# *Smart City 5.0 Testbed in Prague*

M. Svítek, R. Dostál, S. Kozhevnikov, and T. Janča

***Abstract*—In the Smart City concept, it is beneficial to have a part of a city ready to use as a testbed (or better yet, a representative sample common for all cities). In this paper we offer a new approach for Smart City testbeds that will help analyze positive and negative consequences and show the opportunities of implementing new technologies. We analyze Smart City testbeds from a system science point of view and consider all important aspects and overlapping environments. By representing a Smart City as a working system of multiple actors or agents, we can achieve equilibrium in such aspects by making sure a proper topography and ontology are described and upheld.**

***Index Terms*—Agent based modeling, Computational modeling, Data infrastructure, Digital ecosystem, Key performance indicators, Regional development, Smart City 5.0, Testbed.**

## I. Smart City Testbed

The term Smart City Testbed is used to describe a combination of fresh approaches and modern technology to already existing city infrastructure. For the purpose of this research we will consider a *Smart City Testbed as a strategic part of larger city where technologies, which the users might benefit from, are implemented with a clear vision*. Such technologies shall be compatible and also integral to the future development of both the area at hand as well as the entire city.

We will also consider this particular *Smart City Testbed as a testbed for the approach described in more detail below and the technologies to be implemented causing measurable benefit and feasibility*. From experience gathered in this Smart City Testbed a future project may be driven.

We define the end goal as: *The sustainable development of a chosen city through smart implementation of technologies based on a methodical approach and experience*. In more detail: the goal is to create such an environment that allows for easier optimization of most aspects of city life and city management and also acts as a testbed environment for new technologies. This is achieved via a combination of different fields of study foremost, and through framing and understanding problems that are to be addressed from the perspectives associated within each of said fields.

Further, we need to consider the Smart City resilience properties as the ability to return to the basic condition, the ability to smoothly change the system, and the ability to evolve and adapt. Urban resilience is one of the key factors in smart city planning [1]. To guarantee a resilient city, it is necessary to manage the flow of resources, paying special attention to their interrelationships, thus optimizing use [2]. Processes need to be planned in real-time within a complex system model [3], [4].

## II. Smart City Testbed in Prague

### *A. Importance*

The location for such an endeavor was chosen considering several criteria (e.g. strategic importance). In the Czech environment, Prague would be the first choice for a first-time, real-life application of a Smart City Testbed. Prague is a historically, culturally and technologically important metropolis. Choosing the perfect location within the city is, however, more complex. It depends heavily on what purpose the hypothetical testbed should achieve. A smart City testbed, as such, is meant for connecting new areas of expertise, new technology and new approaches, all in one location. It is therefore a best practice to choose such a location, which offers as many different opportunities for development and controlled experimentation as possible.

We built this experiment on four basic fields of study: Urbanism (or utilization of public space), Transportation (or Mobility), Energy, and Environment. The qualification criteria for urbanism can be reached in any area that has both standing structures and new development projects. For Energy, it is imperative to have an energy network big and diverse enough (not just electricity, but gas and water as well) to allow further optimization. From an environmental perspective, emissions and their impact on the environment are the key emerging threats to larger cities. That leaves transportation as the most challenging criterion, causing great difficulties in pinpointing the location.

The subject of a Smart Street is very attractive in the year 2020 and has been for some time. There are multiple related projects, one of which was our inspiration.

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The Smart City Prague Testbed was inspired by a project conducted in Berlin – "DIGINET PS". It consists of a 2.3 mile long corridor from Ernst-Reuter-Platz to Zum Brandenburger Tor in the heart of Berlin. DIGINET PS. offers the possibility for investors and developers: to test and validate new technologies, to gather and analyze data, to develop, make workshops and commerce (visibility). While the idea is robust and could create an environment where new technologies are being developed and tested (possibly even autonomous vehicles), in this project the scope has been expanded.

In the first step we included more modes of transport within the testbed. There is only one location in Prague that offers each main mode of transport to include: aviation (Václav Havel Airport Prague), tramway, bus, subway, railway, personal road transportation, and pedestrian. Only Evropská street has each of these modes of transport in addition to fulfilling the criteria for other fields (urbanism, energy, and environment). The only modes that are not included are the modes of small impact and importance in Prague: a waterborne transport, drone transport, and newly emerging modes. Furthermore, Evropská street is also heavily impacted by road traffic. This corridor is used as a connection from not only the airport but also the rest of the northwest regions, including Kladno, into the city Center. Considering all these aspects, Evropská street was chosen as the Smart City Testbed.

