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COMPARISON OF BICYCLE DETECTION METHODS IN PRAGUE TRAFFIC

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Abstract. The paper focuses on the detectors used to detect bicycles. It contains research part which describes various methods of bicycle detection and their possible advantages and disadvantages. The other part focuses on testing the methods under real conditions. Testing on 32 different location was conducted. The data from these tests were used to select the appropriate technology for each specific use case. The results show that current detectors are not the best option for bicycle detection and that videodetection and piezoelectric strips are the best way to go.

Keywords: Bicycle detectors, detectors, cyclist movement monitoring, induction loops, microwave radars, piezoelectric detectors, pneumatic detectors, videodetection, magnetometric detectors.

1. Introduction

The issue of bicycle detection is very topical. Detection can be useful for several applications. For example, for dynamically controlled intersections with traffic lights, where bicycles need to be detected, otherwise they might stop at red lights until a car that is detected arrives. This is nowadays mainly solved by induction loops that are able to detect both car and bicycle. A second example of the use of bicycle detectors is counting for analytical and statistical purposes.

The number of cyclists passing through strategic areas can be used to determine the main routes used by cyclists, their directionality, an overall overview of cyclist movements in an area, and to determine the utilization of current cycle paths. For example, the latter reason can then be used to justify the need to revitalise or widen a given cycle route or to build new ones where needed.

The goal of the research is to define various use cases for bicycle detectors while testing as many detectors currently in use as possible. The result is a recommendation for the use of different detectors for different situations, including how to install them.

1.1. Types of bicycle traffic detection

This paper looks at the technologies most commonly used, whether intrusive or non-intrusive. There are other options for counting bicycle traffic, such as magnetometric detectors, ultrasonic detectors, infrared detectors or pyroelectric detectors. These technologies are not addressed in the research as they are practically not used for bicycle traffic detection because they are too simple technologies that cannot classify between bicycles and other road users or are very inaccurate.

The following bicycle traffic detectors were evaluated:

- induction loop,
- piezoelectric detector,
- microwave radar,
- videodetection,
- pneumatic detector.

1.1.1. Induction loop

In its simplest form, an induction loop is a coil of buried wire connected to a source of alternating current that creates a magnetic field. When a vehicle passes over the induction loop, the magnetic field changes and reduces the perceived inductance of the loop [1].

Because bicycles do not contain large amounts of conductive materials, the induction loop must be modified to detect them. Either by a smaller conductor placement depth or by a specific loop shape. Rectangles placed diagonally across the road or diamonds are most commonly used [2].

For actual bicycle detection, the part of the bicycle closest to the road is the most important. This is mainly the rims. Nowadays, bicycles made of non-ferromagnetic materials such as carbon fibre are increasingly being used, mainly due to their lower weight and improved handling characteristics. Thus, this trend may pose a challenge for induction loops in detecting these bicycles [3].

For the purpose of this research, testing was carried out with a carbon fibre bicycle. The bike went back and forth through an induction loop. This data was then paired with data from the loop. The carbon bicycle was detected in only 11 cases out of 63. That is, in less than 18 % of the cases.

1.1.2. Piezoelectric detector

Piezoelectric detectors collect data by converting mechanical energy into electrical energy. When a piezoelectric cable is compressed, a voltage is generated that is linearly proportional to the applied pressure. This enables them to detect bicycles from other road users [4]. Piezoelectric detectors are becoming increasingly popular for detecting bicycle traffic. The main reason is their accuracy (manufacturers report an accuracy of around 98 %) and multimodality, i.e. the fact that they can detect more than one mode of traffic. Piezoelectric detectors can be placed in places where cars or motorcycles will pass over them in addition to bicycles [4, 5].

1.1.3. Microwave radar

Microwave radar works on the principle of the Doppler effect. The radar transmits a continuous signal of low-energy microwave radiation to the target area and then analyses the reflected signal. Microwave radar for vehicle detection should be positioned at least 1.5 metres above the road. Therefore, it must be mounted on a traffic sign or a public lighting pole. The radar should distinguish between a pedestrian and a bicycle, so it can be used in cases where multimodality is desirable. The actual categorisation is primarily done by the speed of the object in most radars. A slow-moving car can thus be classified as a bicycle and cause a false-positive record [6, 7].

1.1.4. Videodetection

Video detection is a non-destructive detector that works on the principle of extracting information from the image for further software processing. The camera itself is most often placed on the nearest infrastructure element (most often a public lighting pole or traffic light) [8].

