoid that the system identifies individuals or that the recordings can be viewed later by a user or operator or any other natural person.

Volánbusz is Hungary's largest national bus operator, with around 6,000 buses, many of which are equipped with modern drive trains and are electric. In the future, the company would like to equip more of its vehicles with cameras, for which the described concept in this article could help to provide a basis. This company provides main bus services in Zalaegerszeg, that is why the Volánbusz company was involved.

According to the above written legal conditions, the raw data collected by the sensors will not be available for an audit. However, the system resulting from the project will be suitable for use in any area with conditions similar to those in the test environment. As a result, the results of experimental projects will be reproducible at any time without affecting privacy rights.

Conclusions

The developed (TRL 3, with all elements on TRL 9) system could be used in the following areas, according to the data processing levels:

Operational level

- Influencing the traffic of cities in real time, vehicle entry restrictions.

Tactical level

- Assessing real-time traffic condition of cities and the traffic load of their zones.

Strategic level

- Development of parking systems. (occupancy indication, integration into navigation application).
- Route optimization of scheduled bus trips, real-time route planning,

- Development of public transport system (vehicle tracking, vehicle utilization monitoring).
- Monitoring the road condition of cities, predictive forecasting for the scheduling of road renovations.

In conclusion, the Complex Road Information System represents a significant scientific contribution by integrating advanced technologies and methodologies to create a cohesive framework for urban transportation management for the three area (Road condition-, Traffic-, and Parking monitoring). The key findings reveal that, while individual components may not be groundbreaking, their synergistic combination—encompassing a sophisticated structure, cloud architecture, edge cloud layers, and interconnected measurement tools—yields a powerful and effective system for real-time data collection and analysis.

Through this research, valuable lessons were learned regarding the importance of collaboration with city stakeholders and the need for robust IT infrastructure to support such a complex system. Although the Complex Road Information System has not yet been implemented in practice, ongoing initiatives with urban authorities indicate a promising path toward real-world application.

Future research should focus on the practical deployment of this system, including pilot projects in various urban settings, to assess its effectiveness in enhancing road quality monitoring, traffic management, and parking solutions. Additionally, exploring further innovations in data analytics and machine learning could amplify its potential to predict and mitigate road-related issues, ultimately benefiting urban planning and public safety.

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