The location is presented as the entire Evropská street that spans from Vítězné náměstí in Dejvice through Bořislavka (subway station) to Nádraží Veleslavín (subway and railway station) continuing on to Václav Havel Airport Prague. Throughout the entire length of the testbed, there is personal transportation involved in addition to busses and tramlines (presently covering half of the corridor). The basic corridor is depicted in Fig. 1.

Evropská street is quite different from other streets in the City of Prague for its beneficial location that collects all possible attributes and possibilities for implementing new technologies. Not every solution and idea implemented for the Evropská street can be scaled up to the whole city. But the idea of the smart city testbed is to try as many technologies as possible and find out which of them can be applicable and transferred, and under what conditions.

In this case Evropská street is optimal right now for its strategic value and presence of other technologies. It is therefore easier to drive progress (which can also lead to a much higher beneficial impact) and learn from obstacles in this location than it would be on a road or street segment of lower importance. We may then use what we have learned and implement it further.

## B. *Future Development*

Due to Evropská street's strategic placement and geometrical disposition, it is very likely to be a target for future developers. Even now, there are several projects being realized. One of them is Bořislavka - a center that is already being built, another example is the Sekyra Group building at Vítězné Náměstí. Both existing and future actions can have a sizeable impact on transportation, logistics and services in the area. It is challenging to determine exactly where the pinch points will be.

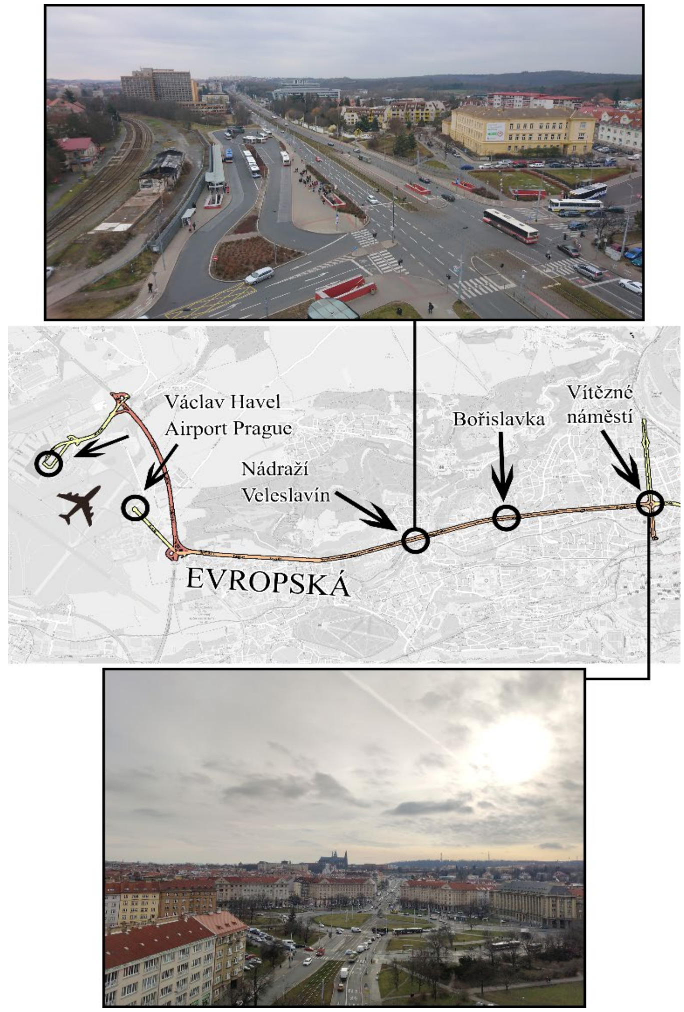


Fig. 1: Evropská street (Vítězné Nám. and Nádraží Veleslavín)

In the future, the new buildings might not be the most important risk to the overall capacity of the corridor or its intersections. The Prague airport has been experiencing steady growth in travelers through the venue each year. This growth can be estimated at 5% growth each future year in the near future [5] (not considering the unpredictable development of current pandemic crisis). This can create a complex problem, since the surrounding infrastructure and connected services (public transport) are already at their maximum capacity. The bus line 119 from the Airport to Nádraží Veleslavín, for example, is the most heavily used line in the entire city. ROPID (Regional Organizer for Prague's Integrated Transportation) is balancing costs and benefits of strengthening the line and is considering possible electrification of the line, turning it into a semi-electric system. There have also been many efforts in the past to connect the airport via train and subway. This may be one of the optimal solutions but it faces many obstacles.