When using video detection, one of the most important features is the angle of the image capture. The best camera placement seems to be perpendicular to the road and at a sufficient distance and height. One of the main advantages of using video detection for monitoring bicycle traffic is its multimodality, i.e. the ability to distinguish and monitor the intensity of different traffic modes. When used on a path, the camera can easily distinguish between pedestrians, cyclists and other users.

1.1.5. Pneumatic detector

Pneumatic detectors are rubber tubes that are placed on the road surface. The hose is plugged into the roadside unit at both ends and then placed on the roadway perpendicular to the direction of vehicle travel. Detection is made by the change in pressure in the tube that occurs when a vehicle passes over it. This detection method is mainly used to determine the intensity. It can also be used for vehicle classification, occupancy and, if the tubes are placed sufficiently far apart, for speed detection. Although there are variants that are specifically made to count bicycles, most pneumatic detectors are more suited to counting cars. In these cases, bicycles are too light or going too slow for detection to occur (some manufacturers quote a minimum speed for identification of $10\,\mathrm{km\,h^{-1}}$) [9].

Pneumatic detectors are not intended to be permanently installed on the roadway, primarily due to limited hose life, battery capacity, and overall vulnerability to intentional damage. The main use of a pneumatic detector is in one-time traffic surveys. Part of this paper was testing it for detecting bicycle traffic and it has been shown that most cyclists do not know if they can cross the tube and so avoid it or stop in front of it. So the detection itself proved to be not very suitable. For this reason, the pneumatic detector is not considered in the next part of the paper.

1.2. Comparison of different detector types

Table 1 shows all the considered detectors and some of detector characteristics. One letter is filled in for each detector and each characteristic. The letters are as follows:

Y – stands for Yes which means that the detector meets the given characteristic.

P – Partly means that the detector only partially satisfies the given condition. For example, with very reduced accuracy.

N – No means that the detector does not meet the given characteristic.

2. Methodology

In order to discover different use cases and to define them, places in Prague where bicycle traffic monitoring already takes place were all examined. These locations were then divided into several sets based on various differences. For example, whether the detector is located in an area of car traffic, or whether it is an area inaccessible to cars. Other examples of use were selected based on recommendations defined by the suppliers of the cycle counters. Some of the selected use cases were later merged together, because of similarities and similar detector recommendations. The following use cases were selected:

- Traffic with cars on the road.
  - ▷ Traffic with cars on the road to the left of parked cars.
- Cycle lane.
  - ▷ Cycle lane to the left of parked cars.
- Path with possible passage of cars.
- A path for cyclists and pedestrians.
  - ▷ A path for cyclists and pedestrians on the footbridge.
  - ▷ A path for cyclists and pedestrians on the pavement.

	Induction loop	**Pneumatic detector**	**Microwave radar**	**Videodetection**	**Piezoelectric detector**
Possibility of counting pedestrians	N	P	Y	Y	P
Heading distinction	Y	Y	Y	Y	Y
Resolution of more than two directions	P	P	P	Y	P
Not susceptible to weather conditions	Y	Y	P	N	Y
Detection of non-metallic bikes	N	Y	Y	Y	Y
Non-intrusive	N	Y	Y	Y	N
Not vulnerable to damage from normal traffic	P	N	Y	Y	P
Possibility to count several bicycles passing at the same time	P	P	Y	Y	P
No need to connect to the power grid	P	Y	N	N	P

Table 1. Comparison of different detector types.

Use case	**Average accuracy regardless of the detector used**
Traffic with cars on the road	63 %
Traffic with cars on the road to the left of parked cars	49 %
Cycle lane	60 %
Cycle lane to the left of parked cars	41 %
Path with possible passage of cars	87 %
A path for cyclists and pedestrians	77 %
A path for cyclists and pedestrians on the footbridge	85 %
A path for cyclists and pedestrians on the pavement	69 %

Table 2. Average accuracy on each use case.

Testing was then carried out at defined locations in Prague to determine the accuracy of the technology at that location. The results of this testing are then reflected in the recommendation of the detector selection for the given use case.

