Research and innovation in underground space

Towards a common European research agenda
for the critical nodes in our infrastructure

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Prepared by the COB International Working Committee

Contents

1. Why a European (research) agenda for tunnels?

A well performing transport infrastructure network is essential for achieving the European ambitions and goals on competitiveness, growth and jobs, achieve alignment with the UN Agenda 2030 and related sustainability goals. The EU played in important role in defining these goals. Infrastructure is essential for the prosperity of Europe, especially in the peripheral areas and the TEN-network. The position of tunnels in these networks is extremely important. As important nodes, often without alternatives, their availability is crucial for the economic heartbeat of the European network.

With this paper as a starting point we want to influence the research and innovation agenda of Europe. We believe tunnels deserve to be on the priority-list. We deserve European attention and European funding. We are supported in this opinion by both CEDR and EIM as owners of the rail- and road infrastructure, and by Infra4DFuture who believes tunnels should be a special topic in their strategic approach.

Many of the tunnels in the European transport network are aging and need major renovations. The required high availability will be impossible if we approach this issue in the classical way by shutting down tunnels for a long period of time. Large knowledge gaps make that reliable predictive maintenance is still impossible and insecure.

Another focal point for underground infrastructure is the strong growth in mobility and urbanisation. Cities will suffer massive strokes if we cannot use underground space more effectively and without hindering existing networks, such as metro-systems, and city life at street level. Building and renovating must be done whilst 'the shop is open for business'.
A third focal point is a high demand for adding value. Getting tunnels resilient, making them climate-proof, making them part of a safer network, making them smarter, making them more adaptive to still unknown change, making the people working in underground infrastructure more capable to work with these challenges…
All these demands can only be addressed at a global or at least European scale. Addressing these challenges will make our position on the global market stronger and our own society a better place to live.
Those focal points give us momentum and opportunity. Because of the volume of these tasks and the fact we simply cannot postpone them, we need to fundamentally change our approach. Infrastructure managers and operators on a European level need to work together and define the capabilities that infrastructure is expected to provide to the end users and society.

For us, this is the starting point of our journey, which starts now and ends in 2040.

With the support and cooperation of 9 countries the COB (Dutch Centre for Underground Building and Infrastructure which represents over 75 organizations in both the Netherlands and Belgium) initiated a European group from Flanders (AWV, BVOT-ABTUS), Germany (STUVA, OBB-Infrastruktur AG, Norway (Norwegian Tunnel Safety Cluster) and Denmark (Sund und Baelt), France (CETU and PINI France), Austria (ASFINAG), Switzerland (Amberg group), Italy (Daniele Peila, Prof of Tunnelling, Politecnico di Torino and of course the Netherlands. This group is supported by all stakeholders – including owners (private and public), policy makers, market parties, academia and society. We want to join forces, work together and answer the future challenges from a joint vision. This paper sketches the impact of future developments to society. We have identified knowledge gaps and we want to address these gaps in a shared, strong, and effective program. We have identified issues and now want to address them and find applicable solutions.

Aims and challenges

We see three major aims that can be addressed individually but are interdependent.

1. **Availability is key**. To achieve this aim we have to
    A. Renovate and build tunnels without disturbance for the traffic flow and the surrounding society
    B. Get 80% of the refurbishment activities integrated as part of normal maintenance
    C. Resolve the knowledge gaps that prevent us from performing predictive maintenance

2. **Digitalisation is crucial to meet up with societal needs.** To achieve this aim we have to:
    A. Develop digital tunnel twins that are designed for the entire lifecycle of tunnels
    B. Find solutions for the gaps between the lifecycle phases
    C. Develop skills for all parties involved within the lifecycle to be able to benefit from digitalisation.

3. **Adding value is a must**.
    The complexity of society demands a holistic view of both problems and solutions. So we must always build, operate and renovate with the perspective of adding value. If we spend public funds, do we really get the best value for money? To achieve this aim we have to:
    A. Develop a roadmap for resilient and sustainable tunnels
    B. Develop a roadmap for an integrated view on (tunnel) safety as part of an integrated system-safety framework (from object thinking toward system thinking)
    C. Develop industrial innovations to build and maintain without disturbance

Appeal to ourselves and Europe: learn and innovate together

The time is now. The huge challenge we all are facing gives us **momentum** and a **chance to learn and innovate together**. Each tunnel should be constructed or refurbished with the above aims integrated in its scope. When we develop a roadmap, each separate tunnel project can contribute a small step, thus making large steps on a European scale and contributing to the competitiveness of Europe on the Global market. To achieve this aim we have to develop a shared knowledge roadmap based on the current demands from the perspective of tunnel owners and operators. This paper is a starting point for this knowledge roadmap. We believe we should always include real tunnel cases within research programmes so that we can learn while we are doing. And, last but not least, we should organize a European platform for knowledge dissemination, networking and innovation.

