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Mobility Data for a Safer and Greener Transport

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Abstract: Traffic network operators are using several channels to share their traffic related data, on one hand because of legal obligation, on the other hand to ensure a higher level of service for their customers. Of course, the value chain, and the provided content will change a lot with the emerge of connected and automated driving, or with the spread of Mobility-as-a-Service solutions and Alternative Fuel Infrastructure Regulation (AFIR) related data sharing in the near future. This paper gives a comprehensive overview of the current practice in Hungary, introducing the ways of distributing multimodal traffic related information, some existing services that were implemented based on these automatic data channels. The paper also gives an overview on the ongoing transition towards automatic data provision and how the regular road operators' role change to digital road operators, furthermore the European harmonisation process that was started in the framework of the Napcore project.

Keywords: Mobility data; Automatic Data exchange; Multimodal travel information; National Access Point; EU Green Deal; MaaS

I. INTRODUCTION

Recently a wide range of Traffic and Travel Information Services (TTIS) are available for travellers. The Reference Handbook for harmonized ITS Core Service Deployment in Europe [1] defined the following five different core services of TTIS:

- Forecast and Real-time Event Information (information about both expected and unexpected events, incidents),
- Traffic Condition and Travel Time Information (information on the traffic conditions – Level of Service, and travel times on identified road segments of the network),
- Speed limit information (static and dynamic speed limits),
- Road Weather Information (road surface condition, visibility, exceptional weather conditions),
- Multimodal Travel Information (comparative information of different modes/means of transport, and/or combination of different modes/means of transport with the same route).

Services and applications available on the market are made up by the combination of these core elements. The main mission of TTISs is to inform travellers about planned, e.g. road works, major (sports) events, closures; or unplanned events e.g. accidents, obstacle on road, bad visibility, slippery road, etc. in order to support them in reaching their destination in a calm and safe way and to provide reliable, and up-to-date information on traffic conditions and estimated travel times to support their decisions on the go. It is also important to mention the differences between traffic and travel information. Traffic information concerns the conditions of traffic, or the state of the road, containing forecast and/or real-time information. Detailed forms of this type are danger or incident waring, and control support information. Travel information is a kind of information or advice e.g. route guidance derived from the actual state of the transport system. End users can decide whether they use the information or advice, or not. Travel information can be used before and on-trip to facilitate planning, booking, and to adapt to disturbances, service changes or any other types of events. Having the proper information, the traveller can even alter departure time, mode choice, take alternative routes, or reconsider the decision to travel.

There are several studies about the positive effects of TTIS. These impacts are related to safety, network efficiency, and environment, however in most cases these are theoretical and difficult to quantify e.g. the provision of travel information on the go has positive impact on road safety because on the one hand drivers will be informed, and aware of the hazards along their journey; and on the other hand well informed drivers are calmer, and refrain from risky driving behaviour.

TTISs are aiming to meet the different needs of the end users. User needs depend on several circumstances, like the nature of travel, or personal preferences, disabilities, etc. Current information needs may also depend on the stage of the journey, the position, or the way one is willing to consume the information. There are several ways to categorize end users, the easiest way is to distinguish private and business/commercial travellers. Private travellers might be commuters, or leisure travellers. Other key actors of the Traffic and Travel Information value chain according to the TISA Value Chain model [2] are the content owners/providers, the service operator (who uses content to generate information with added value), and the service provider (the interface to the costumer).

II. Provision of TTIS in Hungary

Hungarian Public Roads is responsible for the operation and maintenance of more than 32 000 km of national public roads. With regards to its 6000 employees and its economic indicators the company stays within the first ten state owned enterprise in Hungary. Activities of the Hungarian Public Roads consist of operation, as well as the routine and preventive maintenance of the national public road network including expressways and motorways. In addition to that, the Company is responsible for the issue of route permits for oversized vehicles, the control of these vehicles at weight control stations, the provision of trainings for professionals within the entire road sector and the operation of the Road Information Services ("Útinform"), the National Road Databank and the Road Museum in the town of Kiskőrös [3].

Útinform department of the Hungarian Public Roads collects essential information on the circumstances, events and incidents affecting the traffic flow and safety on the national public road network. Based on the collected information, the road users are informed through various channels on every issue that affects the traffic flow and safety on the national public roads, including accidents, road closures and weather-related obstacles. Útinform is not only a division of the company, but it is also the Main Responsible Body for Transport of the Ministry for Construction and Transport, and responsible for the operation of the National Access Point (NAP) in Hungary. Information flow within the territory of Hungary is managed by the Útinform department, but in the Central South Eastern European (CSEE) region, corridors are passing through many different countries, and after a couple of hours driven one can get from Vienna to Belgrade via Budapest. Traffic incidents can have impacts far beyond the territory of a country. Many drivers are foreigners, and major part of the trips start/end in a third country. In this environment only cross border thinking works, and solutions based on cooperation are effective. Standards and corridor projects are really boosting the elaboration of common solutions, and services along the TEN-T corridors as an outstanding European added value of an initiative like the CROCODILE (Cooperation of Road Operators for COnsistent and Dynamic Information Levels) corridor project [4]. Recognising this fact, countries of the region have been working together for more than a decade, in the field of traffic management.

There were several milestones of the co-operation, like the MoU signed in Opatija (Croatia), in 2014. that was signed by the neighbouring road/motorway operator companies in Austria, Croatia, Hungary, Italy and Slovenia. Since then several bilateral and multilateral agreements were signed for specific issues (e.g. exchange of camera images). Since 2014, Hungarian Public Roads together with its partners is continuously working to fill the signed cooperation agreements, and made a huge step forward from keeping in touch via e-mail to implement automatic data exchange and launch an Application Programming Interface (API) developed for DARS, Slovenia to initiate cross-border traffic management measures. There are bilateral agreements on the exchange of webcam images and automatic data exchange based on DATEX II signed with the ASFINAG and DARS, and in December 2022, an agreement of similar content was also signed with the Croatian partner (HAC). The results are already tangible: the webcams of the partner companies are now available via the Útinform website, and vice versa.

Meanwhile a system based on dynamic and static network models (PTV Optima) were introduced on both the Slovenian and Hungarian sides. This system provides reliable traffic forecasts, with or without specific traffic management measures, which might be a higher level in elaborating, and executing cross-border traffic management plans. The technical preparation of linking the two models is currently underway.

III. Objectives

The European data strategy aims the European Union to become a leading player in a data-driven society. Establishing a single market for data could allow the free movement of data within the EU and it should also enable the European Union and its Member States to chart a data economy where public and private interests are balanced. By 2025, the value of the data economy in the European Union will be close to 830 billion euros, compared to 300 billion euros in 2018. Thus, the data-based economy is a lever to foster the emergence of a 3.0 mobility industry, based on intermodality and diversification of services to citizens. Data-based technologies will also make it possible to limit the impact of the transport sector on the environment. Indeed, data is the fuel for technological development in the transport sector and the digital transformation of infrastructure.

Consequently, access to a volume of quality data and the value it generates are essential for innovation in transportation: traffic regulation, improved safety, and supply chain optimization. For example, road transport navigation using real-time traffic avoidance devices can save up to 730 million hours. This represents up to 20 billion euros in labour costs. [5]

Even in Hungary we are witnessing a permanent development of the technology, and an environment where user expectations are constantly changing, where all road operators have to adapt to these changes. The aim of this paper is to provide a comprehensive overview of the ways of distributing traffic related information, by introducing the platforms and operation of a key traffic data provider in Hungary, and the ongoing transition towards automatic data provision, and Digital Infrastructure [6]. Sharing traffic related data facilitates the implementation of comprehensive information services to all EU citizens regarding interconnections, interoperability and multimodality and as a result also contributes to reducing external costs, such as congestion, damage to health and pollution of any kind including noise and emissions. A good example of socio-economic benefits of Intelligent Transport Systems (ITS) is given by the French part of the Arc Atlantique Corridor project. Over a 5-year period of ITS services deployment, the calculated minimum savings on French conceded motorways were:

- 7 fatalities, 17 seriously injured and 143 slightly injured,
- 136 000 vehicle hours lost,
- 565 000 litres of fuel,
- 1,524 tons CO2 emission for the congestion volumes.

The socio-economic benefits corresponding to these savings, amount to 5,2 M€ per year, giving a return on the investment programme of French motorway companies of approximately 3 years. Similar results can be seen by the ITS Corridor projects URSA MAJOR Neo, Next-ITS and MedTIS. [7]

IV. Types and characteristics of direct information channels

1. Website/call centre

Hungarian Public Roads operates two different websites for the costumers, one for the company (kozut.hu) and one dedicated for Road Information Services. The general website is the portal for publishing legally binding data and information of public interest [8]. The Útinform website (www.utinform.hu) provides information about events occurred along the national road network that affect the continuity and safety of traffic flow.

Information about these kind of incidents is made available to road users by the Road Information department via the available service channels (website, Interactive Voice Response – IVR system). On the interactive map, colours are helping in expressing the severity of an incident (from green – no impact on traffic, to red – blocked lanes/carriageway). The Útinform website has been using a so called responsive web design, in order to have a web page that looks good on all devices for a long while. Statistic data based on Google Analytics clearly shows, that more than 80% of visitors are using smartphones or tablets, and only a 16% of costumers use desktops. The share of smartphones has risen around 3% compared to the same period of the previous year, meanwhile there is a drop in the number of tablets (0.5%), and desktops (2.5-3.0%). Útinform has registered altogether 1.78 million (different) active users visiting the website (around 55% of the visitors are returning to the site). The number of visitors correlate with measured road traffic volumes in general, with a significant rising trend (around 10% per year). The average traffic of the website was more than 10,000 visitors per day in 2022 (varies within the range from 3,131 to 34,395), but the figures rise sharply when one or more incident(s) with higher impact occur(s). The Information service operates an IVR system for handling incoming telephone calls. The Infoline is available 0-24 h, anybody can call it from Hungary or abroad without extra charges (+36-1-336-2400). The options for each button are the following in the IVR system:

- #1 – Accidents, congestions, and other incidents (actual traffic information, updated continuously)
- #2 – Major planned roadworks/closures for main roads, secondary roads (updated daily)
- #3 – Major planned roadworks/closures for motorways/expressways (updated daily)
- #4 – Information regarding road and weather conditions (updated several times a day)
- #5 – Dispatching services of other companies (phone numbers)
- #6 – Privacy Policy

- #7 – Talk to the operator

On a normal day, the number of incoming calls is between 150-200. 7th January in 2023 was a busy day for the information service. 15 cars crashed in 5 accidents along motorway M1, 15 km long queue has built up, at another crash site on motorway M5, and workers from Eastern Europe were heading back from the Christmas Holiday. **Figure 1.** shows the visible impact on the number of information requests via the call centre, and the number of visitors at the website.

2. Social media

Companies today use social media platforms as a new channel to reach their customers. Following profit oriented private companies, more and more public service providers appeared on these platforms, and started to make efforts to produce content for their followers. Hungarian Public Roads usually publishes posts on a daily basis, but sometimes only 1-2 posts are published per week. The company has currently 38,000 followers (the number of likes is 37,000). In 2021, a total of nearly 2.19 million people were reached thanks to the Facebook posts, which was 38% increase compared to 2020. During this period, the followers of the Facebook page increased by 4,541 people (17%). In 2021, the company put a lot of effort into launching the Instagram page. Thanks to the conscious and persistent strategy, the number of followers of the page increased by 13,841 people, which means a 60% grow in one year. The site's reach exceeded 1.1 million, which is a 35% increase. Through the YouTube channel, 2.32 million views were achieved in 2021 and the number of subscribers increased by 1.628, which means an increase of 90%.

TikTok was the company's most dynamically developing social media site, which attracted nearly 34,000 followers in 2021, so already that year it overtook the number of Facebook followers and is closely following the Instagram profile. The secret of success is continuous experimentation, publication of confrontational content, monitoring and application of trends, youthful communication that fits the needs of the target audience. Similar to Instagram and YouTube, the male-to-female ratio of followers here is 70-30. In 2021, a total of 45 posts were created, which generated 8.725 million views. By the end of 2022, the TikTok profile reached 58 thousand followers and collected 1.1 million likes.

Although Hungarian Public Roads is indeed one of the most active companies operating in the domestic transport sector, with typically 1-2 entries per day, the road management/motorway management companies of neighbouring countries are, in many cases, even more active. However, the volume of posts is not the best measure of the effectiveness of a social media platform. I examined the social media presence and the number of followers on Facebook of road operator companies of Visegrád group and neighbouring countries. It was obvious that besides an official website, every company is present on

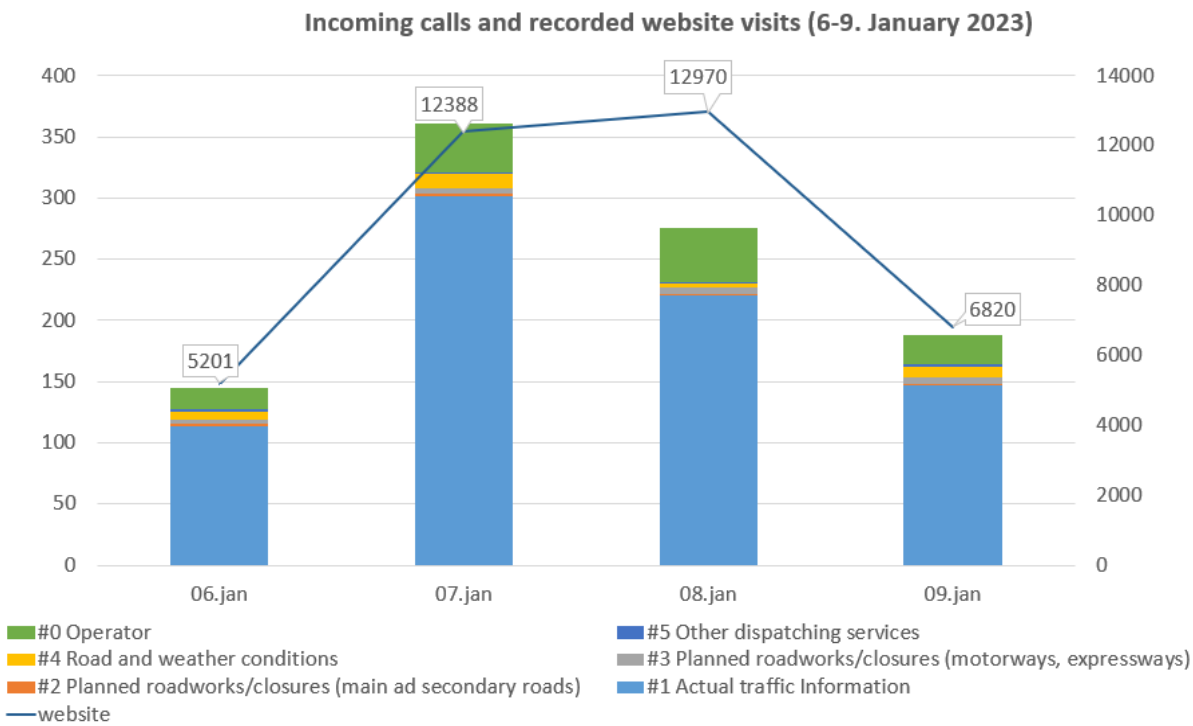

Figure 1. *Impact of serious incidents on information requests (website and call centre)*

***Table 1.** Social media presence of road operator companies in the CSEE region*

Company	Country	facebook	Instagram	youtube	twitter	linkedin	Tiktok	Mobil App.	Followers on facebook [1000 follows]
DARS d.d.	SLO	+		+	+	+			57,4
ASFINAG	A	+	+	+	+	+		+	80,4
NDS AS	SK	+		+					25,9
Promet SI/DARS	SLO	+			+			+	9,1
Hungarian Public Roads (MK)	HU	+	+	+	+	+	+		38
CNAIR SA	RO	+		+					66
RSD CR	CZ	+	+	+	+				20,7
GDDKIA	PL	+	+	+	+	+			64
Putevi Srbije	SRB	+	+	+	+	+		+	10,3
MKIF	HU	+	+	+					0,8
HAC	HR		+	+				+	

social media. This is also the case with the new Hungarian motorway concession company (MKIF), which, in addition to the most popular Facebook, has an official Instagram and YouTube account, too. Only the Croatian motorway company does not have a Facebook page. However, the Slovenian DARS company has two registrations, as the Promet SI, the local information centre similar to Útinform, can also be found on Facebook with more than 9,000 followers (see **Table 1**).

Regarding the activity of the companies, again based on Facebook, the Serbian and Austrian companies are the most active with 3-4 posts per day, and the Czech, Romanian and Polish companies also share content on a daily basis. Several posts are also published daily at Promet SI, but it should be noted that this site specifically shares traffic information, and a large amount of traffic information is also included on the Czech RSD site. Of course, there is a significant difference in the content shared by the companies, as the activities of road managers differ from country to country, in many cases the road operator is carrying out investments, and in some cases the collection of tolls is one of its tasks (such as in Slovenia and Austria). In such cases, of course, the palette will be expanded with communicating the achievements of developments, as well as information related to toll collection. Despite the fact that it is the duty of each company to inform travellers, there are companies where traffic information is not in focus at all. This is the case with Hungarian Public Roads, or ASFINAG, too. These sites rather give an insight into the company's activities, employee stories, or share information related to customer services.

3. Variable Message Signs (VMS)

There is a great variety of VMSs using different technologies to indicate traffic signs. However, only a few versions of the two main types have spread widely in practice. Among electromechanical signs, only prism VMSs are still in use today. Among lighting technology signs, light emitting diode (LED) and fibre optic panels are the ones worth mentioning. On the Hungarian road network, most of the displays are the most modern light-emitting diode (LED) panels. There are also a number of fibre optic signs in which the light from the bulb inside the VMS is conducted at the appropriate points on the front side via fibre optic cables. These signs can only display the previously "wired" signs. There are also LED signs displaying only predefined signs, but most of the panels are full matrix signs, where the displayed images can be designed and modified free. Colour LED signs produce colours using the three basic colours (red, green, blue), which means that one pixel on the surface of the sign consists of three light emitting diodes, such as mobile phone displays, but the pixel distance is much higher, typically 20-25 mm. On text only displays, one pixel consists of only one single yellow LED but, any edited image can be displayed on them, too.

We can distinguish three main functions of VMSs:

- Traffic management: this function includes measures related to traffic diversions and restrictions, such as lane closures, diversions, overtaking bans for lorries, variable speed limits, sometimes different for each lane, and the display of the recommended speed
- Danger warning: warning road users of unexpected events (accidents, congestions, road works, any other potentially hazardous incidents) or adverse road and weather conditions (such as fog, slippery road surface, icing, etc.). For such purposes in most cases a specific VMS type is used called Dynamic Route Information Panel (DRIP).
- Useful information: this might be information about a specific section or the entire network (e.g. journey times between junctions, waiting times at border crossings, closing bridges in the capital, possibly displaying detours). Traffic safety content can also be displayed as part of a comprehensive traffic safety campaign.

The appearance of the gantry and the layout of the VMSs show significant differences depending on whether the display is for information only or is part of a traffic management system. For instance, the above mentioned Dynamic Route Information Panels are mainly used for the purposes of danger warning. Neither their layout nor the distance of the gantries allows them to be used for traffic management purposes. VMS gantries operating as part of a control system always have an overhead VMS per each lane, as speed limits placed above the traffic lanes always apply to the given traffic lane in a speed management scheme. For other types of dynamic management systems, additional traffic signs (e.g. danger warning signs) may be placed above the lane lines or on the two sides of the carriageway in order to provide more detailed information. According to the special function of the M0, and due to the number of alternative routes through the city, a special type of VMS gantries was applied along the Budapest Ring road, combining the capabilities of DRIP and the dynamic lane management types. The gantries have two levels, on the lower level, there are colour displays suitable for displaying traffic signs, while on the upper level there is a large, monochrome text display. At the lower level, the two signs positioned at the two sides of the carriageway are able to display restrictions or danger warning signs valid for the entire cross-section, while the others (signs above the lanes) can display a restriction apply only to the traffic lane below.

When we compare the use of C-ITS with the traditional VMSs (as they can take over their functionality in the long run) we can see significant differences, in implementation and operation costs. The implementation of a VMS is approx. 10 times higher, and the energy consumption is even higher. On the other hand, the information transmitted via the VMSs is quite limited, 2-3 pictograms and approx. 3 × 20 characters long text can be displayed on it. In comparison, the C-ITS system is capable of practically unlimited data transmission, and the communication is bidirectional, it can also receive information from the vehicle.