Testing was conducted at 32 locations, but the individual directions at each site were evaluated separately, so the total number is 64 sites. Induction loops or microwave radars were installed at most sites. In two cases, video detection was used. During the testing, individual traffic modes were manually counted. Testing was conducted at each site for one hour during the morning peak (most often between 7:30 a.m. and 9:30 a.m.) and for one hour during the afternoon peak (between 4:00 p.m. and 6:00 p.m.). The manual data were then paired with the count data. The accuracy of the technology could thus be calculated for each location, direction and time. This was calculated using the following formulae:

- If the number of bikes counted on site was lower than the number given by the detector, the following formula was used:

$$\text{Accuracy [\%]} = \frac{\text{number of bikes counted on the spot}}{\text{number of bikes counted by the detector}} \times 100$$

- If the number of bikes counted on site was greater than the number given by the detector, the following formula was used:

$$\text{Accuracy [\%]} = \frac{\text{number of bikes counted by the detector}}{\text{number of bikes counted on the spot}} \times 100$$

3. Measured results

Table 2 shows the tested use cases and the average accuracies that resulted from the testing. It was calculated from all the accuracies counted on each use case regardless of the detector used.

3.1. Traffic with cars on the road

The first use case of a cycle counter is the counting of bicycles on a road with normal car traffic. In some cases, the lane may be supplemented by a cycle corridor. There may be situations where bicycles need to be counted in traffic with cars on the road, but there is a parking lane between the pavement with

Figure 1. Induction loops on Hlubočepská street.

Figure 2. Microwave radar overlooking cycle path on Vršovická street.

the lampposts, where bicycle counters are most often placed, and the lane. In this case, bicycle counting is considerably more difficult.

A total of 12 locations falling within this use case were tested. Microwave radar was installed at nine locations. At the remainder, an induction loop was installed. The average accuracy of the induction loops in the use case was 89 %. The average accuracy of the microwave radar was 41 %. A major difference between the sites that could explain the level of inaccuracy of the microwave radar is the intensity of car traffic. 2 radars are located on Plzeňská Street in Prague, where around 20 000 vehicles pass on a working day. Many vehicles pass through the area at relatively low speeds. The radar, which classifies primarily on the basis of speed, can assess these as bicycles passing [10].

Another example can be found on Hlubočepská street where the counting is done across the entire width of the street. This can be seen on Figure 1.

According to the technical parameters, video detection comes out best in this example. Its only problem is that most roads with car traffic are too wide for a single camera to cover both directions. and the second-best option is a piezoelectric detector. Given its physical properties, it can be said to be suitable for this use case. It can easily distinguish between a car, a motorcycle and a bicycle and because it can distinguish between two signals at least 0.1 seconds apart. The most important thing, however, is to first assess the situation, namely the intensity and average speed of the cars on the site, ideally on a weekday at rush hour. In locations with very low traffic volumes (up to 100 cars per hour), inductive loops (taking into account the fact that they only count metal bikes) or piezoelectric detectors can be used.

If a parking lane is present, it is best to avoid the location or find the nearest bottleneck where there is no parking lane [11].

3.2. Cycle lane

This example of use is often seen in cities where streets are wide (lane widths greater than 3.5 m). It is a dedicated or protective cycle lane between the car lane and the pavement. Very similar to a dedicated cycle lane is a separated one-way cycle lane, which is used in one-way roads to allow cyclists to go in both directions. As with traffic with cars, there may be situations where bicycles need to be counted in the bike lane over parked vehicles.

Example of the protected cycle lane can be found on Vršovická street near the Vršovice train station. In this case the counting is done by microwave radar. This example can be seen on Figure 2.

Neither technology has very high accuracy. Again, this is most likely related to car traffic in the vicinity of bicycle traffic. The inaccuracy of the induction loop may be affected by passing cars. When a car passes close to a cycle lane that a cyclist is using at the same time, the cyclist can easily be overshadowed. The average technology accuracies at the test sites falling within this use case are as follows:

- Microwave radar – 57 %
- Induction loop – 78 %

It should be noted, however, that the radars were tested at two sites and had 88 % accuracy at one site and 25 % at the other. At that location, cyclists often avoided the radar and rode on the adjacent pavement. For the induction loop, again, the installation of the loop matters most. It should not extend into the car lane as it could be disrupted by passing vehicles. The piezoelectric detector also seems to be suitable despite the lack of data to verify it. For video detection, it depends on the installation, but technically it is also suitable.

3.3. Path with possible passage of cars

This situation arises in places where the intensity of pedestrians and cyclists is significantly higher than that of cars. In city centres, this use case can only be encountered in areas where vehicular access is restricted and free movement of cyclists and pedestrians is allowed. Prague's Císařský ostrov is an example. The counting here is done by induction loops. It can be seen on Figure 3.