The most interesting part of the Evropska street is Nádraží Veleslavín. First, this is the part of the corridor with the greatest amount of modality (excluding only air traffic operations from the core modes). Second, a railway station exists here which could be part of a project managed by Czech Technical University (CTU). This project aims at innovating and improving the station's surroundings and the station itself. This creates an opportunity to support the future development of multimodality in this part of the corridor. This location might even be perceived as the gateway to Prague for many arriving visitors. In cities, railway stations have the potential (due to their frequent and numerous usages) to become Smart Mobility HUBs. Here technology should be concentrated to ensure higher quality public transport and a more pleasant environment for the individuals utilizing the station's services. Furthermore, stations that offer a higher number of other modes of transport should be the first choice in considering what stations to choose for these pilot projects.

Most of the projects and programs described above have the potential to make the public transport more viable of an option (attractive and optimal), which can have a positive impact on the overall quality of transport on Evropská street. Furthermore, considering the strategic placement and importance of Evropská street, any changes both positive and negative would have a noticeable impact to the whole transportation network of Prague. This alone is reason enough to manage traffic on Evropská street using modern solutions for better optimization.

## III. System architecture

### A. System Science

The *Smart City Testbed* and its components were reviewed as a complex system [4] from the system science point of view. We design for future developments, and for this reason every possible implementation. Because of this scope the entire coordination needs to be systematic and open to unforeseen changes. We would be prudent to consider this as a service oriented Smart City, as the users are the center of our attention and the users need be the core consideration. The entire system is then subordinated to the users acting as a service to them [6].

We may also understand the Smart City Testbed's system as a sheltering component, integrating all its individual subsystems. When describing a system structure, one should first determine the hierarchy of each layer. Such hierarchy is described as a pyramid in Fig. 2.

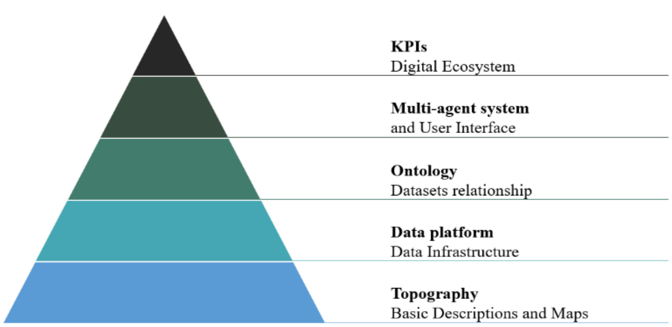


Fig. 2: Hierarchy of system layers

### B. Topography

When dealing with *topography*, we mean mainly 3D mapping of the proposed area. Having detailed and precise maps is imperative in order to achieve any advance in traffic organization and management, energy savings, proper communication infrastructure or additional optimizations. This would include records of every part of the involved infrastructures with a detailed description of its parameters and how it might be maintained (BIM – Building Information Management). This leads to an optimal overview of how the system can be managed long term and allows for the creation of models optimizing the "as is" and "to be" situations.

### C. Data Platform and Data Infrastructure

We consider a *Data platform* or a data communication network as a vital step prior to describing the system and its components. The possibilities of the current data infrastructure and its ability for further development/modernization greatly influences which technologies and parts of system should be included in the greater system.

Additionally, the data platform influences all system components. This includes determining whether the current data infrastructure (meaning optical cables) along the strategic network suffice. If the current data infrastructure is deemed unsatisfactory, new infrastructure needs to be erected in its place. The object is to coordinate this possible modernization with other infrastructural changes (such as road/sidewalk construction). The data infrastructure is greatly influenced by particular pieces of technology (mostly telematics) that are going to be placed and where they would be placed. Finally, is the question of wireless transmission. In order to ensure a robust and reliable data infrastructure, the city of Prague or district 6, may want to prepare for the advent of new technology by making this part of the city ready for *5G technology*.