This does not mean that no more VMS gantries will be built from tomorrow on, in fact, roadside C-ITS transceivers will be installed on VMS gantries and will gradually replace LED displays over a long period of time. Until then, of course, the legal background needs to be improved to handle speed limits appearing in the form of bits and bytes instead of roadside traffic signs, visible to everyone. And this information will be interpreted by the infotainment systems of the car instead of the driver.

V. Automatic data provision/exchange

1. Traffic Message Chanel (TMC)

One of the first and still existing real-time travel information services was the so called Traffic Message Chanel (RDS-TMC). The RDS-TMC service was developed in the 1980s and it has widely spread across Europe, and some other parts of the world. With the help of RDS (Radio Data System) technology, the broadcaster can transmit traffic information using the radio signal that provides real-time information on the traffic situation / events. The message appears on the RDS display of the vehicle's FM radio in the user's language without interrupting audio broadcast services or on the display of a navigation device capable of receiving TMC, and the navigation device even incorporates the received information into the route planning and, if necessary, recalculates the route based on the information received. The bandwidth available for the service is very low, so the messages has a very limited content, the events and their position are all coded. It is therefore essential for the operation of the system to have the same code table on the receiving and sending side, otherwise the message cannot be interpreted. Event codes are fixed, but the road network is slowly but steadily changing, new sections and junctions are being built, so the location table needs to be updated from time to time and downloaded to the navigation device for the proper operation.

TrafficNav is a private limited company, registered in Hungary. Its main activity is to collect real-time traffic data, process and deliver it to end users. Such processed data forms the basis of the TMC service in Hungary that TrafficNav is providing. The service has been operating since the 1st of August 2008. TrafficNav started a TMC service in Slovenia in June 2009, and later the service was launched in the Irish Republic, Greece, Bulgaria and Turkey, too. [9]

2. National Access Point (NAP) [10]

"The accessibility of accurate and up-to-date static road data, dynamic road status data and traffic data are essential for the provision of real-time traffic information services across the Union. The relevant data is collected and stored by road authorities, road operators and real-time traffic information service providers. In order to facilitate the easy exchange and re-use of this data for the provision of such services, road authorities, road operators and real-time traffic information service providers should make the data, corresponding metadata and information on the quality of the data accessible to other road authorities, road operators, real-time traffic information service providers and digital map producers through a national or common access point. The access point can take the form of a repository, registry, web portal or similar depending on the type of data."

The first version of the data exchange platform in Hungary was launched years before the above quoted 2015/962 Commission Delegated Regulation, in the framework of the EasyWay project (data portal development). On the basis of this work, the data exchange platform was upgraded in 2015, in phase I of the CROCODILE project. The development of the data portal included the upgrade of the system to the latest version of the automated data exchange standard (DATEX v2.3), and also the implementation of the full code table that makes it possible to define all the information – contained in the standard – on the receiving side and at the same time the information optionally collected / available can be published (e.g. measured traffic data and weather data can be published). [11] The developed system relies primarily on the topology data of the National Road Data Bank (OKA), but it can handle several standard location identification systems, such as ALERT-C (ISO 14819-3:2004) and the WGS coordinate system, or DATEX HUB completed in the CROCODILE project was also expanded with the OpenLR standard during

Table 2. *Data categories available via NAP Hungary [12]*

Data category, description	Type of the data	Localization of data	Format
Static road network data Current, up-to-date, comprehensive map database of the national road network, regularly updated with OKA content. A current, up-to-date, complete map database of Budapest's road network, regularly updated by Budapest Közút.	National road network data (express road, main- and secondary road, cycle path network)	nationwide	shape-zip; gml2; gml3; json; kml; gpkg
	Annual cross-sectional traffic data	nationwide	
	Road segmentation	nationwide	
	Speed limits	nationwide	
	Total number of vehicle lanes	nationwide	
	Static data for rest and P+R parking	local/ nationwide	shape-zip; gml2; gml3; json; kml; gpkg; DATEX
	Bridge usage conditions (e.g., restrictions)	nationwide	shape-zip; gml2; gml3; json; kml; gpkg
	Road name and category	nationwide	
	Road identification points	nationwide	
	Type and width of enclosure	nationwide	
	Bus stops	nationwide	
	Refuelling station and e-station data	local	shape-zip; gml2; gml3; json; kml; gpkg; DATEX
	Budapest roads data (geometry, road junctions, road classification, freight zones, destination restrictions)	local	shape-zip; gml2; gml3; json; kml; gpkg
Dynamic parking information	Truck dynamic parking data	nationwide	DATEX
	Dynamic data of P+R parking	local	
Information on traffic signs (e.g. bridge conditions, permanent traffic restrictions: height restrictions, weight and speed restrictions).	TN-ITS data	local/ nationwide	via TN-ITS link
	Location and availability of transport areas	local	shape-zip; gml2; gml3; json; kml; gpkg
XML link to MK ÚTINFORM news, fresh, complete, regularly updated news file.	Roadworks	nationwide	DATEX
	Dynamic data of road status	nationwide	
	Traffic management measures	nationwide	
	Temporary traffic management measures	nationwide	
	Real-time traffic data	nationwide	
	Traffic safety information	nationwide	
	Unforeseen events and circumstances	nationwide	
Multimodal information	Timetables and information on multi-modal transport		In preparation

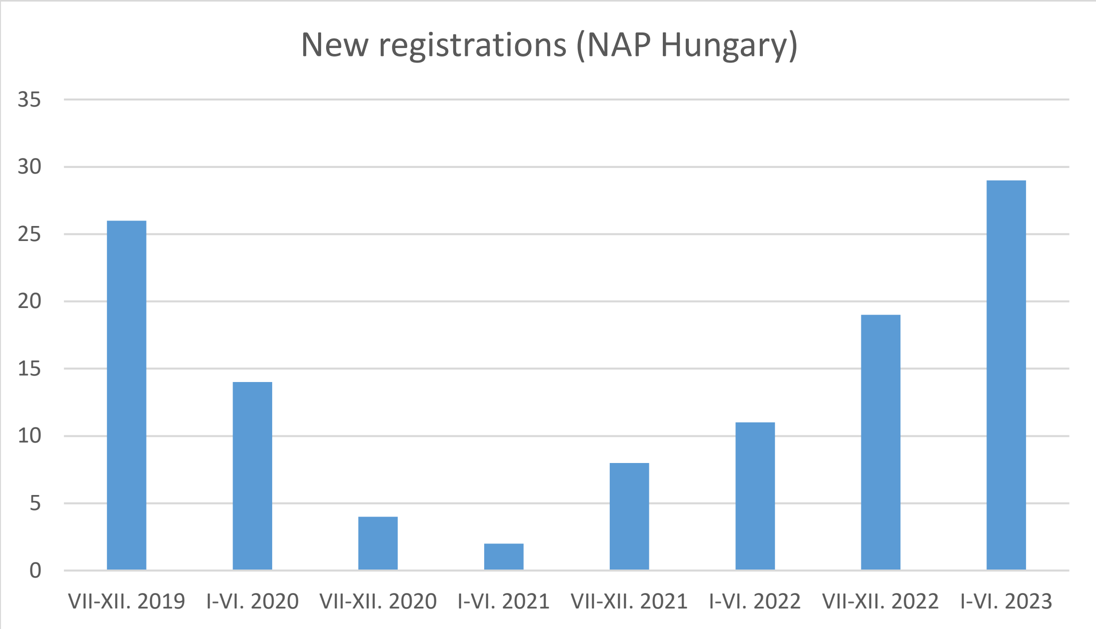

Figure 2. *New registrations (NAP Hungary) until 2022*

development. The currently available data categories are the following:

The monitoring, and evaluation of the system is continuous, and there is also useful feedback from the registered users. In 2021, a complete revision of the portal and the admin functions was carried out, paying particular attention to implement user-friendly features and menu structure. As a result of the assessment process, several minor modifications, corrections and a number of change requests and further development needs were identified. The first upgrade of the system was published in February 2022 containing most of the minor improvements. As some of the tasks require major changes in the code, a second phase development package was set up for the complex developments. Within the framework of the CROCODILE 3 Hungary CEF (Connecting Europe Facility) funded project, besides DATEX II. version 2.3., we have introduced the latest v3.3 version and the D2Light standard, too. By introducing these new standards, we expect to reach more clients both on the data provider's and user's side.

Currently there are two active data providers publishing datasets via the NAP portal: Hungarian Public Roads (local) and Budapest Public Roads (nationwide), however through the Útinform service of Hungarian Public Roads and the National Road Data Bank (OKA), also operated by Magyar Közút, data recorded on the sections of the concession motorway companies (MKIF, AKA, M6 Duna, M6 Tolna, M6 Mecsek) are also available. On the data user side, a number of private individuals, and several Hungarian and multinational tech companies and digital map service providers have registered to the portal. In the first 3 years of operation, after the initial boom, there was a decline in the number of new registrations, but a second run up can be observed (**Figure 2.**) starting from the second half of the year 2021.

3. Cooperative ITS (C-ITS)

Cooperative ITS (C-ITS) is a set of technologies and applications that allows effective and direct data exchange through wireless communication channels between components and actors of the transportation system, most commonly between vehicles (vehicle-to-vehicle or V2V) or between vehicles and infrastructure (vehicle-to-infrastructure or V2I). C-ITS deployment in Hungary has started back in 2015. One of the main drivers to foster C-ITS deployment in Hungary was the involvement in the above-mentioned European CROCODILE project [4][13]. The project objectives were to improve the quality and availability of traffic data, to secure exchange of this data with neighbouring countries in DATEX II format, to improve road safety, i.e. in work zones, and to provide quality traffic information services to drivers. In line with the above-mentioned objectives, Hungarian Public Roads company has selected part of its network for C-ITS services deployment, a 136 km-long stretch of motorway M1 between Austria and Budapest. The system is in operation from December 2015. The pilot system itself has covered the following 'Day-1 services': Traffic jam ahead warning, Hazardous location notification, road works warning, Weather conditions, In-vehicle signage, In-vehicle speed limits. The communication between RSUs and OBUs was thus far based on ITS G5. ("ITS-G5 technology supports vehicle-to-vehicle, vehicle-to-everything short range, ad hoc communication. The defined access layer of the communication stack is collectively called ITS-G5”). [14]

Meanwhile, several research and pilot implementations were carried out Europe-wide, like the European ITS Corridor [15]. The need for a harmonised approach was identified on the basis of the insights gained in all previous initiatives and, at the same time, commitment and readiness for deployment was also visible. However, at the technical level, the projects and corridor initiatives did not take the final step to a coordinated pan-European approach, which was however necessary to ensure that all national efforts grew together in a harmonised way. To ensure this cross-border harmonisation of C-ITS, the C-Roads Platform was realised in 2016 [16]. Hungary has joined the platform as an observer right from the start, and became a core member in 2017.

Recent deployments in the framework of C-Roads Hungary concentrated on the upgrade and extension of the 2015 pilot in terms of coverage and functionality, and implementing the ability of a hybrid (G5, and cellular) communication (deployment sites: **Figure 3**). Additional so called Day-1 use cases were introduced with the capability of hybrid communication along motorway M1 (towards Austria), and motorway M7 (towards Croatia and Slovenia). Besides core network corridors, special attention was also paid to urban applications. Traffic light controllers were improved in the town of Győr in order to provide Time-to-Green (TTG)/ Green Light Optimum Speed Advisory (GLOSA) information at 10 neighbouring junctions along the main traffic route, where intersection safety services are also available. The pilot sites have been operational since February 2021.

Hungary has also signed the grant agreement for C-Roads 2 Hungary, as a continuation of the C-ITS deployment. The planned Hungarian work programme devotes particular attention to the creation of an urban test environment for connected and automated vehicles in the town of Zalaegerszeg, linked to the Automotive Proving Ground Zala (APZ), building on the experiences of the pilot project in Győr. The deployment will focus on Day-1 and Day-1.5 C-ITS services with the option of scaling up to Day-2 C-ITS services. The “ZalaZone” is the greater area that includes the town and the test track that will be ready for autonomous vehicle testing, but there are even more ambitious plans. As part of trilateral multi-level cooperation, Austria, Slovenia and Hungary plan to implement cross-border test routes [13]. C-Roads 2 Hungary will enhance this effort by implementing C-ITS services in the greater city area of Zalaegerszeg, and TEN-T corridors (with domestic and cross-border sections).

VI. Multimodal travel information

Multimodal journey planners will raise the efficiency of the transport system, as they ensure

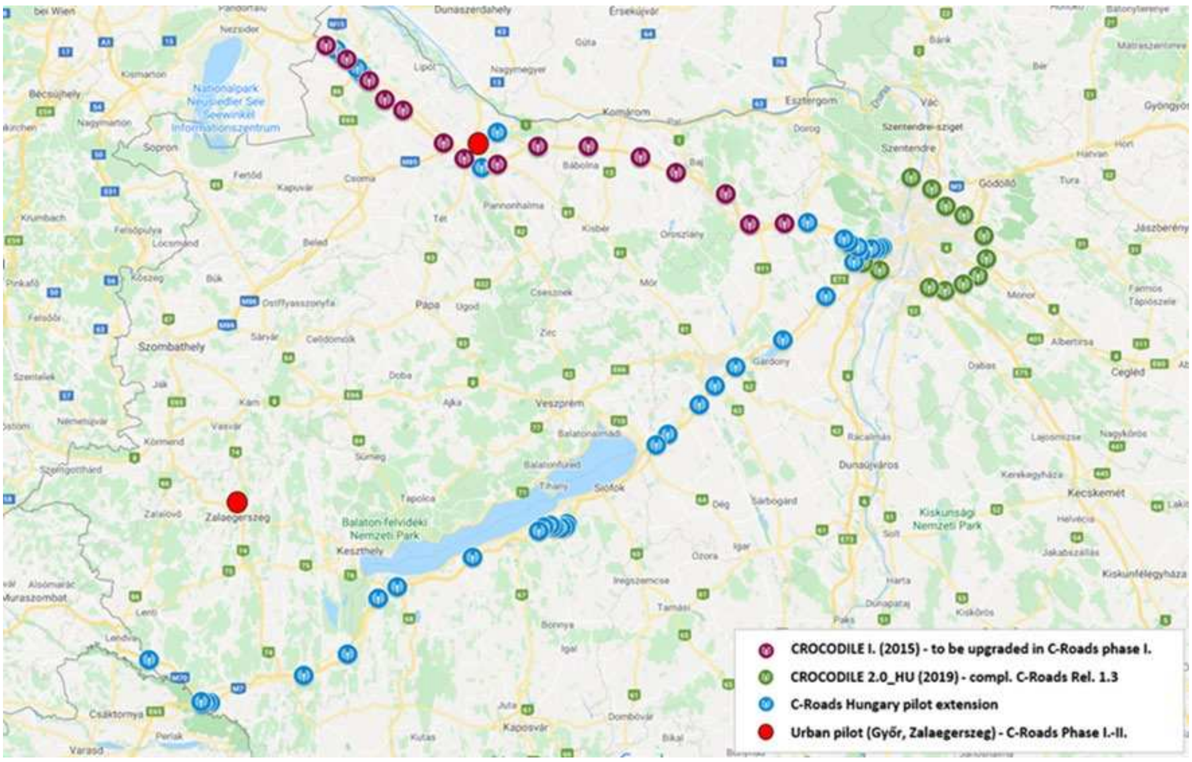

Figure 3. *C-ITS deployments (until 2022)*

seamless door-to-door travel information integrating different transport modes, and service providers. In line with Directive 2010/40/EU, EU specifications have been adopted in order to ensure compatibility, interoperability and continuity for the deployment and operational use of Intelligent Transport Systems. In order to further support the harmonised implementation of the provision of EU-wide multi-modal travel information services, EC has adopted Commission Delegated Regulation (EU) 2017/1926 with regard to the provision of EU-wide multimodal travel information services [17]. According to the delegated regulation National Access Points should collect travel and traffic data (static data, timetables, etc.) from all modes of transport from public and private service providers. Travel information service providers shall share routing results that help linking the travel information services for other service providers. The main goal is to provide useful tools/applications for travellers, supporting their responsible mode choices, and their mode shifts to sustainable means of transport. [18]

It is obvious that there are huge differences in the preferences of drivers, and passengers of public transport. Drivers prefer navigation-based information, with voice directions, and/or directions on an interactive digital map, displaying the hazards, speed limits, alternative routes, etc. When using public transport, it is easier to use e.g. social media for this purpose, but the leading sources are the multimodal travel planner applications like Google Maps. The apps of Hungarian Public Transport companies have remarkable penetration, too, both MÁV (national railways), and BudapestGO (Centre for Budapest Transport) apps have more than 1 million downloads, but they are not real multimodal apps. BudapestGO has reached the highest grade in this regard, with integrating suburban transport routes operated by the national railways (MÁV), and the bus company (Volánbusz), and integrating some basic information of micro mobility (BUBI bike share docking stations, and the number of available bikes). Both MÁV and BudapestGO provides on-line purchase of the tickets, but only for travel services within their own responsibilities. The first Mobility-as-a-Service (MaaS) trial was implemented in the framework of MaaS4EU (End-to-End Approach for Mobility-as-a-Service tools, business models, enabling framework and evidence for European seamless mobility) project [19]. The main objective of the project was to remove barriers, and establish the frameworks and tools of a co-operative, interlinked and unified solution in line with the MaaS concept. The project has proven, that it is possible to integrate different service providers like public transport operators, shared mobility service providers, cab companies in one single mobility platform, where one only need to register once to use and pay for all available services offered via the MaaS operator, using a single mobile app.

VII. European dimension

As stated in the chapters before, Hungary has implemented its NAP system according to the directive 2010/40/EU, just as the other European countries also did in the late 2010's. The most important perquisites were fulfilled, with launching those sites, providing datasets described in the directive, but there were no obligations regarding visual appearance, content requirements or accessibility needs. As a result, the 27 EU Member states and other countries have established for each country an individual portal. Each site fulfils the needs of the directive, but those differ in many ways from the NAPs of neighbouring countries, causing a fragmentation on a European level. On a microscopic view the directive has reached its purpose, but on the macroscopic approach it has caused a new problem what had to be solved to ensure interoperability.

"As it has become apparent, the existing NAPs are quite different in their setup and data access interfaces. Also, the data formats and standards used differ throughout Europe. To work on a better alignment the National Access Point Coordination Organisation for Europe (NAPCORE) project was started.

NAPCORE is co-financed by a Programme Support Action under the European Commission's Connecting Europe Facility. NAPCORE has been launched as coordination mechanism to improve interoperability of the National Access Points as backbone of European mobility data exchange. NAPCORE improves the interoperability of mobility data in Europe with mobility data standard harmonisation and alignment. Also, NAPCORE increases access and expands availability to mobility related data by coordinated data access and better harmonisation of the European NAPs. Furthermore, NAPCORE empowers National Access Points and National Bodies by defining and implementing common procedures and strategy, strengthening the position and the role of NAPs, supporting steps towards the creation of European-wide solutions to better facilitate the use of EU-wide data." [20]

The harmonisation process is not only on structural, visualisation and content level of each NAP, but very much on a technical as well. Many standardised, yet different data formats are used currently EU-wide, like DATEX, TN-ITS, Multimodal and Metadata, to exchange different types of data. The overall aim is to ease and to atomise the data exchange processes and deliver the data in a machine-readable format, independently of the sender/receivers whereabout and data format, if it is within the accepted datasets. To create and enhance automatising, so called API (Application Programming Interface) is necessary. These APIs are a set of definitions and protocols which enables the building and integrating application software on the data. A separate workgroup within the project is busy with developing an API prototype which will be released probably early 2024.

Among previously mentioned others, the projects goals are to:

- facilitate EU wide coordination of NAPs and the supervisor National Bodies (NB) for the harmonization of the implementation of the European specifications on the ITS Directive
- increase interoperability by (further) establishing standards and recommendations for data exchange formats, content, access, and data availability in the mobility domain in Europe [21]
- empower the NAPs as the backbone for ITS digital infrastructure and mobility data exchange in Europe
- address existing and upcoming developments and challenges with a joint European strategy, vision, and voice.

The project is working closely with DG-Move and the NAPCORE Advisory Board (which consists of experts from several organisations among others e.g. CEDR, C2C, EAFO, TISA and many more) to continuously guide the project according to legislations and market needs. The project has furthermore delegated ambassadors within the project to drive the important topics. Currently parking, cycling, MaaS and alternative fuels have an own ambassador group to represent and drive these continuously evolving topics.