Figure 3. Induction loops on Císařský ostrov in Prague.

Figure 4. A path for cyclists and pedestrians on Povltavská street.

There are 6 such locations in the test sample. 2 locations are equipped with induction loops, 2 locations with microwave radars and 2 locations with video detection. The average accuracies of each technology for this use case are as follows:

- Microwave radar – 91 %
- Induction loop – 89 %
- Videodetection – 79 %

According to the data, of all the examples of use in motorized traffic, this example is the most suitable for monitoring the movement of cyclists. Videodetection achieves the worst results. This is probably due to the placement of the cameras at the test sites, these were installed parallel to the cyclists' movement and the cameras could have mistaken a cyclist for a pedestrian. According to the data, the induction loop is suitable for this use case. It is essential that the loops are installed across the full width of the roadway. The disadvantages are the passage of a cyclist and a car at the same time and the inability to detect all types of bicycles.

The piezoelectric detector is similar to the induction loop but has the advantage of detecting all bikes. Observations at sites show that microwave radar is only suitable when the roadway is not too wide for radar coverage. Videodetection must be installed appropriately. It has been observed that cameras installed on the side of the observed road achieve better results.

3.4. A path for cyclists and pedestrians

A total of 3 use cases were defined on the cycle and pedestrian path. These are merged into one for simplicity and similarity.

The cycle and pedestrian path is the most frequent place for bicycle monitoring, at least in Prague. The main feature is that motor vehicles cannot enter this location. Then there is the fact that pedestrian traffic is often counted at these locations. An example is the path in Povltavská Street and the A2 cycle path between the Troja Bridge and the Prague Zoo. It is appropriate to count both traffic modes on this section, but currently only cycling traffic is counted using induction loops. Image of this situation can be seen on Figure 4.

A total of 33 sites falling under this use case were tested. Two sites had videodetection and the remainder had induction loops, microwave radar or a combination of these.

The average accuracies of each technology for this use case are as follows:

- Microwave radar – 69 %
- Induction loop – 78 %
- Videodetection – 94 %

Video detection performed best in this use case. In these cases, the camera is pointed perpendicular to the trail, which improves its accuracy over a parallel to the trail installation. Induction loop is the most commonly used technology on trails. It is installed along the entire length of the trail to avoid going around it. Its main disadvantage in this case is the inability to detect all types of bikes. In theory, the piezoelectric detector should perform better, the only disadvantage is the poor quality of the pedestrian count, which can be an important factor in the choice of detector.

For microwave radar, it depends on the installation. A suitable installation is primarily for use on a narrower path.

At one site, a radar was observed installed next to a tree whose leaves partially obscured its field of view. This location greatly reduces the average accuracy of the radar in this use case.

Intrusive technologies cannot always be used when used on a footbridge. Either because of lack of space or because of interference from the metal structure of the footbridge. It is therefore appropriate to use radar or a camera. However, a camera cannot be installed perpendicular to the footbridge and parallel to the footbridge may not give the best results.

For sidewalks, these are locations where cyclists can legally move while being completely separated from the road. This is usually a relatively narrow space, so microwave radar is more suitable than video detection, which needs to be higher and also perpendicular rather than parallel to the pavement.

4. Results and discussion

The aim of this paper was to find out which technologies are most commonly used nowadays to detect and monitor the movement of bicycles. At the same time, to find out in which situations these bike detectors are used and to propose a suitable technology and installation for each situation.

Table 3 shows an overview of examples of use and the main detectors mentioned. In the table, the suitability of a given detector for a given use case is indicated by one letter. All the knowledge used to create the table is included in the text above. The selection of suitability was done by professional assessment from the physical characteristics of the detectors and the data from testing and on-site observations. The literature used in the paper was also used when making assessments. The cost of using each detector was not taken into account.

Test results are limited by the number of detectors tested. Only detectors used in Prague were evaluated. To gain more insight into the use of bicycle traffic detectors, more investigations should be conducted in different areas. For example, in other cities where other technologies are used.

The following letters can be found in the table:

- S – Suitable, indicates the appropriate detector for the given use case.
- P – Problematic, indicates a detector that would measure well at a given location, but might have some problems. For example, it requires a specific installation, or it cannot detect all types of wheels (for this reason, the induction loop is never marked as suitable).
- RU – Rather Unsuitable, Marks detectors that can only be used in a small number of site-specific cases.