### D. Ontology and semantic interoperability

The Smart City concept is characterized by the ability to produce, store knowledge, and learn based on experience [7]. This characteristic can denote the high complexity of the Smart City as the system of systems (or urban ecosystem) and provide better interaction if developed based on a common knowledge base and multi-agent technologies (MAT) [8].

Ontologies can facilitate the integration of information with data [9], collected by various agents, which in turn make it possible to create an integrated knowledge base for a Smart City. Also, the reliability of ontologies in describing the meaning of concepts as part of the communication process has been proven [10].

The basic principle of creating a new ontology for the Smart City is an incremental approach. It should start from the basic generic components of the city (streets, roads, buildings, citizens, etc.), subsequently injecting more complicated cases. In the final step, different ontology layers can be created (more specific ontologies: energy, ecology, transport, security, etc.). But when creating the new ontology there is a need to design and consider the "primary data source", rather than collecting knowledge from existing ontologies.

The Smart city ontology should be designed with the service's cooperation/competition of principals in mind. A city can be considered “smart” only by providing competition and or cooperation between services on a platform level [11]. Authors do not know a good example at present time with such negotiations between all the services in the city.

To achieve this, we need to implement ontologies as the instrument of semantic interoperability of services (services that can communicate amongst each other and understand one another, therefore they can cooperate). The use of ontologies is the most promising method of ensuring urban interoperability.

In the first approach for a Smart Testbed we can extract knowledge from databases and store it in the ontology-based repositories. In that case, different smart city services implemented for our Testbed will use a manageable common knowledge base.

In order to achieve successful collaboration between multiple agents, all elements should be able to understand and manipulate data obtained from different sources. For this reason, a semantic interoperability between services is required.

Semantic interoperability (SI) is a key factor for those systems, which are required to exchange or understand information through a shared meaning. Building SI-based networks is a way to help services communicate with each other and act on good information.

There are several approaches to achieve semantic interoperability between multi-agent systems. Compare two techniques, which should help the agent to interpret new ontology and to further update it: Machine Learning and Deep Learning [13]. Ontology in this case is a tool for interpretation the nature of the information exchanged

### *E. Multi Agent Systems*

There are multiple areas of expertise in a city that deserve consideration when managing the system. Each area has its particular needs and its own approach to problems that may arise. In our paper we consider the Smart City Testbed from four different points of view that overlap in this testbed. Those are: Urbanism (utilization of public space), Mobility, Environment, and Energy. These areas of expertise and their relationships are depicted in Fig. 3.

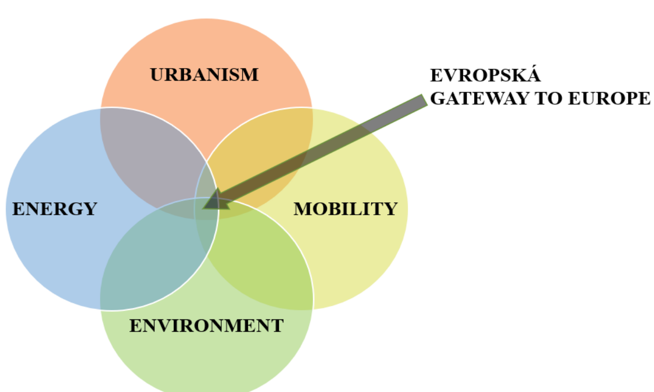


Fig. 3: Areas of Expertise in a Smart City Testbed

We consider these four areas of expertise to be most prominent and important in public spaces. Even though there are a large number of topics to consider, these four have proven to drive volumes of research and development projects and therefore are our top priority to include. These are also the only areas of expertise that we believe are worth modeling and thus worth including in a complex multi agent system.

A city is a complex system because it is open (open for new services, open in behavior, open for new residents, etc.), because it is created from many elements and components while having no singular unique control. In developing the Smart City, it is necessary to deal with complex system management and multi-agent technologies as the best way to manage such a complex system [8].