The EC, on the other hand envisions not to stop at an individual yet harmonised approach. In their opinion there is a need for a European Access Point (EAP). This EAP would receive all the datasets defined in the delegated regulation and would work as a data hub above the member states' individual NAPs to enhance the interoperability of data on an EU level. This would not only be a link repository, but would be a fully automatized data site, harvesting the data from the individual NAPs. The establishment of this ambitious approach is not in the scope of the NAPCORE project itself, but during the project a commonly agreed interface to facilitate this data exchange will be reached. This sets the importance of the harmonisation and technical coordination work done by the project even higher.

VIII. The importance of alternative fuels (AF) and digitalisation

"Mobility plays a key role in the EU economy. However, the EU transport sector still relies heavily on fossil fuels and is responsible for one quarter of Europe's greenhouse gas (GHG) emissions — a share that keeps growing. In addition, the sector is a significant source of air pollution despite significant progress achieved since 1990, especially of particulate matter (PM) and nitrogen dioxide (NO2), as well as the main source of environmental noise in Europe. Current efforts to limit the sector's environmental and climate impacts in Europe are not sufficient to meet the EU's long-term climate and environmental policy objectives." [22] These long term ambitious goals are set in The European Green Deal, and the goal of being the first climate-neutral continent by 2050 requires ambitious changes in transport, too. The Council adopted this year on 29th March, the regulation setting stricter CO2 emission performance standards for new cars and vans. The new rules aim to reduce emissions from road transport that has the highest share of emissions from transport - and provide the right push for the automotive industry to shift towards zero-emission mobility while ensuring continued innovation in the industry. The new rules set the following targets:

- 55% CO2 emission reductions for new cars and 50% for new vans from 2030 to 2034 compared to 2021 levels,
- 100% CO2 emission reductions for both new cars and vans from 2035.

A regulatory incentive mechanism for zero- and low-emission vehicles (ZLEV) will be in place from 2025 until the end of 2029. As part of this mechanism, if a manufacturer meets certain benchmarks for the sales of zero- and low-emission vehicles it can be rewarded with less strict CO2 targets. The benchmark is set at 25% for cars and 17% for vans.

The regulation contains a reference to e-fuels, whereby following a consultation with stakeholders, the Commission will make a proposal for registering vehicles running exclusively on CO2-neutral fuels, after 2035, in conformity with EU law, outside the scope of the fleet standards, and in conformity with the EU's climate neutrality objective.

The regulation includes a review clause that foresees that in 2026, the Commission will thoroughly assess the progress made towards achieving the 2035 100% emission reduction targets and the possible need to review them. The review will take into account technological developments, including with regard to plug-in hybrid technologies and the importance of a viable and socially equitable transition towards zero emissions. [23]

The ambitious goals set, need harder commitment from the countries as well and new datasets need to be collected and processed. The current version of the delegated regulation, which is still is in force has been extremely outdated in only a few years, before all the member states could even implement it. The revision of the delegated regulation 2014/94 is currently being finalized and will be published in the upcoming months. This version will contain very strict requirements regarding the development of alternative fuel infrastructure and the sharing of the data related to alternative fuels.

A PSA called IDACS (ID & Data Collection for Sustainable Fuels in Europe) was started in 2019 to build up a unified database and coordinated data transfer on alternative fuel filling points, in line with the EC's expectations and to implement a unique identification method for electromobility actors. [24] Yet only a bit more than half of the EU Member states participated in this project and implemented the local IDRO (ID Registration Office) which collects the data and forwards these to the national NAPs, so there are still a considerable number of NAPs – which comply with all the delegated regulations – yet they do not have any data related to alternative fuels.

The number of EVs and hydrogen powered vehicles are progressively growing, and the technical advancement of these vehicles and the battery/charging technology enables a larger range (distance travelled / recharging). Not long ago, approx. 10-15 years, the maximal range of these vehicles was 100-150 km, which made them good option for domestic travels. Nowadays ranges can exceed 500-600 or even 800 km with one charging, which makes trans-European travels viable. With this transition the CPOs (Charging Point Operators) had to adapt and open their services to new foreign users, but still having their own registration, charging and payment methods used. As this segment is profit driven and lot of different standards were used, furthermore some of the data collected is sensible, and not all the data providers are willing to share for e.g. the availability of their charging points or the price of ad hoc charging costs caused severe gaps in the data sharing services. Furthermore, this also caused a cumbersome preparation necessary before and during every international travel with an EV as every CPO had its own database, available only after pre-registration. Usually, one country is covered with more than one, up to 3-5 bigger CPOs and many smaller ones. As this gap in the market appeared, many third-party suppliers have built a service from this, by acquiring this data and showing it on a digital, opensource map and providing the data to their subscribers. Yet these secondary databases were still not complete, did not contain all the charging point data or were not up to date, causing even more confusion to the users.

The EC has a clear view, how to change this chaotic situation. As mentioned earlier, the revision of the delegated regulation 2014/94 will contain standardised data formats and data fields, what every Member state must make publicly available, for free of charge. The CPOs will be forced to do so and will be held responsible for the quality of their data. The previously mentioned, locally operated, yet harmonised on an EU level NAPs will fill the mediator role and collect all the national data from the CPOs and publish them on a local level and with the support of the APIs it will be also possible to automatically harvest this data to the envisioned EAP at a later stage.

IX. Conclusions

Enabling the interoperable exchange of travel and traffic data in accordance with the requirements outlined in ITS Directive and its Delegated Regulations improves traffic information and traffic management services. These services contribute directly to improvements in efficiency and sustainability, by stimulating and enabling traffic information service providers develop new services and tools.

Útinform, as the main traffic information hub in Hungary collects and distributes traffic related data, and information for the national road network. Through the Útinform website, the call centre, media relations, and live broadcasts or via the automatic data exchange channels the Road Information service tries to ensure that the essential information reaches the end users. With the help of the automatic data feed, traffic information can also be accessed via several online navigation devices, by browsing websites of road operators abroad, and popular mobile applications (e.g. waze). C-ITS is a relatively new branch of intelligent transport services, and it takes time to raise the penetration rate without EU legislation, however the service is ready to use, and there are a lot of services available even in Hungary. There is a huge potential in this new service, that can save a number of lives on roads. The above-mentioned automatic channels gained huge relevance in delivering traffic related information to the end users recently, and their importance will keep on raising in the coming years. Despite these new channels, and the popular mobile applications, there is still a huge amount of costumers, who still prefer to visit a conventional website or talk to a dispatcher, and that must be taken into account during a transition period towards higher level of automation.

As our vehicles and the infrastructure collects and generates more and more data, and this data is crucial to analyse due to traffic safety and environmental protection, harmonisation, regulation sharing of Mobility data on an EU level was never so important. There are several measures which the member states will have to take in the upcoming years, yet this is the way, the green path towards a sustainable Europe.

AUTHOR CONTRIBUTIONS

T. A. Tomaschek: Conceptualization, Data collection, Writing, Review and editing.

A. M. Selmeczy: Writing, Supervision, Review and editing.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Risks and the management of construction in the environment of nuclear facilities

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Abstract: Everything in the world is about risk, from individual decisions to global manipulations, which is of fundamental importance in a nuclear power plant environment. The question is whether, in a given situation, this risk is acceptable or no longer acceptable. In some respects, the risk analysis applied to construction projects differs from the risk analysis applied to nuclear installations. For nuclear installations, the risk as such is nuclear risk. Primary safety is nuclear safety. Secondarily, we talk about other risks, for each of which it must be assessed whether there is an impact on nuclear safety. In view of this, for investments involving a nuclear installation, the risk analysis to be carried out must be carried out at two separate levels. In the case of civil engineering works in the immediate vicinity of a nuclear installation, it is particularly important to analyse the construction risks. The main problem for a nuclear installation is the unequal subsidence, which causes the building to tilt. The primary objective is to determine the value of the expected settlement, which forms the basis for an accurate determination of the risks. The first level is the traditional construction risk analysis, and then as a second level, each risk item should be classified from a nuclear risk point of view. In this paper, we present the nuclear exposure of construction risks and the possibility of mitigating these risks through a real-time monitoring system. In our research, we are concerned with the determination of the risks of deep construction activities and their impact on a specific nuclear site. We will also investigate possible risk mitigation activities that can be used in the nuclear power plant environment and their effectiveness.

Keywords: construction risk, risk analysis, nuclear power plant, geotechnical and building monitoring

I. INTRODUCTION

Everything in the world is about risks, from the decisions of individual people to grand global situations. Everything poses a risk. Each decision has elements of financial, environmental and sociological risk [1]. The question is whether or not this risk can be shouldered under the given circumstances.

Risk can be of many kinds, the specific project always determines the type of risk, who or what is the purpose of the risk, as well as what levels are allocated [2].

Even Karl von Terzaghi dealt with the issue of risks generated by specific construction projects. When and what sort of methods allow these risks to be mitigated. The construction site itself is a separate risk factor, as is the determination of the geotechnical parameters. Furthermore, the evaluation of the results and the choice of the evaluation method also pose significant risks [3].

In general, soil and water are the two most significant factors that determine the risk levels of a given building or structure. Knowledge of the soil is far more than extensive than knowledge of the physical parameters of the soil. The mineral composition of soils, their interaction with water, and their granulometric parameters all contribute to the exact determination of the load-bearing capacity of the soil in question. Each structure must be designed and constructed according to the construction site, taking into account the special conditions of the site [4].

Any structure we design or construct has a relationship with the soil and the rocky environment, so geotechnical risks are everywhere. The accuracy of the geotechnical parameters has a significant connection with the development of risks, which was supported by the testing of the movement of natural slopes. During the review of the risks, the parameters that greatly influence the safety of the given facility must be identified. Furthermore, it is necessary to determine exactly what risk mitigation options are available [5].

In the case of nuclear power plants, the continuous analysis of risks is of great importance. The purpose of our research is to define the construction risks of nuclear power plants and to present the analysis of construction risks also the possibilities for lowering the level of these risk.

II. Defining risks

The journal publishes Research article, Review and Mini review.

Design engineers and civil engineers have two goals for each structure:

1. as cost-effective of an implementation as possible,
2. achieving long-term and short-term safety.

The simultaneous implementation of the two aspects contradict each other to some extent, if we want a cost-effective design, the level of safety can drop substantially lower. Whereas, if we plan something with complete safety, the costs can rise sharply. There are options that create consistency between the two expectations and can significantly increase the safety of the structures. The end result is always created during an iteration process [4].

In the research compiled after the construction of Budapest metro line 4, an analysis was made of geotechnical risks and the possibility of mitigating them. The result obtained during the research points out that the accuracy of the knowledge of the soil, groundwater and all other basic geotechnical and engineering geological data greatly influences the risk level. A precise correlation between geotechnical excavation density and geotechnical risks has been described [6].

Since the first atomic reactor created by Leó Szilárd in 1942, the nuclear industry has been continuously developing. And with development comes a constantly tightening regulatory environment. The 1980 Convention on the Physical Protection of Nuclear Material provides the basic framework for the peaceful use of nuclear energy. Between July 4-8, 2005 the Convention was amended within the framework of a Diplomatic Conference organized by the International Atomic Energy Agency (IAEA). The amendment became necessary due to the fight against terrorism. The amendment was unanimously accepted and signed by all countries in Vienna. To help implement the Convention, the International Atomic Energy Agency (IAEA) issued the document on the Physical Protection of Nuclear Materials and Nuclear Facilities (INFCIRC/225/rev.5, 2011), which describes the necessary structure of each state system, the classification of nuclear materials, the summarizes the protection requirements for nuclear materials in use, stored and transported, as well as the requirements for the protection of nuclear facilities against sabotage.

Working with hazardous materials, including radioactive materials, results in significant extra precautions in the given power plant and on the entire site. This is because there are significant additional regulations and requirements for the design and operation of power plants using these hazardous substances to ensure safe operation. The activities that compromise safety must be precisely defined. Defining which directly threaten human life and which indirectly affect it. The International Atomic Energy Agency provides precise regulations for this under the title Guidelines for integrated risk assessment and management in large industrial areas issued under the number IAEA-TECDOC-944, classifying health and environmental hazards. It also gives suggestions for dealing with these dangers [7].

III. Construction risk

Construction risk is multifaceted by construction risk, we consider countless risk factors, from the loss of stability of the structure to a significant delay in the implementation of the project. In many cases, the significant financial risk of the project must also be classified here [8].

In 1984 R.V. Whitman created the basis for the classification of construction risks of geotechnical origin. Over the years, the theory has outgrown the tight field of dealing with risks of purely geotechnical origin and has been extended to include various other risk factors [9].

In 2020, J.-L. Briaud drew three pre-defined boundaries, which clarify the expenses of the expected death and material losses associated with the occurrence of each event [10].

Geotechnical risks ultimately lead to the entropy of structures. The causes of entropy of structures can be determined and the probability of their occurrence can be provided with a mathematically quantified value, just as there is a way to categorize the causes of risks. [8] However we cannot only talk about the risks of structures, but each project also has its own risks. Construction risks must also be taken into account from the perspective of the project [11].

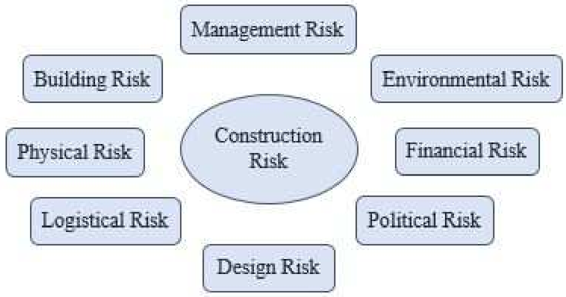


Figure 1. *Complexity of construction risk*

Construction risk is a multifaceted concept, as shown in **Fig. 1**, it includes the project-level risks of the given construction. Such as:

1. Design risk: the risk of the adequacy of the design;
2. Political risk: influence of large and giga investments at national and international level;
3. Financial risk: the financial safety of the customer background, which ensures the continuity of the project's financing, and the sustainability of the project's budget;
4. Environmental risk: risks arising from geological, geotechnical, meteorological or other factors related to the site and its immediate surroundings;
5. Managerial risk: the risk inherent in the decisions of the project managers;
6. Execution risk: risk of "erroneous construction" during the construction phases, non-conformity;
7. Physical risk: possible pre-planned terror/violent action or random event, as a result of which the project will be structurally damaged, the duration and the cost of the construction shall increase;
8. Logistical risk: an impedimental circumstance or obstacle in the procurement and application of the entire, raw material and/or equipment necessary for the implementation of the project.

This list can of course be extended further, taking into account the specificities of each project. In each case, the location of the project, the sociological, demographic and political context must be taken into account. It is the combination of all these factors that makes it possible to accurately determine the project risk.

The determination and further management of construction risks can be defined as a significant task at the start of the project, in the planning phase. Construction risks are always project-specific. A unique procedure must be followed.

IV. Safety of nuclear power plants

The safety of nuclear power plants is guaranteed by several separate methods.

We distinguish 3 main safety functions, all three safety functions must be able to individually ensure the safety of the power plant and its environment (**Fig. 2**).

The three safety functions:

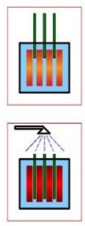
1. Regulation and closure of chain reaction	2.Cooling	3.Containment
		

Figure 2. *Safety functions of nuclear facilities*

The purpose of the 3rd safety function is the containment of radioactive materials, which includes a series of engineering dams. The outermost engineering shell is the containment itself [12].

In addition, the Safety System must be distinguished. Among the safety-important systems of nuclear facilities, those that were designed and installed partially or exclusively for the purpose of performing safety functions are classified as part of the Safety System, in the nuclear industry, equipment whose sole function is to maintain safety is called a Safety System. In all cases, they become necessary only after an initial undesirable event. Their application and purpose is to maintain and restore safety, as well as to mitigate the consequences of undesirable processes.

Another element of the safety protocol is Protection in Depth, which is divided into 5 levels (**Fig. 3**):

1. Conservative design, high-quality construction and operation; Preventing abnormal operation and malfunction.
2. Adequate regulation, operating limits and prevention of exceeding them; Correct handling of abnormal operation and detection of malfunctions.
3. The start of automatic safety systems and the necessary human interventions; Handling plausible dimensioning accidents.
4. Additional measurements and action plans. Dealing with serious accidents, mitigating the consequences and mitigating the severity.

5. Accident prevention action plan; mitigating the consequences of radioactive emissions outside the facility [13].

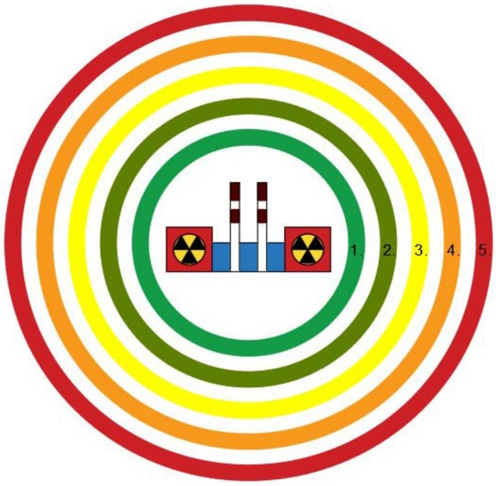


***Figure 3.** Protection in depth*

The nuclear risk is synonymous with the full protection of the environment. No radioactive material may leak into the environment, which could endanger the environment or the lives of the surrounding people [14].

In the online book Risk and Safety in Engineering written by J. Köhler, the author writes in detail about the risks of impacts on structures and the probability of occurrence of risks. A separate section is devoted to the risks of nuclear power plants as a special structure with special risks. The conclusion states that the malfunction of nuclear power plants can occur as a result of one or more failures of the components and systems that make up the systems, thereby making the power plants generally safer.

The critical system of nuclear power plants is the reactor cooling system and their control valves, the malfunction of which can lead to the loss of reactor cooling, which in turn can have serious consequences, such as reactor damage and possible zone meltdown. Further studies have shown that both physical and human causes are important. Leaks and natural malfunctions are the main physical causes, while human errors result from inadequate maintenance and plant design errors [15].

In the case of nuclear power plants, we can differentiate external and internal threats. External threats are those that do not arise from nuclear technology, but from other external influences. There may be dangers arising from natural disasters, as well as dangers arising from human activity. This also includes construction risks.

In the case of nuclear power plants' large or early emissions, the occurrence frequency criterion of 10^{-6}/year must be met, and the transport of the excess heat to the final heat sink must be ensured. The frequency of its loss cannot be greater than 10^{-7}/year. That is, the annual frequency of the risk of serious accident operating conditions, which can lead to environmental pollution or catastrophe, cannot exceed 10^{-7}/year. This level of risk involves significant mortality risk and material risk.

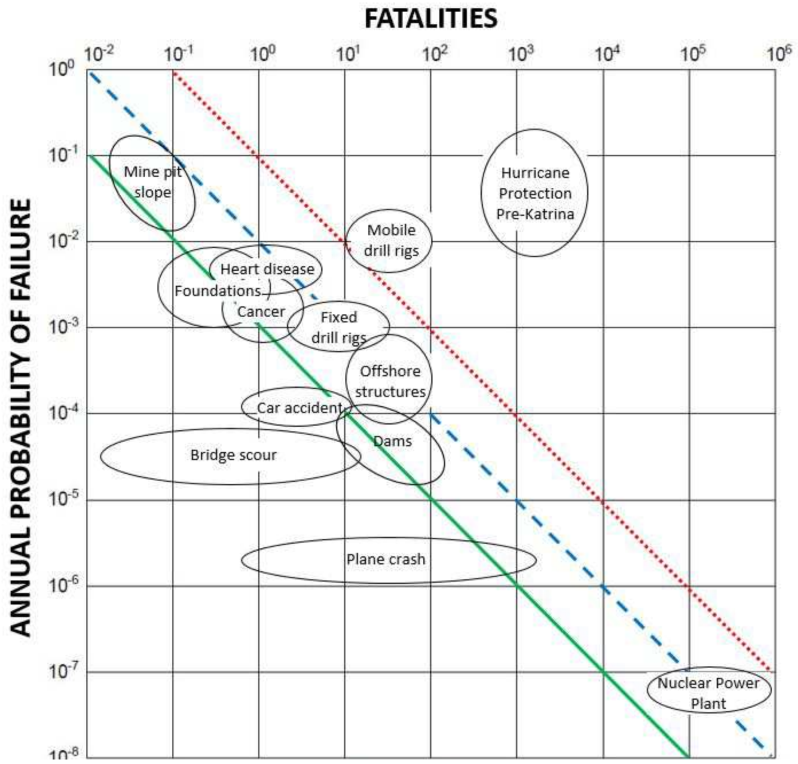


***Figure 4.** Risks of serious accident operating conditions of nuclear power plants, associated financial and mortality risk*

We placed the operational state of serious accidents of nuclear power plants in the network of probability of occurrence, death and financial risk.