The comparison shows that the piezoelectric detector performs best. However, it is judged only on the basis of its technical characteristics. Its main disadvantage is the fact that it is intrusive technology, so it must be installed into the road. Another suitable detection method for most applications is video detection. This only has a problem with correct installation and with cases where it cannot be installed at a good angle and at a sufficient distance and height. Half of the observed videodetection cameras during the testing were installed inappropriately and thus didn't work as well as they could have. On the other hand, the induction loop comes out of the table the worst, it is not suitable mainly because of the impossibility of counting all the bicycles and is also not always suitable for use in traffic with cars, where there is often interference from passing cars or cars standing in the adjacent parking lane.

The next step should be to use the acquired knowledge and data to renew the current technologies and to advance the monitoring of bicycle traffic in Prague. It should also be pointed out that cost benefit analysis should further narrow down the choice of the right detector since videodetection and piezoelectric detectors are the most precise but also most expensive of all the considered detectors.

To provide better data the testing should be done on all the use cases with all considered detectors, this couldn't have been done since there are no piezoelectric strips for counting bicycles in Prague. The testing should also be done again after the current technologies in use, which are more than 5 years old, will be replaced. That should provide more accurate data about current bicycle detectors.

The further use of cyclist detection approaches aligns with the ongoing development of cycling infrastructure in areas undergoing revitalization or modification. This includes existing locations in the city of Prague, such as Výtoň, where the application of cyclist detection could provide valuable insights for decision-making regarding site revitalization [12]. Another potential use for cyclist detection involves the redevelopment of brownfield sites, which focus on repurposing currently unused industrial areas, offering significant potential for enhancing cyclist detection, particularly among young people [13]. In existing urban areas, traffic monitoring is primarily focused on vehicle detection; however, with the integration of new technologies like C-ITS, cycling traffic can be better incorporated into overall traffic management [14, 15]. Moreover, these new detection technologies and data processing methods have the potential for broader application in accurate data collection and future prioritization of cyclists using C-ITS, similar to trends observed in other Western European cities. Cyclist detection data should also inform new approaches in design, implementation, maintenance, the adaptation of parking spaces for shared bikes, and other innovative uses of cycling detection technology, as seen in comparable cities.

5. Conclusions

In this paper 5 commonly used bicycle detectors were evaluated and recommended for specific use cases and installations. Bicycle detectors were tested at a total of 32 locations in Prague for better overview of their functionalities. These sites have been divided into several use cases. For each use case an average accuracy was calculated based on the conducted tests. These tests served as a basis for recommending the optimal detector. These results were subsequently combined with observations made at the site. Such as the fact that the cyclists were using sidewalks for pedestrians instead of cycle paths on the road.

Each of the detectors currently in use showed some disadvantage. For induction loop it was non-ferromagnetic bikes. For microwave radars it was the

	Induction loop	**Microwave detector**	**Videodetection**	**Piezoelectric detector**
Traffic with cars on the road	RU	P	S	S
Traffic with cars on the road to the left of parked cars	RU	RU	S	P
Cycle lane	P	S	P	S
Cycle lane to the left of parked cars	RU	RU	S	P
Path with possible passage of cars	P	S	P	S
A path for cyclists and pedestrians	P	P	S	S
A path for cyclists and pedestrians on the footbridge	RU	S	P	P
A path for cyclists and pedestrians on the pavement	P	S	P	S

TABLE 3. Summary of results for each detector and use case.

speed of the object or objects moving the same speed as bicycles. For videodetection it was the angle of camera. These disadvantages were also taken into account.

The article also highlights the potential use of cyclist detection in new locations to support better decision-making regarding the implementation and development of cycling infrastructure in urban areas. New project proposals and approaches leveraging AI, information modeling, and testing, including data processing, could significantly enhance the accuracy and understanding of cycling traffic usage in cities like Prague [16, 17].