All elements of the Smart City are diverse, have different degrees of freedom but are strongly connected. In a multi-agent approach all components of the Smart City can be called “Agents” and the process of management of the city can be described as the process of these “Agent’s Negotiations”.

This approach is scalable because of the holonic concept of MAT architecture [12]. At face value, the solution will allow us to model the general situation between transport, ecology, energy and others areas. Going on to the next, more detailed level, the transport system can be divided into airplane, bus, tram, cars (including management of parking lots) layers. In the case of the energy services, the general energy model can be divided to the energy hubs, areas, buildings, and flats. Furthermore, we can drill into a lower level to provide each and every bus, car or pedestrian with an agent. The lowest level when every sensor on Evropská street will have their own agent.

Conversely, the MAT approach can help to create a digital ecosystem of services. Service for transport, service for the energy provision, service for ecology and urban design. This service-oriented approach will be more complicated, but will be more user oriented.

In this approach we define the consumers and providers of services. Providers compete with each other finding the best balance on market. This, in the same way can be applied to consumers. During rush hours a taxi costs more yet remains at a fair enough price to find a client. If the price were too high no one would take a taxi. On the other hand, four people going from the airport in one direction can take a taxi for almost the price of a bus ticket. The same principal can be achieved in other areas of service ‘coopetition’.

The first MAT approach will need monitoring or at least supervision from the government. The second approach can feature self-organization.

From a technical point of view, they will need one data base, one knowledge base and different MAT engines to ensure planning and the possibility to negotiate between each other.

Smart City developed as the digital ecosystem of smart services, as an open, distributed, system can autonomously schedule the resources of large-scale applications.

### F. *Digital Ecosystem and KPIs*

Smart City 5.0 is a new vision of a city as a digital platform and eco-system of smart services where agents of people, things, documents, robots, and other entities can directly negotiate with each other on resource demand principals providing the best solutions possible [11]. It creates a smart environment making possible self-organization of individuals, groups and system-wide objectives.

Like natural ecosystems, the digital ecosystem of Smart Cities should be adaptive, resilient and sustainable. In theory, the evolutionary negotiations and improvements of services will never stop [8].

Based on the agent approach, every service will be represented by an autonomous agent. They can cooperate or compete with each other through a special enterprise service bus (ESB) and interact both horizontally between different services and vertically with the Knowledge base, Digital twin, AI instruments or other technologies on the basis of specialized protocols. Top-level services can be constructed as autonomous multi-agent systems of a lower level, where an agent of such a system can recursively reveal a new service for itself [11].

For example, a taxi waiting at the airport should know about people that arrived and proactively offer them services. In that case the parking service can also be part of the system. If the taxi driver knows definitively that in 20 minutes, he will have the passenger, he/she could then pay for the parking. All the payments could be done automatically based on block chain technology. For this we need semantic interoperability of services based on a common knowledge base.

For managing this digital eco system the city managers need only to adjust the set of city KPIs that will be considered by agents in their decision making.

## IV. Implementation

### A. *Criteria and Conditions*

We have defined how the system or ecosystem of services should be structured and built. The last step is choosing the services or the technologies providing the services, so that we may include them into the greater system of the *Smart City Testbed*. The choice must be based on several criteria. In short, we need to make sure the technology is:

1) An open and transparent solution (allowing for integration);
2) Flexible (Adjustable to emerging needs);
3) Manageable (enabling remote access, control, and management);
4) Sustainable (cost, lifecycle, energy, management, service);
5) Aligned with the end goal.

### B. *Technologies*

Presently, there are several technological solutions, that can be defined as "smart" and fit the criteria described above. These are technologies that truly benefit both the whole system, and the individual users. We need to ensure the use of solutions that are actually applicable here and those that can benefit the program measurably.

When creating a Smart City testbed, the first thing to mention would be *telematics* using *data and sensory infrastructure* alongside a typical street. Creating an infrastructure, that is able to collect data, and transfer it to either a data platform or the vehicles on the road, is one of the first steps of creating a Smart Street. For Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V) communication the results of the C-ROADS project [14] will be used. C-ROADS Czech Republic is closely connected to the international initiative C-ROADS and is aimed at the utilization of ITS (Information Technology Service) and C-ITS (Cooperative Information Technology Service) technologies to evaluate feasibility of these programs in the field.