On the **Fig. 4** can be seen that the risk of nuclear power plants in a serious accident operating condition is very small, but the direct or indirect death rate associated with it can extend up to 1 million people, and the loss of production and the financial side of damage can also be measured in billions of dollars.

V. Geotechnical and Building Movement Monitoring System as a Guardian of the Environment

When opting for a monitoring system, it is essential to determine exactly what the purpose of the measurement is, what conclusions we want to draw from the results of the measurement during processing, and what exactly we want to measure with it.

In engineering, we can divide the measurable elements into three large groups:

- Movement measurements: settlement measurement; tilt measurement; twist measurement; deformation measurement.
- Voltage measurements: soil pressure measurement; pore pressure measurement.
- Change over time of all measurement results listed above.

The precisely formulated measurement goal also determines the type of measuring instruments to be used during the building movement and geotechnical monitoring system.

After the precise definition of the purpose of the measurement, it is necessary to compile the requirements for the instruments of the monitoring system and their priority.

Requirements in relation to instruments:

- **Reliability:** In all cases, the accuracy and resolution requirements of the data measured by the instrument must be precisely determined, as well as the accuracy and deviation.
- **Real-time processing of measurement results:** The processing speed of the measured results in nuclear facility environments requires real-time processing. That is, the measured result becomes visible at the moment of the measurement, and we receive a picture of the position and condition of the examined structure without delay.
- **Measuring lifetime of the instrument:** When opting for instruments, the criteria of the instrument's durability and the environment in which it should be placed in must be taken into account. Is outdoor or indoor placement required? With regards to the instrument being placed below the surface, should it measure below or above groundwater? Also, how aggressive the ground water or the soil is.
- **Method of data management:** The collection of data and their transmission to the specified server/storage location determines the level of data management of the monitoring system.

VI. Building Movement and Geotechnical Monitoring System Elements

Just as during every single construction investment, there are points and structural elements that must be specially measured and checked in the case of nuclear facilities.

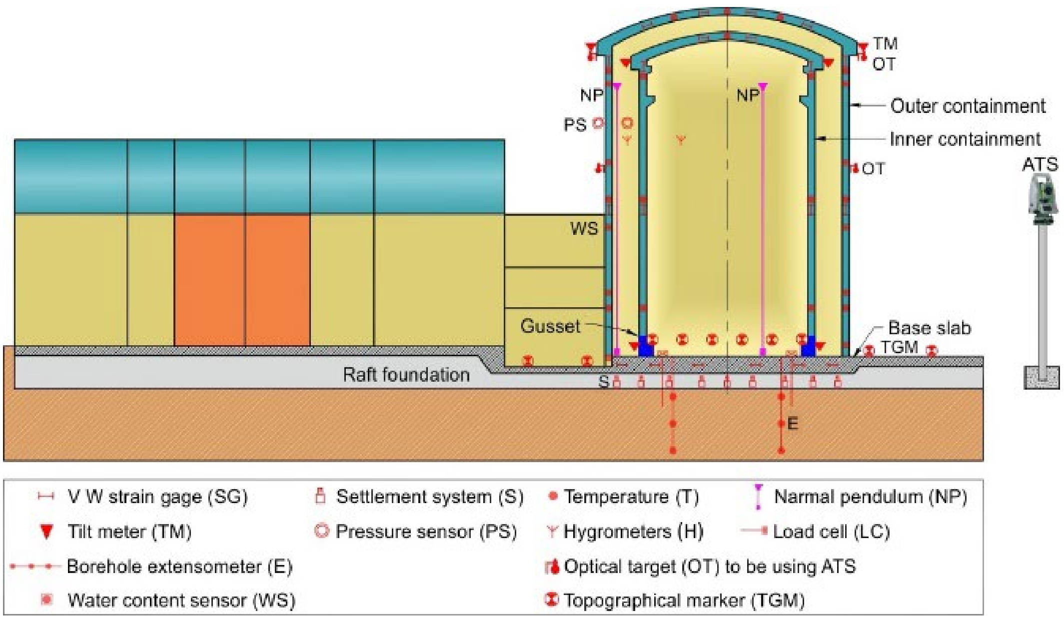


***Figure 5**. Outline plan of the monitoring system of nuclear power plants [16]*

Fig. 5 shows the recommended devices and measurement points that are necessary during the safe long-term operation of a nuclear power plant.

They can provide data on the state of the structural elements and built-in materials, and their state changes during operation. These proposed measuring devices go beyond the current research topic, which is the possibility of reducing construction risks by using real-time building movement and geotechnical monitoring systems.

Among the elements of the entire monitoring system, I shall put emphasis on and discuss those that promote safe construction investments and construction works in the unmonitored environment of nuclear power plants and other nuclear facilities.

As already summarized in the previous chapter, several types of movement can be measured with special instruments. Furthermore, in order to monitor the soil-structure interaction, voltages, changes in voltage, and displacements must be registered.

Several monitoring measurement systems can be distinguished for measuring displacements and deformations, which should be used in combination during the construction of each monitoring system (**Fig. 6, 7**).

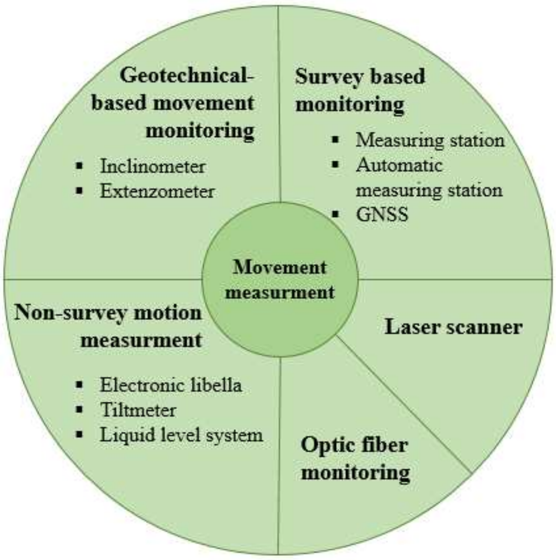


Figure 6. *Movement measurement instruments*

In addition to deformations and displacements, the other major area to be measured is the monitoring of voltage.

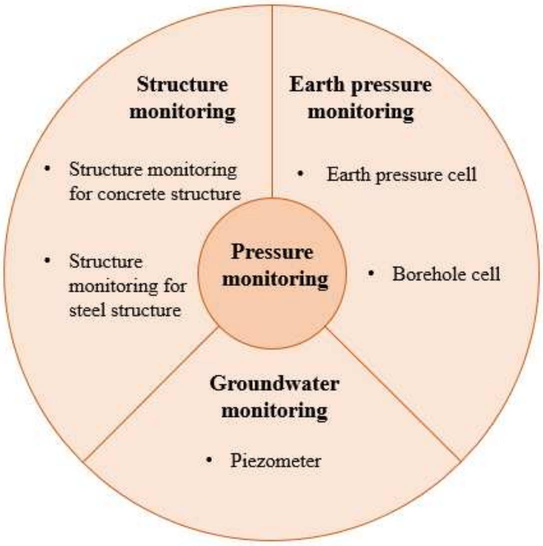


Figure 7*. Stress measuring instruments*

In order to continuously analyse the soil-structure interaction, it is worthwhile to place monitoring elements for the direct measurement of voltage in the case of new constructions during the planning and construction period. These structural voltage devices can also be placed on existing structures, so the effect of increased voltage on the existing structure can be monitored. That is, in the case of existing structures, we can determine voltage indirectly. The voltage measuring device placed on the test section of concrete structures is able to determine voltage values acting on the structure from displacements between two fixed points. In the case of steel structures, it is possible to use measuring devices that can be fixed by welding or gluing. Similarly to concrete structures, in the case of steel structures it is also possible to indirectly determine voltage values from displacement measurements.

In both cases, the frequency of the measurements can be adjusted and programmed. Real-time measurement results can be determined with the devices.

VII. Management and application of data, alarms:

The uniform management of certain measuring devices is crucial for setting up a real-time monitoring system. The reading results from each measuring device should be put together on a single surface, with the use of a standardized scale and system. The underlying reason is the need to make safe, well-founded decision during the evaluation of the obtained measurement results.

The data read from the measuring instruments has to be forwarded to a central data logger, which collects and transmits all the results to the central protected server, where the results are stored, while the processes of evaluation and display are synchronized.

International practice demonstrates that during the investment the data measured by the monitoring system is stored on 3 independent protected servers. One of the 3 protected servers is owned by the Investor, another belongs to the Contractor, and the third one is owned by the Independent Operator that manages the monitoring system. The data stored on the servers can only be modified and any data can be deleted by simultaneously entering an authorization password. In this case, unwanted changes to measurement results can be avoided.

In the design of the monitoring system, it is essential to determine those levels of criteria for each measurement point of the given building that serve as milestones during the operation of the monitoring system. For existing facilities, I think it is important to note that entering status "0" is considered to be a critical action. Therefore, test operation for a significantly long period of at least half a year, i.e. operations in order to set up status "0" are required before the commencement of the actual construction works. In order to determine the temperature and groundwater compensation levels, 1 full year is required for setting up status "0". The level of false alarms can be reduced to a minimum by properly determining status "0", as well as by specifying the associated cyclic curves for temperature and groundwater. The results are displayed in a geoinformation system prepared for the test facility.

Invariably, the determined alarm levels need to be indicated for each measurement type and point.

Once the alarm levels have been reached, the geoinformation system is to trigger an automatic alarm to the professionals concerned both via mobile phone and e-mail.

The applied elements of the planned monitoring system have to be defined in a manner where the measurement results provided by them can be managed in a geoinformation system.

VIII. Conclusions

The purpose of the risk analysis is to precisely define all work phases that may affect the operation of the power plant under protection at any level.

The risk analysis yields an accurate view of the risk index of the defined work phases.

The risk index is objective, based on which the necessary tasks and interventions can be worked out.

The risk analysis needs to encompass a precise description of the auxiliary technologies, proposals and other devices that can be used during risk mitigation. In many cases, on the level of permitting plans, in preparation for the events when their application becomes necessary. It is particularly important in a power plant environment where each technological change, further construction interventions are allowed only with the special approval of the competent authorities.

In the context of nuclear power plants, it is indispensable to define the auxiliary technologies accurately, and present them to the permitting authorities on the level of designs, and in the case of nuclear power plants to the local IAEA.

In today's world, where an energy crisis is starting to emerge, some nuclear power plants are being shut down in some places, whereas elsewhere new ones are being built, developed or transformed, or extended operating hours are being introduced, accurate risk analysis is essential to ensure safe operations.

New power plants are being erected, and are often built in the immediate vicinity of existing power plants that are already at the end of their operating lifetimes. The construction of new power plant units increases the risks associated with the safe operation of the existing power plant to an unprecedented extent.

What is to be achieved? The goal is that the entire construction of the new power plant units should consist of work processes that belong to an acceptably low (L) risk classification. If it cannot be achieved, then it becomes necessary to identify the technological options, changes in the construction schedule and auxiliary technologies that allow risks to be largely mitigated.

The risk analysis should present an itemized list of all the phases of construction, each of which needs to be provided with a specific risk index. In the case of activities classified as carrying medium, high and very high risks, a proposal for potential risk mitigation measures has to be made. When opting for risk mitigation potentials, feasibility and the degree of risk mitigation should be the principal considerations.

In the case of nuclear power plants, economical realization is not the goal to be set, rather the sole option should be maximum safety. Achieving this level of safety is essential even if an operating nuclear power plant becomes involved in another construction project. An example in this respect is when new units are constructed next to operating nuclear power plant units. This is how the level of risks affecting nuclear power plants can be minimized.

In the case of nuclear facilities, safety should be considered above all other aspects, and cannot be questioned.

Nuclear safety is the absolute priority. In some cases, however, construction risks can cause unforeseen, unexpected situations that to a certain extent can compromise the nuclear safety of the given nuclear facility. To avoid such situations, continuous monitoring is necessary for each intervention, construction activity in the entire area of nuclear facilities. It also extends to the elements of the monitoring system for geotechnical properties and the movement of buildings that is used during construction works.

In all cases, the elements selected for the monitoring system should complement each other, and their measurement results need to be managed in a geoinformation system. All the measurement results have to be integrated into a standardized alarm system. As part of the monitoring plan, an action plan corresponding to the given alarm levels needs to be drawn up.

For those risk elements where medium and high risk levels can be determined even after the implementation of risk mitigation actions, it is recommended to develop an additional safety action plan and intervention proposal as early as on the level of the planning of monitoring activities. The underlying reason is that in certain cases additional security activities may call for the construction of additional measuring devices as to be integrated into the projected monitoring system.

In all cases, the movements of building follow the movements occurring in the ground mass with delays in time, and therefore – in order to enhance safety – geotechnical monitoring system elements need to be added to building movement measurements.

All the measurement results have to be integrated into a standardized alarm system.

As part of the monitoring plan, an action plan corresponding to the given alarm levels needs to be drawn up.

Each projected monitoring system has to fit or be able to work in compatibility with the elements of currently operated measurement system for building movements in case there is such a system installed in the measurement area. The existing points of measurement have to be maintained and integrated into the system to be operated in the future.

By using a properly constructed real-time monitoring system, the probability of construction risks in the environment of nuclear facilities can be significantly reduced to almost zero.

AUTHOR CONTRIBUTIONS

E. Horvath-Kalman: Nuclear risk; risk analysis, geotechnical monitoring system.

B. Elek: Risk analysis, construction risk.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Structural Integrity of Turbine Stator Blades Using Different Super Alloys with Internal Cooling at Fluid Temperature Range of 600 K – 700 K

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Abstract: The importance of turbines in power generation cannot be overstated. While the failure in stationary plants can lead to downtime and high repair costs, its failure in mobile plants like the jet engines can be catastrophic with attendant loss of lives. Hence, by all possible means, the prevention of turbine failure is a necessity, and a very good means of doing this is with the use of super-alloys. Super-alloys are tailored to withstand the demands of turbine operations especially stress and elevated temperature and pressure. The blades are thus, manufactured from super-alloys, and of prominence are the Nickel-based super-alloys. The performance of five different super-alloys: (DS) GTD 111, Ti-6Al-4V, Inconel 718, CMSX-4, and Nimonic 80A was simulated using COMSOL MultiPhysics 5.5 at cooling air temperature range of 600 K – 700 K. The mode of cooling employed in the study is only internal cooling. With the developed stress percentage of the yield stress value and the stator blade displacement at the operating conditions as the criteria of performance, super-alloy Ti-6Al-4V faired as the best material for the stator blade.

Keywords: blade Displacement; developed stress; failure; yield stress

I. Introduction

The need for efficient turbines in the engineering world is enormous, as it is a good means of power generation in both stationary plants and jet engines. The need to subject a turbine to very high temperatures and pressure at operation periods places a high burden on its designers in the selection of appropriate materials and as such, turbine blades that are in constant contact with high temperature combustion gases are made from high temperature resistant materials [1]. The very high temperature demand of turbine blades has broadly limited its production materials to Nickel-based super alloys [2, 3] and some other elements like Rhenium and Titanium. To ensure the prevention of turbine blades failure due to very high temperatures, effective cooling is also, a necessity [1, 4]. While it is difficult to attribute a single cause for the reason for turbine failures, the indicators are more glaring at the hot sections and thus, we can attribute it to be direct and indirect consequences of the very high temperatures [2, 5-6].

It is undisputable that the thermal efficiency of combustion engines is a function of their maximum temperature, and thus, optimizing the performance of turbines is dependent on attainable maximum temperature while putting the metallurgical limit into perspective. A situation that is helped with efficient cooling. However, if not well managed, this can be a recipe for failure [1]. This is not just required for turbines, proper cooling is also required in braking systems to avoid brake fade [7]. One of the means of turbine blades cooling is “internal cooling’, others are film and coated cooling. The temperature variation of internal cooling air affects the blades temperature values, such that the lower the temperature the more beneficial it is in terms of keeping the blades temperature below the metallurgical limit [1]. However, this have a negative impact on other its yield, hence necessitating the need for an optimized temperature value to ensure optimal results [1].

Studies on the use of (DS) GTD 111 as a stator blade material using only internal cooling while adopting suitable approximations and assumptions resulted in a cooling air temperature of 660 K for optimized performance [1]. While (DS) GTD 111 is one of the numerous Nickel-based super alloys used in turbine blade manufacture, others exist and there is a possibility of improved performance with their usage. The breakthrough for the production of durable turbine blade materials were brought about by the development of the directional solidification (DS) and the single crystal (SC) method of production [8]. These super alloys have excellent mechanical properties at elevated temperatures that are required for optimal performance of turbines [9].

Titanium-6Al-4V is have good properties qualifying it for use as a turbine blade material such as high strength, high temperature and corrosion resistance, and asides form their applications for turbine blades, they are also good for use in nuclear plants [10-12]. Inconel 718 is one of the excellent super alloys for the manufacture of turbines due to superb tensile strength, fatigue strength, and degree of creep rupture at high temperatures, asides the ease of formability and weldability [9]. CMSX-4 is a single crystal Nickel-based super alloy and finds application in turbine blades because of its excellent properties like superb stress-rupture resistance and corrosion resistance [13]. CMSX-10 is a third-generation super alloy [8] purposely designed for use in turbine blade applications and is a produced using the single crystal technology.

Nimonic 80A and Nimonic 263 are Nickel-based super alloys that finds application in the manufacture of turbine parts [9]. They have excellent oxidation and corrosion resistance even at elevated temperatures, and good tensile and creep-rupture properties. Nimonic 263 provides improved proof stress and creep strength [14-15], and it offers better ductility in welded assemblies over Nimonic 80A.

This study is committed to exploring the outcome of using other materials like Ti-6Al-4V, Inconel 718, CMSX-4, and Nimonic 80A as the stator blade material to determine the optimized cooling air temperature.

II. METHODOLOGY

The heat transfer, developed stress, and structural displacement of the turbine stator was determined numerically using the heat transfer and the structural mechanics modules available in COMSOL MultiPhysics 5.5 Version.

The heat transfer in the stator is gotten using governing equation:

$$\rho C_p \boldsymbol{u}.\nabla T + \nabla.\boldsymbol{q} = Q + Q_d \quad (1)$$

This equation is a simplified form of the general equation of heat transfer in solids with the assumption of steady state temperature over time. The equation applies only to the heat transfer in the stator, and the effect of stresses are factored in by coupling of the equations of motion in the MultiPhysics module.

$$\boldsymbol{q} = \text{heat conduction} = -k\nabla T \quad (2)$$

C_p − heat capacity, Q − heat transfer, u − velocity of fluid, and Q_d − *thermoelastic damping*

The heat flux is gotten using the expression;

$$q_0 = h(T_e - T) \quad (3)$$

The boundary condition here is the specified heat flux, h, is the convective heat transfer coefficient and represents all the physics occurring between the boundary and "far away."

The governing equation derived from the equation of motion based on virtual work is used to solve for the stress developed and the structural displacement:

$$0 = \nabla.S + \boldsymbol{F}v \quad (4)$$

Fv − volume force vector, ∇. S − stress divergence, S − 2nd Piola − Kirchoff stress is as expressed thus:

$$S = S_{ad} + C:\in_{el} \quad (5)$$

C − Viscous damp $= C(E, v)$ *and* $\in = \frac{1}{2}[\nabla u^T + \nabla u]$

The stator geometry is akin to that of NASA power turbine, the study employed a free tetrahedral mesh type with minimum and maximum size corresponding to 0.00228 m and 0.0182 m. the resolution of the narrow regions was set to 0.6, the curvature factor to 0.5, and the maximum element growth rate to 1.45. The generated mesh on the turbine stator blade for CMSX -4 is depicted in **Fig. 1.**

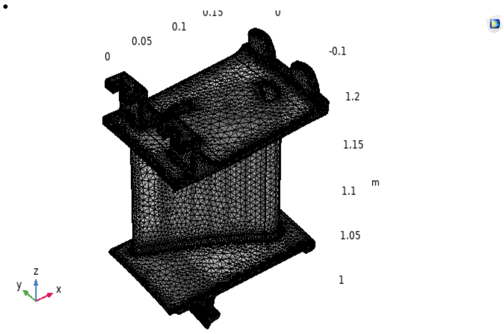

Figure 1. *Meshing of Turbine Stator (CMSX-4)*

The fluid employed for the internal cooling was taking to be air, and some of the parameters used are depicted in **Table 1**.