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REFERENCES

[1] W. Guizhu, C. Zongfa, X. Lingan. Induction loop detection of bicycles flow based on pattern recognition (PR) techniques. *IFAC Proceedings Volumes* **27**(12):31–36, 1994. IFAC Symposium on Transportation Systems: Theory and Application of Advanced Technology, Tianjin, PRC, 24-26 August. `https://doi.org/10.1016/S1474-6670(17)47440-4`

[2] Partnerství, o.p.s. Monitoring návštěvnosti cyklistických a pěších stezek ve městech i v přírodě [In Czech; Monitoring of traffic on cycling and walking trails in cities and in the countryside]. [2024-05-05]. `https://www.scitace.cz/Scitace/media/PDF/Nabidka_Scitace_Eco-counter_2022.pdf`

[3] S. Sheik Mohammed Ali, B. George, L. Vanajakshi, J. Venkatraman. A multiple inductive loop vehicle detection system for heterogeneous and lane-less traffic. *IEEE Transactions on Instrumentation and Measurement* **61**(5):1353–1360, 2012. `https://doi.org/10.1109/TIM.2011.2175037`

[4] D. Fejl. *Analýza metod sběru dopravně-inženýrských dat v městském prostředí [In Czech; Analysis of methods of collecting traffic-engineering data in the urban environment].* Bachelor thesis, Univerzita Pardubice, Dopravní fakulta Jana Pernera, 2022. [2024-05-05]. `https://portal.upce.cz/StagPortletsJSR168/PagesDispatcherServlet?pp_destElement=%23ssSouboryStudentuDivId_802&pp_locale=cs&pp_reqType=render&pp_portlet=souboryStudentuPagesPortlet&pp_page=souboryStudentuDownloadPage&pp_nameSpace=G11662&soubidno=100732`

[5] C. S. Leung, W.-D. Hao, C. M. Montiel. Piezoelectric sensors for taxiway airport traffic control system. In *2013 1st IEEE Conference on Technologies for Sustainability (SusTech)*, pp. 134–141. 2013. `https://doi.org/10.1109/SusTech.2013.6617310`

[6] D. K. Chang, M. Saito, G. G. Schultz, D. L. Eggett. Use of Hi-resolution data for evaluating accuracy of traffic volume counts collected by microwave sensors. *Journal of Traffic and Transportation Engineering (English Edition)* **4**(5):423–435, 2017. `https://doi.org/10.1016/j.jtte.2017.06.002`

[7] ALTA. Bicycle detection, A review of available technologies and practical experience to aid in the creation of smarter intersections that work for all users, 2021. [2024-05-05]. `https://altago.com/wp-content/uploads/ALTA_Bike_Detection_White_Paper_July2021.pdf`

[8] A. Arinaldi, J. A. Pradana, A. A. Gurusinga. Detection and classification of vehicles for traffic video analytics. *Procedia Computer Science* **144**:259–268, 2018. INNS Conference on Big Data and Deep Learning. `https://doi.org/10.1016/j.procs.2018.10.527`

[9] MetroCount. RidePod® BT. [2024-05-05]. `https://www.metrocount.com/traffic-counters-classifiers/ridepod-bt`

[10] TSK. Intenzity dopravy v roce 2023 [In Czech; Traffic volume in 2023]. [2024-05-05]. `https://www.tsk-praha.cz/wps/portal/root/dopravni-inzenyrstvi/intenzity-dopravy`

[11] Diamond Traffic Products. Piezo sensor – BL. [2024-05-05]. `https://diamondtraffic.com/product/Roadtrax-BL`

[12] J. Jíšová, J. Filip, T. Tichý, et al. The application of new transport-engineering approaches in the development of public space. *AIP Conference Proceedings* **2928**(1):190017, 2023. `https://doi.org/10.1063/5.0170427`

[13] N. Szeligova, M. Teichmann, F. Kuda. Research of the disparities in the process of revitalization of brownfields in small towns and cities. *Sustainability* **13**(3):1232, 2021. `https://doi.org/10.3390/su13031232`

[14] J. Růžička, T. Tichý, E. Hajčiarová. Big data application for urban transport solutions. In *2022 Smart City Symposium Prague (SCSP)*, pp. 1–7. 2022. `https://doi.org/10.1109/SCSP54748.2022.9792538`

[15] J. Brož, T. Tichý, V. Angelakis, Z. Bělinová. Usage of V2X applications in road tunnels. *Applied Sciences* **12**(9):4624, 2022. `https://doi.org/10.3390/app12094624`

[16] J. Broz, V. Angelakis, M. Penttinen, et al. Designing an evaluation methodology for the living labs of the elaborator project. In *2024 Smart City Symposium Prague (SCSP)*, pp. 1–6. 2024. `https://doi.org/10.1109/SCSP61506.2024.10552692`

[17] T. Tichý, J. Brož, J. Růžička, et al. Information modelling and smart approaches at the interface of road and rail transport. In *2023 Smart City Symposium Prague (SCSP)*, pp. 1–8. 2023. `https://doi.org/10.1109/SCSP58044.2023.10146231`