Being able to *communicate*, we are able to send and receive most of the data at an acceptable speed (not creating many issues to city). The advances in autonomous control and autonomous vehicles could in the future create a need for much larger computational power. Therefore, the next essential step includes political support in future development of 5G.

It is not enough to collect and communicate, we need somewhere to store, analyze and utilize data. The City of Prague already has a city data platform – GOLEMIO that is an array of technical tools for integration, collection, visualization and sharing of data. The main goal of the GOLEMIO platform is to provide a quality IT service to the city and city districts in the field of Smart City data [15]. Our testbed is expected to maximally use the GOLEMIO services.

### C. *Provided Services*

The next step is to propose advanced services that have the potential to bring us into the next era of what a truly Smart Street and Smart City are to be.

Smarter pedestrian crossings, which can determine whether a person or persons are truly trying to cross the road or not (the current system supports jaywalking by not synchronizing traffic patterns with crossing demand). In the future, systems may be able to detect conflicts (currently not available for machines on the necessary scale) [16].

Smartphones communicating the needs of the user to the infrastructure can adjust to the current need and negotiate the best possible solution for any given situation. This brings us to real time management of the whole area (be it transportation, energy, security, etc.).

We can even challenge some deeply rooted unwillingness to move away from old approaches to traffic organization and management. We believe there is more to be achieved with current static linear preferences in mobility and how it is done. This might allow for more freedom in optimizing a problematic situation.

This would support interesting solutions regarding waste collection (such as waste collection vehicle routing and timing) and much more. We need to understand that properly building infrastructure based on a firm vision can achieve plenty in this aspect.

We described the potential of the railway stations for future development. This is a substantial opportunity. By utilizing new technology and a Smart approach, we may create so called Smart Railway Stations, thus creating a Smart City HUB that includes mobility hubs, logistics hubs, digital hubs, innovational hubs and customer hubs in one place. That allows for some additional optimization.

This Smart Railway Station would include an innovative light control system for arriving trains, higher accessibility for handicapped customers, dispatching center, infrastructure for shared e-mobility such as charging stations, shared bike hubs and the like.

Due to the proximity of concurrent modes of transport at Nádraží Veleslavín, it is well possible to share some of the information. Due to the fact that there is likely going to be a project concerning the electrification of bus line 119, it will certainly be beneficial to share the power grid for possible charging stations and other elements.

It has been expected that soon *autonomous vehicles* will take over and replace individuals as error prone drivers. This Smart City testbed is the ideal testbed for piloting this technology. We can test how the vehicles can monitor the environment and how well it can communicate with the intelligent infrastructure that can provide the eyes and ears for the vehicles (personal cars, buses, trams).

## V. Conclusions

The aim of the proposed testbed is to create a smart city living laboratory in Prague, where it will be possible to test various solutions and services under real conditions. The whole project is aimed at users (residents) who should benefit from it. Our higher goal is to learn to change local behavior in order to increase the sustainability and resilience of urban units.

At present Evropská street already has some technology installed, just as most other strategic streets in Prague and in Czech Republic. It is mainly technology related to traffic control (traffic lights, sensors, etc.) with its own data and energy infrastructure.

Although the technology applied there today is quite well designed, it is mostly aimed at transportation. The Smart testbed lies in integration with other technologies and mainly with other areas of expertise.

The current state is not in line with the proper end goal and is not structured as a service oriented Smart City system. Therefore, the main question should be framed as: *Can the current infrastructure and current technologies be used in the proposed development?* If so, then we may proceed and accelerate. If not, a proper infrastructure should be created.

The plan can be summed up as trying to create a testbed for examining new services for increasing the quality of life of the users in this area. This shall be done through setting a system beneath all future technology in accordance with the principles described above. Subsequently, selecting and implementing technologies meeting the above listed criteria.

With the expected increases in traffic at the airport and overall traffic on the streets of big cities, we may presume Evropská street to play even greater part in the city infrastructure than it does now.

In the future, Evropská street should act as the gateway for all arrivals to the city of Prague. With an increase in technology functioning as one whole digital ecosystem managed through multi agent technologies, Evropská street should draw the attention of additional investors and developers. It could be transformed into a center of excellence creating an avenue of technological companies among the city residents.

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