Some of the assumptions made in simplifying the study are as enumerated:

1. Cooling is only internally by the flow of the air.
2. The combustion gas temperature is 1100 K.

Table 1. *Cooling air study parameters*

Parameter	***Values***
Free stream velocity at platform walls	350 m/s
Stator pressure side gas velocity	300 m/s
Stator suction side gas velocity	450 m/s
Working temperature	900 K
Working pressure	30 bar

3. The adopted Mach number for the pressure and suction sides are 0.45 and 0.7 respectively.
4. The pressure and suction sides of the duct are flat plates.
5. An average Nusselt number correlation was used for the calculation of the heat transfer coefficient. This is possible due to the cooling duct geometry not including the rib details.
6. The turbine has a working temperature of 900 K and a heat transfer coefficient of 25 W/ (m^2. K)

The corresponding Poisson's ratio of the different materials used for the stator blade is as presented in **Table 2**.

Table 2. *Poisson's Ratio values of the studied materials*

(DS) GTD 111	*Ti-6Al-4V*	*Inconel 718*	*CMSX-4*	*Nimonic 80A*
0.33 [1]	0.34 [12]	0.29 [16]	0.39 [13]	0.3 [17]

The air values of heat capacity, Prandtl number, and viscosity at the studied temperature range were determined from literature [1].

III. Results and Discussions

Bearing in mind that the value of the developed stress must be lesser than the material yield stress at the working temperature to prevent failure, the yield stress values for the different utilized blade stator materials is as depicted in **Table 3**.

Table 3. *Yield Strength at 923 K (MPa)*

(DS) GTD 111	*Ti-6Al-4V*	*Inconel 718*	*CMSX-4*	*Nimonic 80A*
645.62	350 [10]	980	1060 [12]	710

The behavior of the stator blade resulting from the modelling with COMSOL MultiPhysics 5.5 for the selected super alloys are presented in figures. These are plots of blade displacement (mm), developed stress (MPa), yield stress value (MPa) at 923 K, and cooling air temperature (K). **Fig. 2, 3, 4, 5,** and **6** present the results for the selected super-alloys; (DS) GTD 111, Ti-6Al-4V, Inconel 718, CMSX-4, and Nimonic 80A respectively.

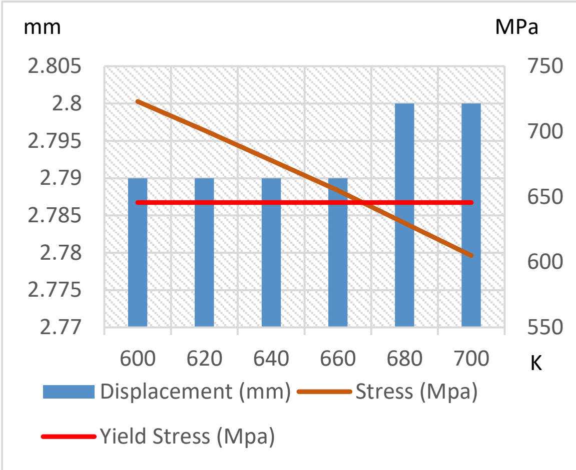

Figure 2. *Stress – Displacement Plots for (DS) GTD111*

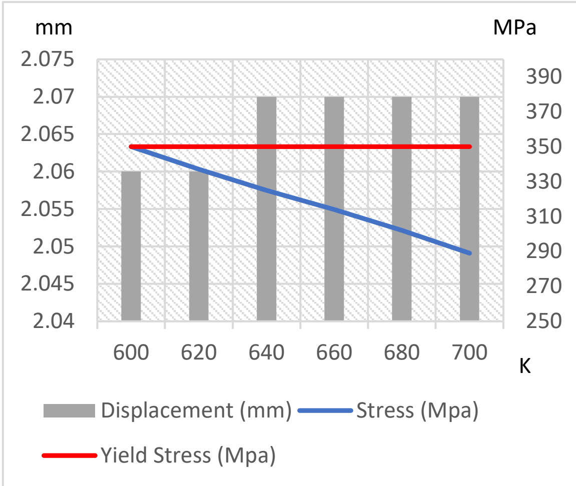

Figure 3. *Stress – Displacement Plots for Ti-6Al-4V*

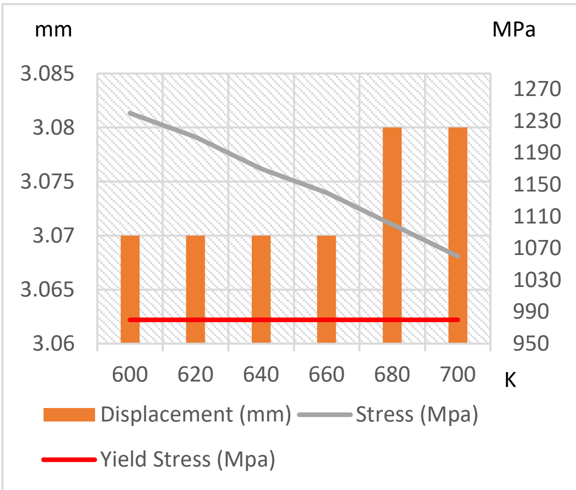

Figure 4. *Stress – Displacement Plots for Inconel 718*

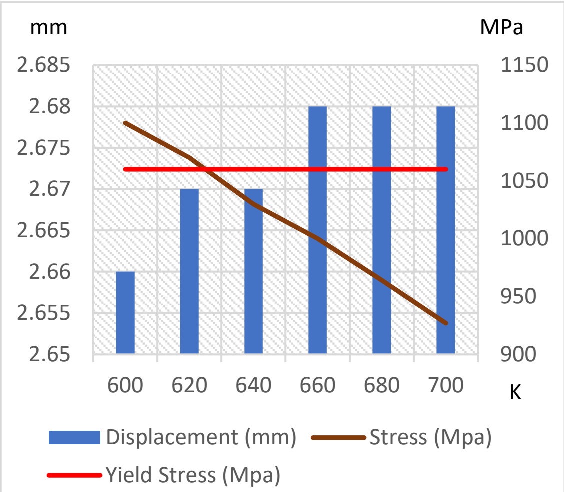

***Figure 5**. Stress – Displacement Plot for CMSX-4*

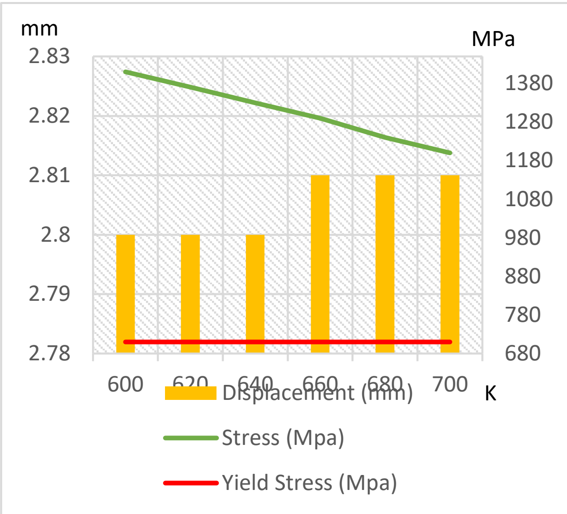

***Figure 6**. Stress – Displacement Plots for Nimonic 80A*

The developed stress in the stator blade increases with the decrease in cooling air temperature and the displacement of the stator blade decreases with decreasing cooling air temperature irrespective of the material used. While as little as possible blade displacement is desirable and is favoured with low cooling air temperature values, which in turn ensures that the material operates below the metallurgical limit, the same does not apply to the developed stress. Exceeding the yield stress at the normal working condition will lead to structural failure, and thus, there must be an optimization of the cooling air temperature to accommodate all the required features.

The developed stress for super-alloys; (DS) GTD 111, Ti-6Al-4V, and CMSX-4 will at a point be below the material yield stress for the considered cooling air temperature range, while for the super-alloys; Inconel 718 and Nimonic 80A this was not the case. Super-alloy Ti-6Al-4V will allow for the least value of cooling air temperature of the three that qualifies for the range 600 K to 700 K, followed by CMSX-4.

It is possible for the developed stress values to be lesser than the material yield stress for Inconel 718 and Nimonic 80A with an increase in the cooling air temperature; however, this will signify increased stator blade displacement and average temperature. From the data provided in Figure 4, the gradient of the line is 1.8 ($m = \frac{y_2 - y_1}{x_2 - x_1}$) and using this to predict the cooling air temperature at which the developed stress will be equal to the yield stress gives the value 744.44 K.

This implies that if the cooling air temperature is made to be ≥ 744.44 K, the value of the developed stress will be equal to or lesser than the yield stress of Inconel 718. And it is only at cooling air temperature values above this value that there will be a certainty of prevention of the blade deformation and failure taking note of only internal cooling.

To determine the most suitable super-alloy for application as a turbine stator blade when cooling mode is only internal, this study calculates the cooling air temperature that leads to a developed stress value that is 98% of its yield stress by interpolation. The presentation of the result is in **Fig 7**.

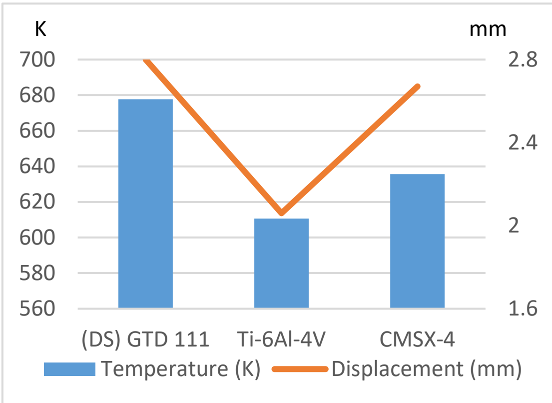

***Figure** 7. Performance Comparison of Some Super-Alloys using Internal Cooling*

Super-alloy Ti-6Al-4V as the stator blade material faired as the best due to the least value of displacement while allowing for the least cooling air temperature of the three. This is an indication that while being subjected to the operating conditions, Ti-6Al-4V super-alloy will experience the least of thermal fatigue stress of the considered materials. This is consistent with its wide application in the aerospace industry providing the required properties even at elevated temperatures.

Super-alloy CMSX-4 and (DS) GTD 111 also demonstrated better performance than the remaining two considered super-alloys and echoed the significance of the direct solidified and single crystal manufacturing technology.

IV. Conclusion

The study employed only internal cooling as the cooling means of the turbine stator material while neglecting film and coated cooling. Based on the studies on five different super-alloys: (DS) GTD 111, Ti-6Al-4V, Inconel 718, CMSX-4, and Nimonic 80A, the following deductions were made:

1. The developed stress of the super-alloys decreased with an increase in cooling air temperature, while the opposite was the case for the stator blade displacement.
2. Super-alloys (DS) GTD 111, Ti-6Al-4V, and CMSX-4 have a developed stress value lower than the yield stress at the studied cooling air temperature range.
3. Super-alloy Ti-6Al-4V showed the least stator blade displacement at 98% developed stress of the corresponding yield stress value of the studied super-alloys.

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AUTHOR CONTRIBUTIONS

O. A. Towoju: Conceptualization, Modelling, Theoretical analysis, Writing.

S. O. Enochoghene: Review and editing.

J. A. Adeyemi: Review and editing.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The possibility of electrification in public transport bus services

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Abstract: From Shenzhen to Philadelphia and Izmir to Delhi, public bus operators around the world are increasingly using electric buses. Their choice is not only justified by support for the green transition or the reduction of background traffic noise: economic calculations regarding the entire life cycle cost also support the need for technological change. The article points out that the inclusion of electric vehicles in the service requires a complex approach and can bring a revolutionary change in our operation. The transport company can become a community service provider that occasionally provides balancing energy for energy supply systems (Vehicle-to-grid, i.e. V2G) or provides a virtual power plant service to the operators of photovoltaic power plants. The bus company can become a producer with independent network power generation capacity, which can sell the excess capacity it produces on the market to the owners of electric cars. The article presents the operating model that connects the transport, energy and battery industrial systems. Last but not least, batteries that have lost their capacity but are still usable can be resold for "storage" or other secondary purposes, even as uninterruptible power supplies. In order to implement the operation according to the model, Volánbusz Zrt. started building its data-driven ecosystem, which enables cost-optimized operation based on the data of an ever-growing electric bus fleet and the solutions of Industry 4.0 technology.

Keywords: electrification; electric bus; public transport; zero emissions; circular economy; Vehicle-to-grid; pilot project description

I. INTRODUCTION

"Thanks to advances in technology, in 2023 the introduction of electric buses in public transport is nowadays no longer an engineer's fantasy dreamed up on the drawing board, but an accomplished reality." [1]

From Shenzhen to Philadelphia and Izmir to Delhi, public bus operators around the world are increasingly using electric buses. Their choice is not only justified by support for the green transition or the reduction of background traffic noise: purely economic calculations also support the need for technological change. This is especially true where energy needs are extremely import-intensive. The energy crisis of recent years has pointed to the seemingly clichéd but all the more important conclusion that a country can be economically successful and stable if it is able to produce its own energy needs and transform its economic structure in such a way that its energy imports are as small as possible.

The revolution in battery technology emerging in the early 21st century is fundamentally transforming the manufacture of cars and buses. Electrification can significantly reduce the need for energy imports in countries which – like our own – have extremely limited fossil fuel resources, and it can also increase such countries' economic stability and independence.

Economic calculations and operational efficiency considerations play an increasingly important role in the rise of electric buses. This is confirmed by the results of tests and measurements carried out with scientific precision at Volánbusz Zrt.

II. THE RISE OF ELECTRIC BUSES IN PUBLIC TRANSPORT

The appearance of electric buses in transport goes back to the middle of the 19th century. Electric buses were first developed on an experimental basis in the late 1880s and early 1890s, and were in use in some cities as early as the late 1890s.

One of the early examples of electric buses was the British city of Brighton, where an electric bus line was put into operation in 1890. After that, they started experimenting with electric buses in other

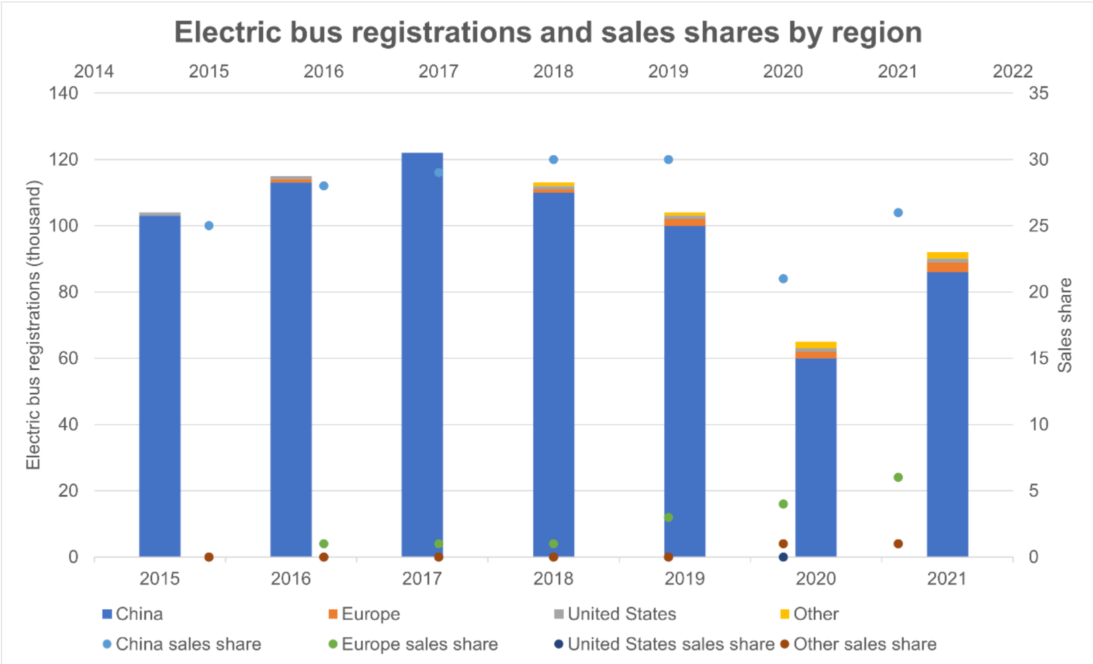

Figure 1. Electric bus registrations (dots) and share (bars) of total bus sales by region, 2015-2021 [3]

cities; for example, the first electric bus line in New York began operations in 1907.

The popularity of electric buses has fluctuated over the decades, and their adoption has been influenced by advances in technology, fluctuating oil prices and other factors. In recent decades, however, electric buses have become increasingly popular in urban public transport as a more environmentally friendly and sustainable transport option.

It is important to note that the technology and prevalence of electric buses may differ in each region and country, and their appearance over time also varies. The transport policies and development directions of the given cities and countries also play a role in the spread of electric buses.

Electric buses have been playing an increasingly important role in public transport in recent years, with their significance growing as cities and countries around the world seek more sustainable and environmentally friendly transportation options.

From the late 2010s to the early 2020s many cities in Europe, Asia, and North America have begun to make substantial investments in electric buses. Several major cities – such as London, New York, and Los Angeles – have announced plans to transition their entire bus fleets to electric vehicles over the coming years.

The upward trend in electric bus purchases is strengthening worldwide. **Fig. 1** shows the registration and sales share of electric buses by region in the period 2015–2021 [3]. In 2015, 103,000 electric buses were registered in China, and 25% of the buses sold there were electric. In 2021, the number of electric buses registered in the European Union increased to 3,000, and 6% of buses sold there were electric.

Analysing the latest data [4], it can be concluded that the registration of zero-emission buses in Europe increased from 1,400 in the first half of 2021 to approximately 2,600 in the first half of 2023. Moreover, their share of the total city bus registration is 22% in 2021, 30% in 2022, and – based on the first half of the year – 37.5% in 2023.

In the years 2022–23, the electrification of public transport in Hungary also started strongly, the decisive player in this being Volánbusz Zrt., which plays a significant role in regional and urban transport. [5, 6]

III. Global forces and trends determining the electrification of the transport industry

When making long-term development decisions related to transport enterprises, it is extremely important to take into account the global impacts and trends affecting the economy and technological processes. **Fig. 2** shows the trends and global impacts for 2023. For the development of vehicle fleets and the cost-effective, sustainable provision of transport services, the main economic and technology trends that public transport service providers must keep in mind are the applicability of circular economic models and the transformation – supported by data-driven decisions – needed to meet the demand for net zero operation of vehicle fleets. [2]

Figure 2. *Megatrends and global impacts for 2023*

IV. Reasons for deploying electric buses in vehicle fleets

The deployment of electric buses in public transport systems is driven by several compelling reasons, including environmental, economic and societal factors. Here are the main reasons to deploy electric buses.

1. Environmental Benefits

Electric buses produce zero tailpipe emissions, which helps mitigate climate change and reduce air pollution in urban areas through reduced greenhouse gas emissions. [7] They do not emit harmful pollutants like nitrogen oxides (NOx) and particulate matter (PM), leading to better air quality and public health outcomes.

These vehicles are quieter than their diesel or gasoline counterparts, reducing noise pollution in urban environments. However, the low noise levels produced by these vehicles, previously seen as an advantage, could pose a new risk to the safety of road users. [8] Due to their reduced noise output, quieter electric buses contribute to a more peaceful urban environment, especially in densely populated areas.

2. Societal factors

The public perception of electric buses that has developed is that they are a symbol of cities' commitment to sustainability and environmental responsibility, as a kind of shift to greener policies which can improve a city's image and appeal. An important health benefit is that cleaner air resulting from reduced emissions can lead to improved public health outcomes, including a decrease in respiratory and cardiovascular illnesses.

Investing in electric buses and related technologies can stimulate innovation and create opportunities for new industries and jobs.

It is important to note that the specific reasons for deploying electric buses can vary by region, depending on local priorities, policies, and the unique challenges faced by each city or transit agency. In addition to environmental and social aspects, factors of particular importance for large public transport companies operating in accordance with the legal and market economy rules of the European Union are economic sustainability, energy efficiency and the application of innovative technologies.

3. Compliance with Regulations

The pace of European transport systems' electrification is also sustained by the European Commission's development of a new package of proposals to reduce greenhouse gas emissions and introduce electric vehicles and other new technologies. Among other things, the decree sets specific dates for the phase-out of internal combustion engine vehicles. According to this, the sale of diesel and gasoline cars must be phased out by 2035, and all new cars must be emission-free. [9]

4. Energy Efficiency, Independence and Security

Electric buses are more energy-efficient than internal combustion engine (ICE) vehicles, leading to reduced energy consumption and operating costs. Due to their regenerative braking system they can recover energy during braking and deceleration, increasing overall energy efficiency.