2. What will the future bring us?

International collaboration is not new within this network but up until now it has been without a joint European perspective. A national level is a too narrow base to gain progress in innovation at a sufficient pace. The required capacity for these tasks is simply too large and European collaboration is needed to successfully carry out the programme. Moreover, transport, by nature, is a field that has to be addressed on a European level. As a starting point for a shared vision on tunnels, we look at important trends in society, the end users, infrastructure owners and the effects of those trends on tunnels

2.1 From the end user point of view: Less tolerance for disturbances

Reducing and even eliminating disturbances will eventually become the norm. Higher availability and less hindrance are key. The impact of a tunnel closure, whether it is short term due to accidents or equipment failure, or long term due to maintenance and renovation, is felt in an increasingly wider area, often affecting the entire region.

The impact that major infrastructural projects, especially in cities, have on the quality of life and the availability of the infrastructure will no longer be acceptable in the increasingly compact and bustling cities. This applies to both construction and management, maintenance, and renovation.

2.2 From the owners' point of view: shifting focus towards operation and maintenance

Building a new tunnel is an enormous task that includes large investments. The total cost of ownership (TCO) is growing and is increasingly determined by adding complexity to operation and maintenance. But it is not just the owners costs that are significant. A tunnel closure can cost society between 1 and 2 million Euros per day. So keeping a tunnel in operation, renovating whilst 'the shop is open', and keeping the TCO at an acceptable and effective level, and aligned with its original building costs is key from this perspective. This also demands a different set of skills for tunnel owners, operators, and people in this industry.

2.3 Space constraints

Demographic developments have a direct impact on the available space in European metropolitan areas. Almost three-quarters of the expected growth of the European population is expected to settle in the larger municipalities. Use of underground space helps to keeping space above ground available and thus ensures and improves the quality of the living environment. In the recent years we have observed that tunnels are no longer regarded as separate objects but have become part of a large transportation system with big overarching ambitions. In addition to the need for cities to be accessible, the **quality of life** has become a new factor. Therefore, the decision-making process regarding the construction of new tunnels and the renovation of existing tunnels becomes more complex. Cities and urban partnerships – be it in combination with private parties or not – are important stakeholders. As a consequence, the role of the central government will change.

2.4 Mobility pressure

Additional pressure on mobility arises in cities because a relatively large part of the travel time is spent inside cities. Apart from the autonomous growth of car and rail-mobility, an increase in small-scale freight transport has also been observed as more and more purchases are made on the Internet. Especially in cities this increase creates additional congestion. Better utilisation of underground space and the utilisation of space around and on motorways and railways will be necessary to make and maintain habitable and economically viable cities. This development means we have to change from object-thinkers into system thinkers. Our concern should not be just on tunnel safety or resilience, but on integral safety and resilience within the system.

2.5 Digitalisation as the key to adding value

Infrastructure is a conservative area but in other sectors (chemical industry, aerospace, health) the benefits of digitalisation are much further developed, and we see willingness from tunnel owners, industry and knowledge-institutes to jump over that gap. We see a trend towards developing 'digital tunnel twins' to move in the same direction. Both the ability to harvest the benefits from digitalisation in internal processes of transport infrastructure management (e.g. planning, design, construction, operation, renovation, end of life) as well as the relation between transport, infrastructure management and its end users are developing rapidly. However, both are missing an integrated framework. How can we learn to combine all separate elements into a working networksystem?

2.6 Smart mobility

Vehicle control will change over the years. Initially, drivers will receive support in performing their driving tasks but, over time, inbuilt systems in cars will fully take over. This development will lead to smart road systems/networks and different safety risks. Because autonomous driving vehicles need to be able to distinguish between different objects, nearby objects will in some cases have to share information. However, not all the required intelligence will be located inside the vehicle. It is expected that some intelligence will have to be placed inside the infrastructure itself. Does this mean tunnels have to become smarter, or can they be made 'dumber'? It is too early to say how this will materialize. There will probably be a transitional period during which several systems will co-exist. We cannot predict yet to what degree new technology will be incorporated in tunnels but we definitely do not want tunnels to become an obstacle in these developments such as platooning, etc. We also have to understand how to influence the user's perception and how people and technology will interact.

2.7 Big data

Tunnels will become part of smart cities, where all kinds of objects collect data. Analysis of that data provides opportunities to improve flow and safety in tunnels, save energy and improve services. But there are risks too. For example, information systems can be hacked. Attention to privacy and cybersecurity is therefore a must. Technology is developing so fast that there will be numerous applications that we cannot even envisage at the moment. We do not yet have an idea of the duration of the transitional phase. Moreover, it is not self-evident that the potential benefits of big data will actually ever be achieved. Friction may develop between central and individual optimisation. There is a trend towards considering the human factor in big data development. We are not able to fully control that factor, but we will have to understand and learn to influence it more. As for the acceptance of the use of big data, we do not only deal with professional decision-making, construction and maintenance, but also with the behaviour of operators/administrators and tunnel users. As technology options increase, users' expectations grow too, both in terms of ambition and speed. Road users expect that traffic flow disturbances will be considered as avoidable in the future. It is no longer the user who has to adapt to the network, but the network that has to adapt to the user. Safety systems will move from prevention through signalling to prevention through prediction, whereby road systems, including tunnels, will be proactively communicating with road users and vice versa. These developments speed up the process of change from thinking in terms of objects to thinking in terms of systems.