Deploying electric buses reduces a city's dependency on fossil fuels, and by diversifying and using renewable energy sources, it greatly improves energy security.

5. Technological Advances

In addition to improving traffic safety, important cost-saving potential is offered by innovative functions used in electric buses, such as route optimization telematics, regenerative braking and integration with smart city systems. The charging infrastructure designed to operate electric bus fleets can also provide services for other electric vehicles, such as cars and trucks, providing a source of income to cover the costs of operation.

6. Cost Savings – Total Cost of Ownership

In addition to the aspects of sustainability and climate protection, electric buses must also compete with diesel buses in terms of total cost of ownership (TCO).

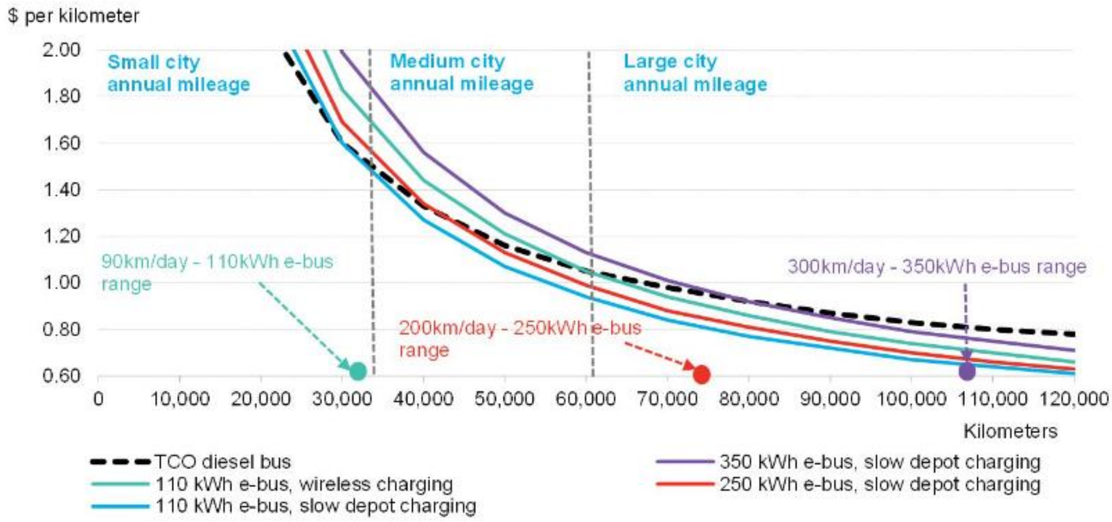

Figure 3. Comparison of e-bus and diesel bus TCOs in relation to annual mileage

Electric buses have fewer moving parts, require less maintenance, and have lower fuel costs compared to diesel or natural gas buses. All this contributes to lower operating costs.

Although the capital cost of electric buses may be higher, their lower operating and maintenance costs can result in long-term financial savings.

Fig. 3 illustrates that, assuming a given price of diesel and electricity, the TCO of an electric bus may be more favourable at higher daily mileage levels. As electric bus and traction battery manufacturing technologies advance, purchase prices may continue to fall, further improving TCO. [10]

In order to achieve optimal TCO in the electrification process of sustainable public transport, a continuous task is the comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles.

A cost-benefit analysis (CBA) was already carried out in the mid-2000s, which indicated that plug-in hybrid and electric city buses have the best potential to reduce energy consumption and emissions. But the most critical factors for improving the cost-efficiency of these alternative city bus configurations and reaching an appropriate TCO are the capital and energy storage system costs of city buses. [11]

In the electrification of city bus networks, the cost-effective location of the **charging infrastructure** and the battery sizing of fast-charging electric bus systems play an important role. By developing an optimization model, the TCO can be significantly improved. [12]

In the electrification of city bus networks, the cost-effective location of the **charging infrastructure** and the battery sizing of fast-charging electric bus systems play an important role. By developing an optimization model, the TCO can be significantly improved. [13]

A 2018 study concluded that H2FC buses meet operational and performance criteria and are environmentally friendly when using “green” hydrogen. This analysis also confirmed that the economic sustainability of buses in terms of affordability will be equal to their fossil fuel equivalents by 2030, when indirect costs related to human health and climate change are taken into account. [14]

A 2021 comparative TCO analysis of battery electric and hydrogen fuel cell buses for public transportation systems in small and medium-sized cities [15] shows that using short-range all-electric city buses with fast charging infrastructure will be the most economical option in 2030. The study compared the TCO of slow and fast-charging electric buses and hydrogen cell bus models with diesel buses.

The development directions determined on the basis of the experiences gained during the electrification of public transport in Poland in the 1990s–2020s show that the strategy of the national and regional authorities in Poland has focused mainly on electric buses and charging infrastructure, without a thorough analysis of the legality of their operation. It has paid insufficient regard to the energy balance in Poland, where fossil fuels are the main source of electricity production, and to the fact that the development of electric public transport and renewable energy sources should be combined to a greater extent. [16]

V. HOLISTIC MODEL INSTEAD OF SUBSYSTEM OPTIMA

There are quite a few arguments and counter-arguments for the use of electric buses in public transport, but the literature only deals with one or more subfields of the service-related factors, such as fuel consumption, charging infrastructure, battery capacity, vehicle range and investment cost. The purpose of this publication is to present a model with a holistic approach that examines the total lifetime cost of a larger electric bus fleet in a broader context. In the context of the model, it manages the possibility of connecting the systems of the energy industry, transport and battery industries, taking into account the requirements of a transport service provider. An essential part of this system is the circular battery value chain (**Fig. 4**) that links the transport and power sectors. [17]

Through data management and the disruptive tool system of Industry 4.0, the model coordinates the optimal way of procuring fuel with the use and storage of renewable energy sources in a circular economic process system. The data comes from the transport provider's real-time operation and traffic systems and, in connection with energy market information, optimizes the logistics processes in a predictive, prescriptive way. **Fig. 5** shows the logistic model of this data-driven management system.

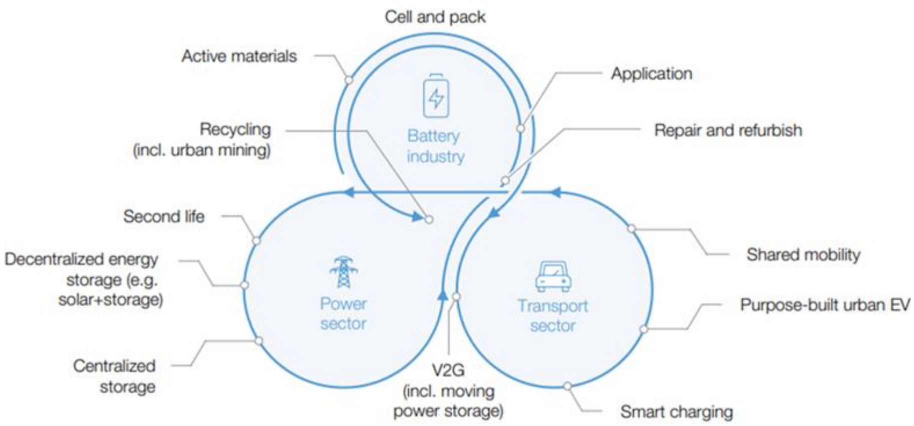

Figure 4. *Circular battery value chain that links the transport and power sectors [17]*

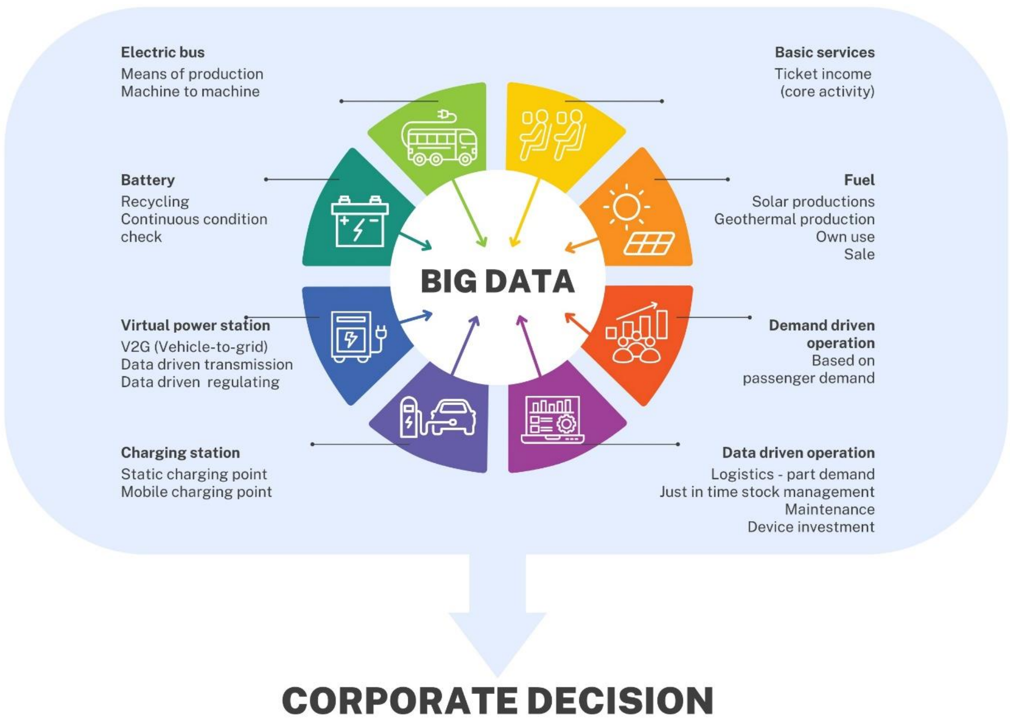

Figure 5. *The logic diagram of the data-driven company management system at Volánbusz Zrt [5]*

VI. THE ROLE OF VOLÁNBUSZ ZRT. IN THE SUSTAINABILITY OF DOMESTIC PUBLIC TRANSPORT

Volánbusz Zrt. is a key player in domestic road passenger transport. With its fleet of 5,247 intercity and 634 local and suburban buses, it transports 539.2 million passengers per year with a daily mileage of 1.2 million kilometres. With 17,755 employees, Volánbusz Zrt. is Hungary's 3rd largest employer.

Currently 95% of the vehicle fleet are diesel-powered buses. A smaller number of compressed natural gas (CNG) and liquefied natural gas (LNG) vehicles also operate, and the introduction of electric buses has also begun.

Fig. 6 shows the expected composition of the vehicle fleet of Volánbusz Zrt. According to the company's plans, the share of battery electric buses – which accounted for 0.9% of the fleet in 2023 – could reach 50% by 2032.

From 2024, Volánbusz Zrt. will gradually renew its bus fleet of local and intercity vehicles and replace most of its diesel buses with electric ones. By 2032, 50% of the fleet will be electric buses. **Fig. 5** shows the planned number of buses each year, according to propulsion system. We do not have any plans to increase the number of CNG buses, and the electric buses purchased will replace diesel buses.

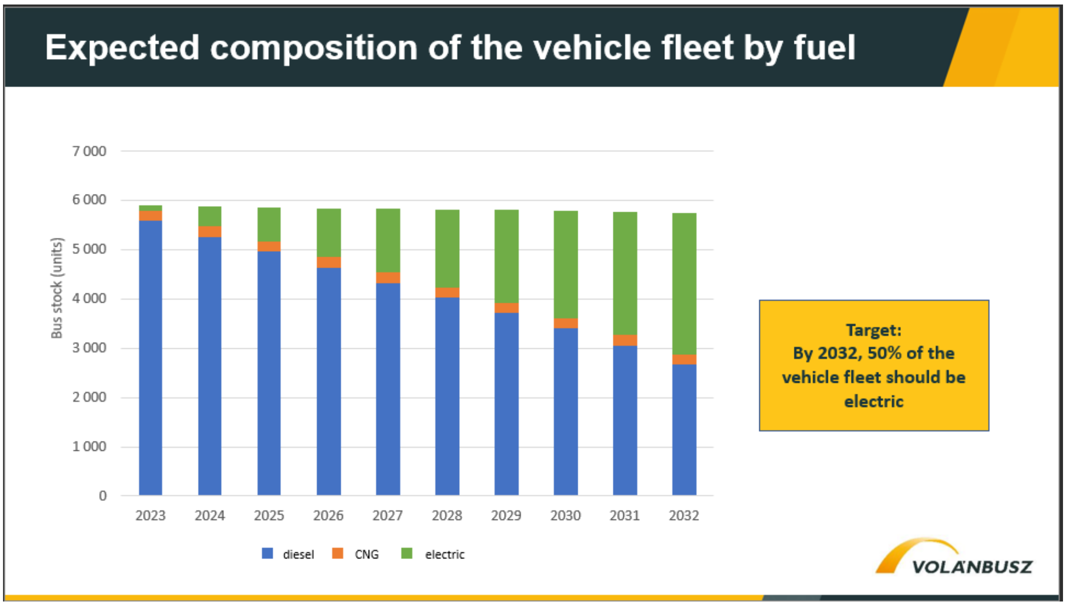

Figure 6. *Expected composition of the vehicle fleet of Volánbusz Zrt [6]*

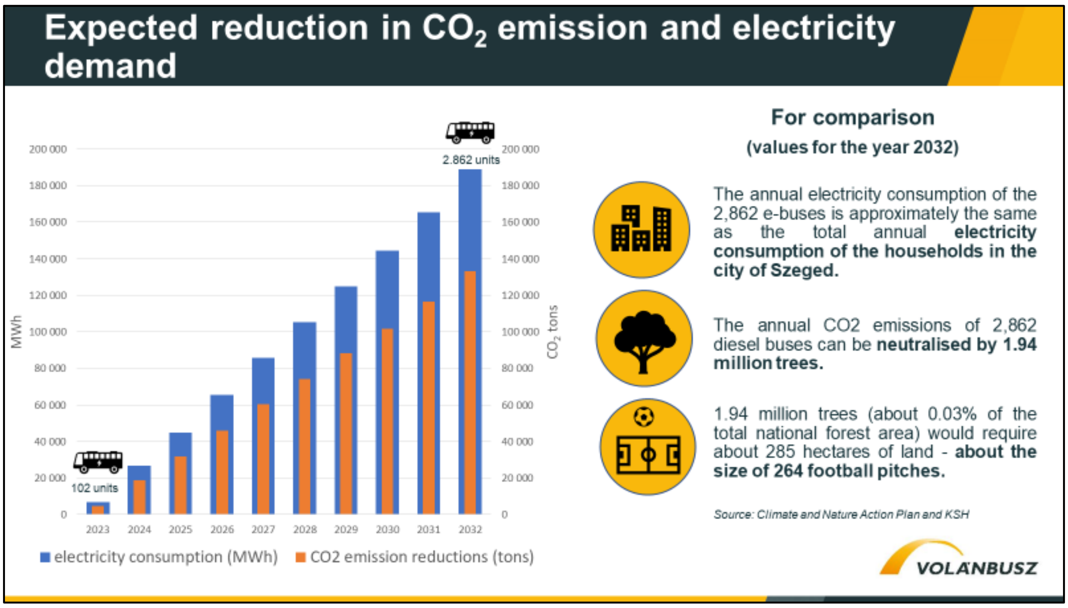

Figure 7. Expected reduction in CO_2 emissions and electricity demand [6]

The purchase of new buses will improve vehicle availability, resulting in a minimal reduction in the total number of buses in the fleet over the next 10 years (a reduction of almost 3% in the fleet by 2032).

Based on the concept presented above, the increase in the number of electric buses will be accompanied by an increase in electricity consumption and a reduction in CO_2 emissions as diesel buses are replaced. This is illustrated in **Fig. 7**.

VII. Technological change and re-evaluation of bus operators' classic role

Given the significant size of the fleet and the considerations outlined above, the question arises as to whether Volánbusz Zrt. could be more than simply a public transport operator. Taking into account today's technological advances and our company's vehicle operating practices, from the above figures it can be seen that with 1,000 electric buses and a battery capacity of 300 kWh per bus, the daily electricity demand of the total electric bus fleet would be 300 MWh. The scale of this could also revolutionise our operations: with this level of storage capacity, further business opportunities would open up. On the one hand, we could become a community service provider, intermittently supplying balancing power to the Hungarian electricity transmission system operator MAVIR (Vehicle-to-grid, or V2G) or a virtual power plant service for the operators of photovoltaic power plants. Our bus company could also become a stand-alone generator with independent generating capacity, which could sell its surplus capacity on the market – possibly also to the public. (There would be the potential to sell electricity to the owners of electric cars at charging stations set up at the more than sixty sites across the country belonging to Volánbusz Zrt.) Last but not least, there is a further business opportunity in the circular economy, with batteries with reduced but still usable capacity being resold as uninterruptible power sources for storage or other secondary uses. **Fig. 8** shows how Volánbusz Zrt. plans to implement this technology change.

The technological change outlined in this article and the re-evaluation of bus operators' classic role could be facilitated by synthesising the contributions of the major Hungarian-owned bus manufacturers present on the domestic market, battery manufacturers which have arrived more recently, and the professional and operational experience of Volánbusz Zrt. – which is unique in both domestic and international terms. Using these three pillars, in my view rapid changes in technology now make it possible to create a new operational structure – a new business model – for public transport bus services, while at the same time taking into account the specific geographical characteristics of our country (the potential for development of solar parks and geothermal power plant capacities, as well as a lack of fossil fuels). In this new structure the bus company can – in addition to its activities as a transport operator – perform energy trading and production tasks, and thus become a catalyst for the electric bus industry.

VIII. Conclusions

Global changes and emerging technological trends in the world, as well as the depletion of fossil energy sources, present new challenges – including for public transport companies. Around the world, operators of public transport bus services are

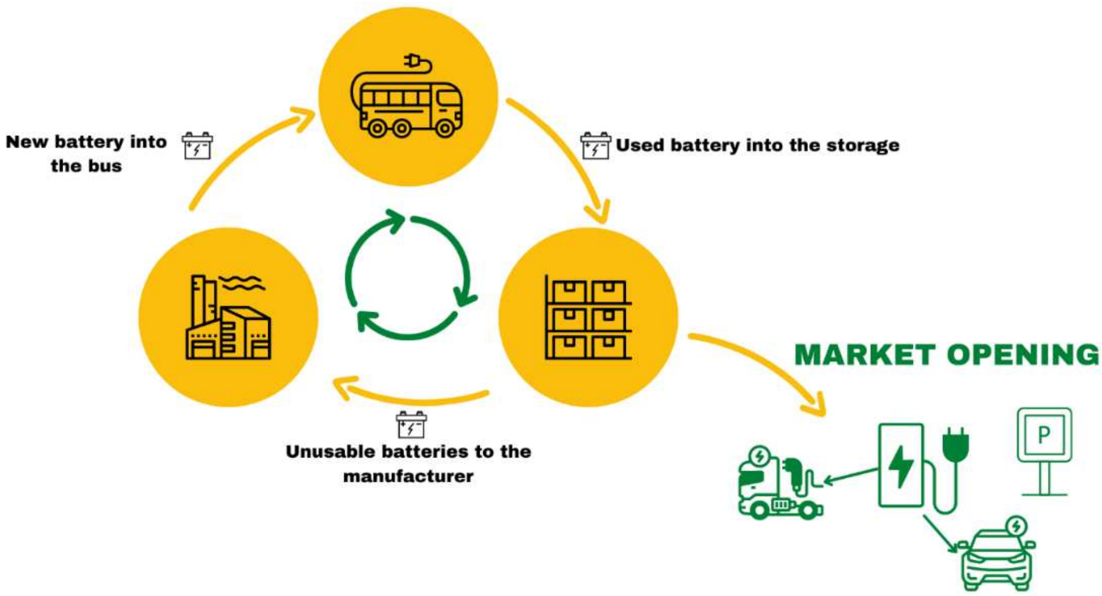

Figure 8. *The technology change model at Volánbusz Zrt [6]*

increasingly using electric buses. The revolution in battery technology is fundamentally transforming the manufacture of cars and buses. Electrification can significantly reduce the need for energy imports in countries which have extremely limited fossil fuel resources.

As confirmed by the tests and measurements carried out at Volánbusz Zrt., economic calculations and operational efficiency considerations play an increasingly important role in the adoption of electric buses. All this confirms the conclusion that technological transformation and reinterpretation of the classic role of the transport service provider are not merely possible, but urgent imperatives.

AUTHOR CONTRIBUTIONS

V. Kruchina: Conceptualization, Experiments, Theoretical analysis, Writing, Review and editing.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Challenges of the visual line of sight operations of unmanned aerial vehicles

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Abstract: The following question often emerges: what is the maximum distance during a visual line of sight (VLOS) operation between the remote pilot and the unmanned aerial vehicle (UAV)? The answer is complex, and there is no particular number because it depends on several factors that have to be jointly taken into consideration. The generally mentioned 1 km rule is not applicable for all cases. In some cases, 1 km means the absolute maximum. However, it should be considered that in certain situations, the operation can get out of the VLOS operation limits, even if obstacles and other factors do not hinder the view of the UAV.

Keywords: *unmanned aerial vehicle, UAS, UAV, visibility, beyond visual line of sight operation, drone*

I. INTRODUCTION

This article presents the challenges and limits of the visual line of sight and beyond visual line of sight operations of unmanned aircraft systems based on European regulations. These factors have a significant influence on the execution of a single operation. The article is based on European regulations, but some American solutions are also presented as best practices or meaningful outlooks. Moreover, the article presents the challenges of BVLOS and VLOS operations from the aviation safety viewpoint.

The topic is current and controversial due to the complex reading of the regulations and the diverse applicable solutions. The topic has not yet been researched, and there is only one empirical result, which is the basis of the German national regulation.

This is the reason why the references of the article consist of only regulations. The topic and the domain of the use of unmanned aircrafts are continuously evolving, and its basis is experience and empirical-based. Thus, the detailed scientific background of the usage is still waiting for. Some technical aspects and use-cases (even post flight evaluation of the captures images and videos) are already well-researched (like datalink communication, structural mountings, aerodynamic elements, batteries, video analysis for infrastructure monitoring, etc.) [1], [2], [3], [4], but usage-related questions regarding the fulfilment of the UAS operations are still open. This results that the standards are constantly changing based on the user experience and the accident and incident data.

In the article, the author presents the results of the regulation in a practical way and shows the difficulties of the usage. Moreover, it reveals a possible future way that may influence the usage and extend the potential technical means.

This article is considered a review of the current regulations in a technical way with operational examples, future implementation and development outlook.

Reviewing the following definitions and the connected explanations is essential for a better understanding of the subject.

- **Visual line of sight operation (VLOS):** Based on the Commission Implementing Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft, Article 2, point 7: „*means a type of UAS operation in which, the remote pilot is able to maintain continuous unaided visual contact with the unmanned aircraft, allowing the remote pilot to control the flight path of the unmanned aircraft in relation to other aircraft, people and obstacles for the purpose of avoiding collisions*” [5]. Based on the definition, it is provided that the remote pilot can see and eye the UAV and its surroundings with his/her eyes during the whole period of the operation. Compared to the EU definition, the American rule specifies much better because it defines what should the remote pilot continuously detect during the execution of the operation: current position, trajectory, course, altitude, orientation of the UAV, and affected airspace for the identification of any potential danger [6]. During the operation, the UAV cannot endanger the physical integrity of anyone, assets, or any other natural formation.

- **Beyond visual line of sight operation (BVLOS):** Based on the Commission Implementing Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft, Article 2, point 8: "*means a type of UAS operation which is not conducted in VLOS*" [5]. Based on the definition, all operations that are not able to fulfil the requirements of VLOS are BVLOS operations. BVLOS operations can be divided into more solutions, depending on the physical execution of the operation.
- **Visibility:** It is a horizontally measured distance where a landmark or an artificial non-illuminated object during daylight conditions fuse with the background but can only be recognised. To measure this, the measurer uses well-known dimension references on the spot. Measurement can be carried out at night, but the comparison is based on well-lit objects located at a known distance. In the case of UAS operations, flight visibility should be considered, which can be different occasionally than the visual range (measured on the ground). The maximum visibility can be set at 5 km, in accordance with VFR (Visual Flight Rules) flight rules. When the sight is ensured beyond this distance, this 5 km limit must be taken into account in all further calculations [7]. Further guidance is given in ED Decision 2022/002/R GM1 UAS.STS-02.020(3) [7].
- **Spatial perception limit of the UAV:** It is a horizontally measured maximum distance until the remote pilot is able to perceive the position, trajectory and orientation of the UAV. The remote pilot can control the trajectory of the UAV and detect its actual altitude and position by visual perception until the UAV reaches this distance. The precise value is determined by an empiric formula, taking the structure (fixed-wing or multicopter) and maximum characteristic dimension (diagonal wheelbase – CD measured in meters) of the UAV into consideration [8]:
  - In the case of multirotor UAV: 327 × CD + 20 meter
  - In the case of fixed-wing UAV: 490 × CD + 30 meter
- **Detection limit:** the distance until other aircraft can be visually detected and enough time is available to execute avoidance manoeuvres. This limit is always 30 per cent of the actual visual range measured on the ground [8]. During night or limited visibility, other limits can be determined experimentally.
- **VLOS limit:** The maximum allowed distance of the UAV from the remote pilot until the circumstances of VLOS can exist. This distance value is the lower value of the spatial perception limit of the UAV or the Detection limit and corresponds to a given operation.

II. Factors that have to be taken into consideration during the UAS operations

The VLOS or BVLOS feature of a single operation significantly emphasises the risk assessment and fulfilment of the operation. When the operation is fulfilled according to BVLOS, it can be conducted according to the rules of the Specific category only. The operational method like BVLOS or VLOS determines the ground risk class, the applicable risk mitigation measures and the compliance evidence that should be submitted to the civil aviation authority. Based on the presented information, the authority assesses the safe and secure fulfilment of the proposed operation – even with the assessment of the UAS-operator and the remote pilot – during the authorisation process.

The remote pilot's responsibility is to observe the rules and regulations during the operations.

1. Conditions for the Open category

In the Open category, only and exclusively VLOS operations can be conducted. It means that the conditions of the VLOS should always be satisfied. Otherwise, the remote pilot should abort the operation (UAS.OPEN.060(2)(b)). The Acceptable Means of Compliance (AMC) issued by EASA submitted to the (EU) 2019/947 regulation says that the remote pilot should control the UAV at a maximum distance from where he/she is able to detect it and determine its distance from the obstacles. If there is no obstacle, then the maximum distance of the UAV from the remote pilot is the visibility limit of the UAV (maximum distance from where it can be fully detected – spatial perception limit). In case of obstacles, this maximum distance should ensure that the remote pilot can assess the relative distance between the UAV and the obstacles.

In the Open category there is no limit for the VLOS border in the regulations. That originates from the fact that several factors jointly determine the VLOS border as a distance limit for the operations. They are the following.

Technical and environmental factors:

- Size of the UAV: the bigger, the better perceptible.

Table 1. *VLOS limits for multicopter UAVs [own edition]*

Type of UAV	diagonal wheelbase (m)	Spatial perception limit of the UAV (m)	Detection limit (m)			VLOS limit (m)		
			Visibility: 5 km	Visibility: 3 km	Visibility: 1 km	Visibility: 5 km	Visibility: 3 km	Visibility: 1 km
DJI Agras T10	2,68	896	1500	900	300	896	896	300
DJI Agras T30	2,98	994	1500	900	300	994	900	300
DJI Matrice 300	0,9	314	1500	900	300	314	314	300
DJI Mavic 3	0,38	144	1500	900	300	144	144	144
DJI Mini 3 Pro	0,25	101	1500	900	300	101	101	101
DJI Mini 2	0,21	90	1500	900	300	90	90	90
DJI Phantom 4	0,35	134	1500	900	300	134	134	134
DJI Air 2	0,3	119	1500	900	300	119	119	119

- Colour and painting of the UAV: UAV with flashy paint and pattern has better perceptibility. It must be considered that a UAV that fuses with the cloud's colour cannot be seen even from a few 10-meter distance (e.g. white or light grey UAV in cloudy weather).
- Actual weather and atmospheric effects: cloudage, cloud base, mist, dust, fog, smoke, sand, etc.
- Illuminance and its degree: sunshine, position of the sun, direction and degree of illumination, night, twilight and day conditions.
- The nature of the built or artificial environment, the location of any obstacles: Which part of the horizon is visible and to what distance?
- Trajectory, course and speed of the UAV: Is the remote pilot able to follow the movement of the UAV based on the intensity of the 3D trajectory of the UAV – considering the actual mental and physical situation of the remote pilot?
- Reference points, shadows: Are there any significant points that support the accurate position detection of the UAV?
- Visibility-enhancing equipment: They are fitted to the UAV to provide a better perception (lights, strobes, etc.).

Human factors:

- Actual physiological condition of the eye, as a sense organ: This is a continuously changing status, partly subjective, but objective standards can measure some elements. Several factors influence this, like age and momentaneous lighting effects (sensitivity and accommodative ability of the eye, etc).
- Actual mental status of the remote pilot: The tasks' complexity, the remote pilot's actual stress level and other emerging external disturbing effects may hinder the remote pilot's effective perception and decision-making.
- The routine of the remote pilot: The effective management of the tasks and perceptions may be a considerable challenge for a beginner or inexperienced remote pilot.

Based on the listed factors, it can be seen that there are situations when the VLOS limit is only a few 10 meters. It has to be considered during the flights.

Table 1. presents the maximal distance (VLOS limit) in meters (round for integers) for multicopter UAVs, considering the spatial perception limit of the UAV in case of different visibility.

Table 1 shows that it is impossible to reach the maximum 1 km distance in VLOS, even with the biggest DJI Agras T30 spraying UAV (Authorised and available in Europe).

It has to be considered if an unmanned aircraft observer (UAO) supports the remote pilot, the operation should be regarded as a VLOS operation because the UAO stands directly alongside the remote pilot, and this person assists the remote pilot in keeping the UAV in VLOS and safely conducting the flight. The UAO does not use aids to visually observe the UAV (like binoculars, electronic devices that present live video or other status stream, etc.), even correction spectacles.

2. Conditions for the Specific category

In the case of Specific category operations (and within it, even in the case of STS [5] or PDRA [5] based operations), the regulation conditions for the maximal distance of VLOS should be taken into consideration, and it has to be assessed uniquely for each operation. VLOS limits indicated in the STSs and PDRAs are absolute distances in all cases, which should not be exceeded even in optimal weather or environmental circumstances. When the Specific calculation regarding a single operation results in a lower VLOS limit than the indicated value, the maximum VLOS distance will be lower, even if the STS or PDRA has a greater limit. The reason is simple: the perception of the UAV is not provided from such a distance due to its size or other limiting conditions.

Therefore, the 1 km (or other indicated) maximum distance is just a guidance. This 1 km can be used only with proper-size UAVs and in optimal weather and environmental circumstances. The 1 km maximum distance originates from STS-02 conditions [5], [7] (UAS.STS-02.020 (6) (c)), because the UAV can move away from the nearest airspace observer only by a maximum of 1 km.

III. The specialities of beyond visual line of sight operations

When the remote pilot conducts an operation where the distance between the remote pilot and the UAV is greater than the VLOS limit, it can only be performed according to the BVLOS operational regulations.

The BVLOS operations have two types – the differentiation is analysed only from an operational viewpoint, and other legal specificities related to the operation are not part of the present analysis, like an assistant person during plant protection operations or other people who are not uninvolved in the operation, etc. [9]:

- **EVLOS - extended visual line of sight:** The operation is conducted with one or more trained airspace observers. An observer is a person who assists the remote pilot by performing unaided visual scanning of the airspace in which the unmanned aircraft is operating for any potential hazard in the air.
- **Single pilot BVLOS – conventional BVLOS**: Airspace observers and other supporting people are not supporting the operations (even the flying). A single remote pilot performs it. The remote pilot has no direct visual contact with the UAV by his / her eyes. However, the remote pilot is able to control the UAV by the help of the available technical equipment and the transmitted data and live video stream. Comprehensive safety solutions enable the single pilot operation.

During the fulfilment of the operations, the remote pilot or the UAS-operator (depending on who is responsible for the planning of the operation) should consider these factors, and based on them, he/she should determine the maximum distance to provide the VLOS (in case of EVLOS).

During the preparation phase, the maximum distance between the remote pilot and the UAV should be determined for all Specific category operations. This distance depends on the dimension and the environment in the case of VLOS operations, and in BVLOS, it depends on the applied technical mitigations and solutions. For all Specific category operations, the issued operational authorisation always determines the mode of operations (VLOS or BVLOS) and other significant conditions that influence the execution (like weather). In the case of BVLOS operation, the operator has the possibility to choose from several operational modes, which limit the maximum distance. They are the following:

- **Operations conducted by pre-defined risk assessment (PDRA):** PDRA provides a framework comprising predetermined risk mitigation measures, which must be used during the operations. The core of the solution is its simplicity. As long as the UAS-operator complies with the measures indicated in the PDRA, it is ensured that that the operations will remain under a given root risk (operations will have SAIL II, which are operations with low risk in the Specific category). Several PDRAs have been elaborated [7], and the UAS-operator can choose the best-fitting variant for his / her operations. The responsibility of the UAS-operator is to build the operational limits according to the PDRA, and it will be the basis of the requested operational authorisation. These limits define in detail the operational scenario (VLOS or BVLOS) and the maximum distance between the remote pilot and the UAV according to the size of the operational staff. PDRAs contain risk mitigation measures as general provisions. This offers flexible working conditions for the UAS-operators to elaborate their limits fitting the characteristics of their intentional operations.
- **Operations conducted by standard scenario (STS):** STSs provide UAV usage under the Specific category without operational authorisation, with the submission of an operational declaration if the operation fits to the framework defined by the regulation [5], [7] and it is performed with UAS that has the proper class identification label (C5 or C6). STSs specify the operational mode (VLOS or BVLOS) and the maximum distance between the remote pilot and the UAV in detail according to the size of the operational staff.
- **Operations conducted by specific operational risk assessment (SORA):** When the UAS-operator would like to perform an operation not covered with an STS or PDRA, then the compliance should be proved using the SORA risk assessment method. Based on the root risk of the operation, the necessary robustness levels should be satisfied by proven methods. In this

case, according to the risk assessment, the maximum distance between the remote pilot and the UAV can be determined, considering the conditions based on the root risk rating.

In the case of BVLOS operation, the physical characteristics and the result of the operation should be considered because they jointly define unambiguously the environment that is essential for the operation. From a technical aspect, the maximum range of the command and control and the video stream have to be considered beyond the performance (maximum flight time, speed, etc.) of the UAV and the vision enhancement solutions. The range is influenced by the built and the artificial environment. Previously known locations should be considered (like high voltage pipelines) where signal loss phenomena may occur and where the transmission of the command and control link becomes unreliable. When the operation should be executed alongside these infrastructures, supplementary risk mitigation measures may be required (redundant antenna system, satellite data communication system, etc.).

BVLOS operations are especially risky because the UAV and its environment are not able to be observed visually. The remote pilot only knows about it through the transmitted video stream watched on the remote controller. This fact justifies the application and availability of further safety enhancement measures.

IV. The future of the beyond visual line of sight operations

BVLOS operations will spread in the future. Detect and avoidance (DAA) systems support the operations. These systems were initially developed for conventional aircraft like transponder. However, smaller, lighter and further developed equipment with a shorter range can be used for the UASs (e.g. ADS-B in, Flarm, etc.). With the help of this equipment, the remote pilot has the possibility to detect the other airspace users (conventional aircraft or other UAVs) that may potentially danger the UAS operation at the given time. Advanced systems and solutions like remote identification can present relevant flight data about other users on the remote controller. Thus, potential incidents (collisions and near-miss events) can be avoided. It is essential that the presented flight information about the other airspace users supports the remote pilot in the correct decision-making. It is not possible that information coming from UAVs may cause unnecessary disorder for conventional airspace users (manned aviation). Therefore, only ADS-B In equipment can be used on the UAVs.

Direct remote identification function named in the EU regulations (similar to remote identification function, which is mandatory in the US) supports these goals [10], [11]. UAVs with certain class identification labels (C1, C2, C3, C5 and C6) should provide this function. The function supports safer operations even in the Open and the Specific category.

The usage area of UASs is broadening. Thus, new use cases are emerging that can be executed only with BVLOS operations. These operations are value-added solutions because conventional living labour can be replaced even in critical areas where human labour is extremely dangerous, slow or expensive. Good examples of this replacement are infrastructure monitoring at high altitudes above the ground (like high-voltage cable or transmission towers), surveying dangerous infrastructures, monitoring linear infrastructure or even the border patrol services.

Autonomous operations will be essential to effectively operate future services like drone delivery. With autonomous operations, the UAV is able to identify potential dangers and solve any kind of conflict on its own without any human intervention, modifying the course if necessary. Autonomous operations can be solved only with such DAA systems. They are capable of detecting obstacles in the air and even on the ground by the joint operation of different sensors.

BVLOS operations will be supported by the emergence and widespread of services like conventional air traffic management functions: UTM – Unmanned Aircraft System Traffic Management, and U-Space – an airspace elaborated by a combination of safety measures where specific requirements must be met by users. With these solutions, the traffic management of unmanned aerial vehicles will be available, and traffic control can also be solved. The latter can significantly reduce the potential collisions and near-miss events that originate from large-scale UAS usage.

Technical development has a significant impact on all areas of UASs. New upcoming technical solutions may trace and transform the future of BVLOS operations, and new standards and regulations may also influence the development. The emergence of increasingly powerful devices will also impact telecommunications and data transmission solutions. Thus, many innovations in telecommunications are also expected in the near future regarding UAS. The range of remote controls cannot be extended indefinitely, nor do environmental obstacles allow unlimited signal transmission, so alternative solutions are needed for longer-range BVLOS operations.

The topic should be further researched from psychology and ergonomic viewpoint because those experimentations can adequately answer operational-related questions. Based on these results, the current regulations may be evolved and cover the reality in a better (enforceable) way to comply it and value-added services can be available more reliably and effectively.

V. Summary

For the identification of the maximum distance between the remote pilot and the UAV in the case of VLOS operations, several factors should be considered jointly. The most important are the size of the UAV and the actual visibility. When the operations cannot be performed in VLOS, it must be considered a Specific category operation. This requires further risk mitigation measures by the UAS-operator that increase the safety of the operation.

Several technical solutions can increase the safety of the BVLOS operation. In the future, further technology developments that can be used even in the Open category operations will also emerge. They are the complex application of different sensors, new data transmission solutions which offer active communication, information display and collision avoidance for the users, thus enhancing aviation safety.

Maximum distance is important for safety or technical; moreover, it significantly influences the applicable operations in VLOS. The technical developments may widen the opportunities due to the emergence of much safer and more reliable mitigation measures that support the fulfilment of the UAS operations.

Author contributions

Zs. Sándor: Conceptualization, Writing, Review and editing.

Disclosure statement

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Simulating the alteration in energy consumption at a zebra crossing considering different traffic rates of electric and rule-following autonomous vehicles

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Abstract: The progressive integration of autonomous vehicle (AV) technology holds the potential to reshape the prevailing traffic landscape. AVs have different driving characteristics than human-driven vehicles, which manifests itself in the strict adherence to speed limit, in giving priority to pedestrians, and in the pre-set headways they can keep. A traffic simulation environment was built around an unsignalized pedestrian crossing to measure the energy consumption of vehicles in the presence of AVs. The simulation environment was modified to adhere pedestrian-accepted gaps between vehicles in case of crossing. Considered vehicle types are yielding or not yielding human-driven, and AVs. Scenarios were built to model the AV traffic share, the different headways kept by AVs, and the various traffic volumes in each direction. The different driving behaviour and traffic share of AVs led to energy consumption changes, which were modelled through scenario analysis. The maximum energy consumption reduction of human-driven vehicles was 10.67% for yielding vehicles and 12.41% for non-yielding vehicles compared to the 0% AV traffic rate. Although, in case of AVs, the energy consumption increased in all scenarios compared to the basic version with only human-driven vehicles. In higher traffic scenarios, where only AVs were on the road, there was a substantial 35,92-96.55% increase in energy consumption, compared to the 0% AV ratio case. Thereby speed of vehicles, following distance and the number of stops affected the overall system efficiency. The results of this study can contribute to the understanding the impact of AVs which can support their introduction.

Keywords: Traffic simulation; energy consumption; autonomous vehicle; electric vehicle; pedestrian crossing

I. INTRODUCTION

The automotive industry has undergone significant changes in the past decade. New drive modes and advanced driving support technologies were introduced. Electric drive is one of the most dynamically developing vehicle propulsion techniques, which is clearly shown by the fact that the electric car market sales exceeded 10 million in 2022 globally. The 14% of new cars sold were electric, up from 9% in 2021 and 5% in 2020. Also, a total increase of 35% in sales was forecast for the year 2023 [1]. The rise of battery electric vehicles in Europe is also remarkable, an increase of 83% was observed between 2019-2020 and 76% between 2020-2021 [2]. To facilitate the transition from internal combustion engines to zero-emission ones, the European Commission has stipulated that from 2035, only zero-emission new vehicles can be sold [3].

Besides the emergence of EVs, highly automated vehicles are spreading which can assist or even replace human driving operations [4]. Autonomous vehicles (AVs) have the potential to reduce human error due to the more accurate and faster environment sensing and control [5].

Our research focused on energy consumption simulation at an unsignalized pedestrian crossing in the era of autonomous and electric vehicles. The aim was to examine how energy consumption varies as a function of speed, acceleration, and deceleration according to simulation time steps. Energy consumption is influenced by many things, including the speed and weight of the vehicle, the elevation of the route, and the driving style. In the simulation, only electric vehicles (EVs) were modeled, which could be traditional human-driven or autonomous vehicles (AVs). AVs have a different driving behavior than traditional human-driven vehicles, which manifests itself in the strict adherence to the speed limit, in giving priority to pedestrians, and in the pre-set headways they keep. The rule-following behavior of AVs was achieved by modifying the simulation parameters. Scenarios were built to model the AV traffic share, the different headways, and the various traffic volumes in each direction. The different driving behavior and traffic share of AVs led to energy consumption changes, which were modeled through scenario analysis.

The structure of the paper is the following: a brief literature review is followed by the description of previous related research in Section II. In Section III, the simulation methodology and the implemented scenarios are discussed. Section IV contains the results of the study. Finally, the conclusions were summarized.

II. LITERATURE REVIEW

Energy consumption was studied in different approaches in previous studies. These are either based on measurements in a real environment [6-9] or based on mathematical modelling and simulation [10-14]. Most of the research rely on VSP (Vehicle Specific Power) models, which estimates instantaneous power requirement based on vehicle kinematic parameters. Parameters that are frequently used to calculate VSP are vehicle speed, acceleration, frontal area of the vehicle, mass, rolling resistance coefficient, drag coefficient, and road grade. The first VSP model was defined by J. L. Jimenez-Palacios in 1998 [15]. An interpretation of the power-based model for electric vehicle consumption was discussed in a study by Fiori et al [16]. They modelled the instantaneous energy consumption of EVs using second-by-second vehicle speed and acceleration as input variables. Their proposed model had an average error of only 5.9% relative to the empirical data. Results also showed that a higher amount of energy is recovered in urban environments compared to higher-speed highway driving. Wu et al. examined real-time power consumption in relation to vehicle speed, acceleration, and road grade [17]. Other studies estimate the effects of ambient temperature [18-19] and road gradient [20] on vehicle energy consumption. Another important factor that can influence energy consumption is driver behaviour, which has also been addressed by several studies [21-22].

To increase the range of electric vehicles, regenerative braking is a frequently used solution. Several research focus on the issue of calculating the efficiency of regenerative braking. Some of these models consider constant regenerative braking efficiency [23-24], while others study regenerative braking as a linear function of vehicle speed [25] or its deceleration [16].

Fuel consumption reductions by AV traffic was also studied in some articles [35-36]. However, fewer studies focus on the energy consumption of electrically powered AVs. Most of them are researching the possibilities in optimizing the relocation of shared AVs [26-27] and connecting them with the smart grid [28]. Other studies in this field rather focus on vehicle-level energy consumption modeling [29-30].

Traffic simulation studies related to AVs are also getting more attention nowadays. Research indicates that AVs may enhance traffic characteristics in both on freeways [31-32] and in urban areas [33]. At the same time, we found only one example of simulating AVs in the environment of a pedestrian crossing [34].

Based on our literature review, it can be stated that the simulation of energy consumption in a specific traffic situation, such as at a pedestrian crossing is a less researched area. The novelty of our research comes from modeling electric-powered AVs in the vicinity of a pedestrian crossing and analyzing the effects of their different behavior characteristics on energy consumption.

III. SIMULATION METHODOLOGY

An unsignalized pedestrian crossing on a 2x1 lane road was modeled in Vissim (2020) microsimulation software. The road section was characterized by straight alignment on a flat terrain, with lane widths of 3.5 meters. Overtaking was not permitted in the vicinity of the pedestrian crossing.

Road-side video camera measurements were carried out in Budapest, Hungary to assess pedestrians' vehicle distance-based crossing decisions. Data collection was conducted over four days, with time intervals typically set at 1.5-2 hour. Pedestrian traffic was normalized to 1 hour, which resulted in 87 pedestrians in west-to-east direction and 91 pedestrians in east-to-west direction. Pedestrian groups were formed according to gender and age categories. We found that the majority of pedestrians chose to cross if the vehicle distance was 50 meters or more.

The drivers' yield ratio was measured 69%, which was also implemented in the model by separating yielding and not yielding human-driven vehicles in the simulation model with different vehicle classes. Speed distributions remained at the default Vissim setting. However, for AVs, a fixed maximum speed limit of 50 km/h was enforced.

Given that pedestrian behavior in the Vissim simulation environment does not inherently consider vehicle proximity, model calibration became necessary. To address this, we deployed detectors with 10 meters range to detect vehicle positions. Subsequently, signal heads were placed on both ends of the pedestrian crossing, permitting access to pedestrians based on their gender, age category, and the proximity of the approaching vehicle. The logic between the detectors and the signal control that handled the signal heads was set with the VisVAP module.

We defined mathematical formulas for energy consumption and regeneration, and subsequently provided these as input parameters to the Vissim software for energy calculations. To accomplish this, we employed the Vissim External Emission Model, and the energy model itself was programmed in the C++ language. Due to the substantial data volume, an Excel macro was written for data processing. Finally, to measure the impact of traffic volumes, AV traffic ratios, and the different headways maintained by AVs on energy consumption, various scenarios were built in the simulation framework.

It is important to emphasize that present study focused on the pedestrian crossing area. Consequently, we examined the area within a 100 meter radius in both directions. Vehicle data beyond this range was excluded with data filtering.

The calibration processes of Vissim with the VisVAP module, incorporating energy consumption calculation formulas, and the development of the simulation scenarios are summarized in **Fig.1**.

1. Scenario building

The simulation model was constructed utilizing data derived from roadside observations. In accordance with the discerned patterns of pedestrian decision-making in response to varying vehicle distances, we established specific vehicle headway values of 50 meters, 60 meters, and 70 meters for AVs. Conversely, for conventional vehicles, we retained the default model parameters.

These predefined vehicle headway values constituted the initial phase in scenario building. We adjusted the proportions of AV traffic, encompassing a spectrum from 0% to 100% in increments of 25%. Subsequently, we introduced five discrete levels of traffic flow rates for each direction, specifically 200, 400, 600, 800, and 1,000 vehicles per hour. Accordingly, a total of 65 distinct scenarios were built. It is noteworthy to mention that the predefined headway settings were not applied if the AV traffic ratio is 0%.

In each scenario, three simulation runs were performed and the average values of them were considered for further calculations. To model the stochastic variations of vehicle and pedestrian arrivals, different random seeds were implemented in Vissim. The chosen random seed values were 5, 7, 9 and 11. Each simulation run lasted for 3600 simulation seconds.

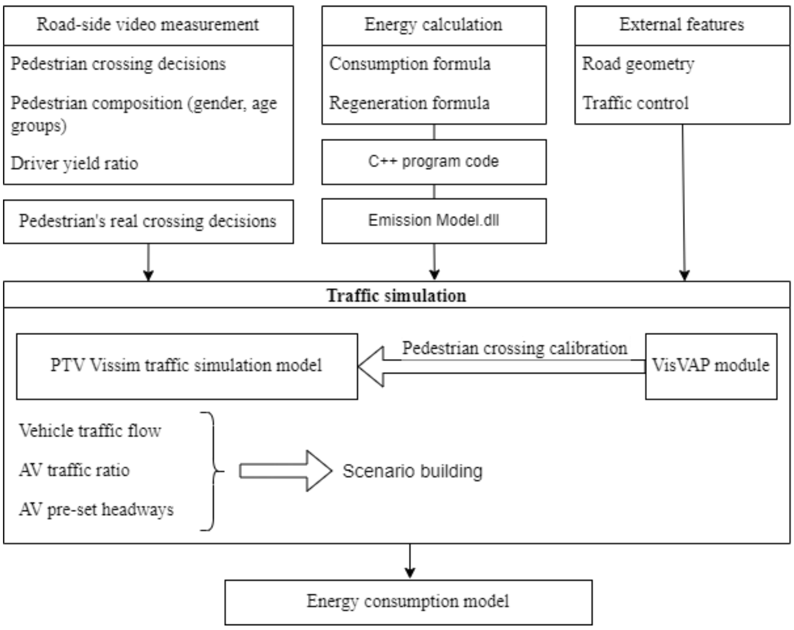

Figure 1. *Methodology overview*

2. Energy consumption and regeneration calculation

Since energy consumption of the EVs is not constant over time, a time step approach was used in the simulation. Vissim generated the speed, acceleration (deceleration), and position data for each vehicle in every t time step which was 0.25 seconds.

The energy consumption model was derived from vehicles' kinematic parameters, with the summation of the forces acting on a moving vehicle by equation (1):

$$\sum F = F_{acc} + F_{roll} + F_{air} \quad (1)$$

Where F_{acc} is the acceleration force acting on the vehicle - equations (2), F_{roll} is the rolling resistance force - equation (3), and F_{air} is the aerodynamical drag force - equation (4).

$$F_{acc} = M \cdot a_t \quad (2)$$

Here *M* denotes the vehicle mass in kilograms, a_t is the acceleration in *t* time step of the EV in m/s^2.

$$F_{roll} = \mathrm{M} \cdot g_t \cdot C_R \quad (3)$$

Where g_t is the gravitational acceleration in m/s^2 in *t* simulation time step, and C_R is the tires' rolling resistance coefficient.

$$F_{air} = \frac{1}{2} \rho_a \cdot C_D \cdot A_{front} \cdot v_t^2 \quad (4)$$

Where symbol ρ_a represents the air mass density in kg/m$_3$, C_D is the aerodynamic drag coefficient, A_{front} is the frontal area of the vehicle in m^2, and v_t is the vehicle speed in m/s in the *t* time step.

The power requirement (measured in KWh) for moving the vehicle at a given velocity *v* was determined with equation (5):

$$P_{acc} = \frac{\sum F \cdot v}{3{,}600{,}000} \quad (5)$$

Regarding deceleration, the regenerated energy (in KWh) was determined by computing the alteration in kinetic energy by equation (6):

$$P_{dec} = \frac{\frac{1}{2} M \cdot (v_{t-1}^2 - v_t^2)}{3{,}600{,}000} \quad (6)$$

The regenerated energy calculated within this expression has a negative sign, signifying the directional vector of energy transfer is opposite to the energy consumption. We note that, due to the inefficient regeneration at low vehicular speeds, data associated with EVs operating at velocities below 10 km/h were omitted.

The comprehensive energy equilibrium of the vehicle through the entire time frame can be evaluated by the difference of energy dissipation and energy regeneration by equation (7):

$$P_{consumed} = \sum P_{acc} + \sum P_{dec} \quad (7)$$

The parameters employed in the emission modelling process are depicted in **Table 1**. The selected parameters fell within the range of values identified in the existing literature.

IV. RESULTS AND DISCUSSION

The energy consumption was calculated for vehicles giving priority, not giving priority, and AVs. Results are showcased for traffic volumes.

In scenarios considering 800 and 1000 vehicles per hour, it was observed that not all vehicles could trespass the area. The resulted traffic congestion may have influential and distorting impact on the energy consumption results. Accordingly, the result of scenarios considering 200, 400, and 600 vehicles per hour are only further discussed in this paper. **Table 2**, **Table 3**, and **Table 4** shows the energy consumption per vehicle under the considered traffic volumes, respectively.

Table 1. *Parameters used in the energy consumption calculation*

Parameter	***Ref.*** [16]	***Ref.*** [24]	***Ref.*** [37]	***Ref.*** [38]	***Ref.*** [39]	***Chosen value***	***Unit***
Mass of the vehicle (M)	1521	1500	2169	1480	2791	2000	[kg]
Rolling resistance coefficient (C_R)	0.0328	0.005	0.013	0.013	0.006	0.01	-
Aerodynamic drag coefficient (C_D)	0.28	0.25	0.23	0.34	0.8	0.3	-
Frontal area (A_{front})	2.3316	2.25	2.341	2.713	2.666	2.3	[m^2]
Air mass density (ρ_a)	1.2256	1.275	1.293	1.204	1.2	1.275	[kg/m^3]

Table 3. *Energy consumption per vehicle [KWh] (traffic volume: 400 veh./h)*

Headway/ AV ratio	***AV 0%***	***AV 25%***	***AV 50%***	***AV 75%***	***AV 100%***
50 m	0.1297	0.1358	0.1453	0.1501	0.1607
60 m		0.1376	0.1467	0.1546	0.1703
70 m		0.1398	0.1498	0.1576	0.1762

Table 2. *Energy consumption per vehicle [KWh] (traffic volume: 200 veh./h)*

Headway/ AV ratio	***AV 0%***	***AV 25%***	***AV 50%***	***AV 75%***	***AV 100%***
50 m	0.1205	0.1200	0.1246	0.1279	0.1310
60 m		0.1198	0.1254	0.1295	0.1350
70 m		0.1212	0.1273	0.1317	0.1381

Table 4. *Energy consumption per vehicle [KWh] (600 veh./h)*

Headway/ AV ratio	***AV 0%***	***AV 25%***	***AV 50%***	***AV 75%***	***AV 100%***
50 m	0.1444	0.1599	0.1765	0.1910	0.2098
60 m		0.1639	0.1839	0.2115	0.2569
70 m		0.1680	0.1909	0.2300	0.2838

Besides the absolute energy consumption values, we illustrate the relative change compared to the 0% AV traffic ratio. These results are also presented with respect to headways kept by AVs and the level of AV traffic penetration. With the rise of AV traffic ratio, headway kept and the amount of road traffic, the energy consumption increased significantly, as presented in **Fig. 2.**, **Fig. 3.**, and **Fig. 4.**

In the context of all three traffic scenarios, energy consumption exhibited an upward trend with the rise of AV traffic ration. In the case of 200 vehicles per hour traffic volume, a 100% AV ratio, and 70 m headway, the energy consumption was 14.57% greater than the scenario without AVs. As traffic density increased, this disparity further magnified. Specifically, in scenarios involving 400 vehicles per hour, the difference surged to 35.92%, and in the context of 600 vehicles per hour, it escalated to 96.55%. This increase can be attributed to the rule-following behavior of AVs, as they consistently yielded to pedestrians, while 31% of human drivers did not yield. Rule-following behavior results in more acceleration phase thus higher energy

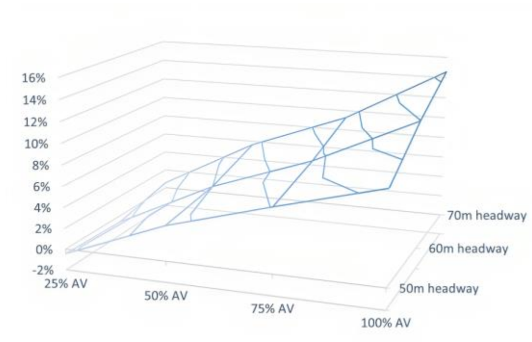

Figure 2. *Energy consumption relative to 0% AV case (traffic volume: 200 veh./h)*

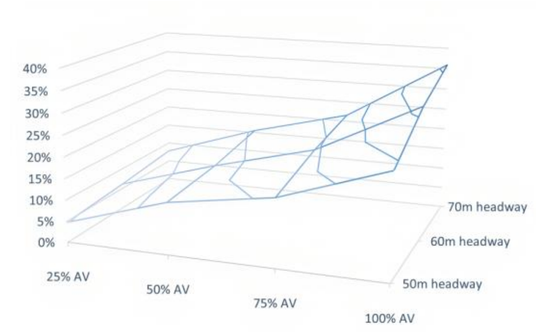

Figure 3. *Energy consumption relative to 0% AV case (traffic volume: 400 veh./h)*

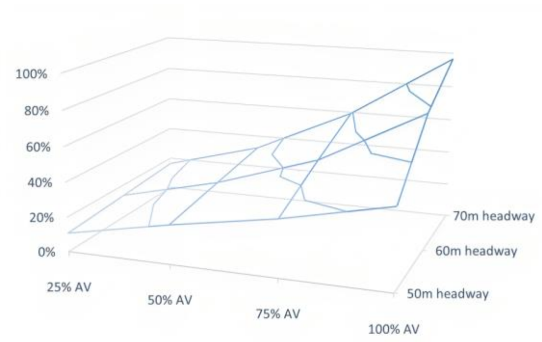

Figure 4. *Energy consumption relative to 0% AV case (traffic volume: 600 veh./h)*

consumption. It is also noteworthy that the rise in energy consumption correlated with the augmentation of the headway maintained by AVs. This additional energy consumption is likely attributed to minor accelerations and decelerations required to uphold the desired inter-vehicle spacing. Furthermore, the lack of wind shadow may also cause an increase in energy consumption when AVs keep greater headways.

In scenarios characterized by lower traffic volumes, the energy consumption of conventional, human-operated vehicles demonstrated a decline as the proportion of AVs increased. This phenomenon can be elucidated by a combination of factors, including the speed limits followed by AVs and the behavior of pedestrians. The first factor results in a reduction of energy consumption as the number of speeding vehicles decreases. In the case of the second factor, due to the greater distances between vehicles, pedestrians tend to cross the road without requiring vehicles to come to a complete stop, which also results in reduced energy consumption. **Table 5** shows an example of such an alteration in energy consumption. With the increase of AV traffic rate, a noticeable decrease in energy consumption due to the adherence to speed limits was measured. Simultaneously, as the headway expands, a slight decrease in energy consumption was detected due to pedestrians transversing the road without the necessity of vehicles stopping at the pedestrian crossing. However, we have to admit that the rise in energy consumption was measured with the increased AV traffic.

Table 5. *Energy consumption per* ***not yielding*** *vehicle [KWh](200 veh./h)*

Headway/ AV ratio	*AV 0%*	*AV 25%*	*AV 50%*	*AV 75%*
50 m	0.1090	0.1143	0.1029	0.0973
60 m		0.1144	0.1025	0.0962
70 m		0.1141	0.1019	0.0955

While energy consumption increased, potential enhancements could be realized through vehicle-to-vehicle communication and pedestrian movement prediction. In both cases, electric vehicles could eliminate the necessity of forceful braking, rather applying regenerative braking and coasting mode. Moreover, it is imperative to note that while there may be a potential increase in energy consumption, the enhancement of traffic safety and pedestrians' sense of security is evident through the reduction in vehicle speeds and the provision of unconditional priority.

V. CONCLUSIONS

In this study, a simulation model was developed to measure alteration in energy consumption of conventional and autonomous vehicles in the vicinity of a pedestrian crossing. We calibrated the model to assess pedestrians' crossing decisions based on vehicle distance. Additionally, the method for calculation energy consumption was provided as an external input. Various scenarios were formulated to examine the impact of different autonomous vehicle traffic ratio, their maintained headways, and varying traffic volumes.

The results show that in case of low traffic, autonomous vehicles may have a slight advantage mainly on conventional vehicles' consumption. In part, this is achieved through the adherence of speed limits, and, on the other hand, by the maintained headways by autonomous vehicles which may result in pedestrians crossing without the stopping of vehicles. Considering low traffic (200 or 400 vehicle per hour), results showed a maximum decrease of 12.41% in energy consumption for not yielding, and 10.67% for yielding vehicles, compared to 0% AV traffic ratio.

However, with increased traffic, AV ratio and headways, the energy consumption increased significantly. Comparing with the 0% AV ratio, when reaching 100% AV traffic, the energy consumption rose by 35.92% and by 96.55% in case of 400 and 600 vehicles per hour traffic, respectively.

Further research is needed to examine the operational aspect of the following distance set for autonomous vehicles and its consequent influence on energy consumption. This requires generating and then analysing short-term data series involving only 2 vehicles.

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AUTHOR CONTRIBUTIONS

Sz. Szigeti: Conceptualization, Simulation, Measurements, Discussion.

D. Földes: Conceptualization, Discussion, Review and editing.

X. Ye: Energy modelling.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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