2.8 Resilience

Europe must become climate-proof. We must anticipate the effects of climate change, including rising sea levels, changing rainfall patterns and heat stress in cities. The current climate adaptation policy creates a major challenge for tunnels. What measures are needed to ensure that tunnels can remain available in times of flooding? In view of the tendency in the water safety policy to rely on more self-reliance and evacuation of people from endangered areas, these are important questions. Evacuation routes from urban areas often go through tunnels that overflow rapidly during a flood. Climate adaptation also raises specific technical questions. Although we have interesting examples of innovative approaches, the extent of this interaction is still not fully quantified.

3. Tunnel for the future

Less tolerance for disturbance, a shifting focus from building towards operation and maintenance, space constraints, mobility pressure, digitalization with shifting trends toward smart mobility, big data, and digital tunnel twins and resilience are the most important developments we are facing. Based on these challenges, the network of tunnelling experts produced a vision about the tunnel of the future:

> *"The tunnel of the future is a smart object integrated fully with its environment, the city and the traffic network. It is built and renovated without causing disturbances and provides maximum availability during its lifetime. The tunnel adds value above and below ground, promotes flow, is safe, and is valued in its form and function by users, owners, citizens and other stakeholders. Decisions (regarding underground space) are based on a balanced assessment of four factors – functionality, safety, availability and quality of life. Tunnels contribute to a climate-neutral and circular Europe. The tunnel experts network ensures that tunnels are considered in an adaptive and integral manner and that there is room for the integration of new technical and social developments."*

4. Examples for innovative answers to current challenges

As a group we can form numerous answers to current challenges. But we want to trigger the European Commission by giving examples that contribute the most to at least 2 out of the 3 formulated aims.

The aims are:

1.Availability is key. To achieve this aim we have to:

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B. Get 80% of the refurbishment activities part of normal maintenance
C. Resolve the knowledge gaps that prevent us from performing predictive maintenance

2. Digitalisation is crucial to meet up with societal needs. To achieve this aim we have to:

A. Develop digital tunnel twins that are designed for the entire lifecycle of tunnels
B. Find solutions for the gaps between the lifecycle phases
C. Develop skills for all parties involved within the lifecycle to be able to benefit from digitalisation.

3. Adding value is a must.

The complexity of society demands a holistic view of both problems and solutions. So we must always build, operate and renovate with the perspective of adding value. If we spend public funds, do we really get the best value for money? To achieve this aim we have to:

A. Develop a roadmap for resilient and sustainable tunnels.
B. Develop a roadmap for an integrated view on (tunnel) safety as part of an integrated system-safety framework (from object thinking toward system thinking)
C. Develop industrial innovations to build and maintain without disturbance

The aims	1. Predictive maintenance: knowing the actual state and residual life of the tunnel	2. Futureproof asset management using digital tunnel twins	3. Plug&Play and Building blocks as solution for adaptability and higher availability	4. Ensuring safe tunnels with changing demands from society	5. The tunnel as a valuable part of its environment
1. Availability is key.					
1A Renovate and build tunnels without disturbance for the traffic flow and the surrounding society		X	X		
1B. Get 80% of the refurbishment activities part of normal maintenance	X	X	X	X	
1C. Resolve the knowledge gaps that prevent us from performing predictive maintenance	X				X
2. Digitalisation is crucial to meet up with societal needs.					
2A. Develop digital tunnel twins that are designed for the entire lifecycle of tunnels	X	X	X	X	X
2B. Find solutions for the gaps between the lifecycle phases		X	X		X
2C. Developing skills for all involved within the lifecycle to be able to benefit from digitalisation.	X	X	X	X	X
3. Adding value is a must.					
3A. Develop a roadmap for resilient and sustainable tunnels.		X	X	X	X
3B. Develop a roadmap for an integrated view on (tunnel) safety as part of an integrated system-safety framework (from object thinking toward system thinking)		X	X	X	X
3C. Develop industrial innovations to build and maintain without disturbance		X	X		X

Proposed topic 1: Predictive maintenance: knowing the actual state and residual life of the tunnel

(Contributes to 1b, 1c, 2a, 2c)

Worldwide, renovation of tunnels is a huge challenge. Due to the large costs and the need for accessible infrastructure, choices need to be made as to which tunnel will be renovated first and which can be postponed, and what should be the scope of any renovation project. Unfortunately, we lack the knowledge to develop a proper asset management strategy.

Specific challenge

This problem of course applies to all infra-objects, but for tunnels the situation is more serious as:

- We lack fundamental and practical knowledge about the actual state and residual life of the structure. There is a lack of knowledge on degradation of tunnel components or lifespan models for concrete, joints, transition structures and foundations;
- Little fundamental and practical knowledge exists about the relationship between the (changes in) physical environment of the tunnel (soil, groundwater, changing river depths and widths, nearby construction activities) and the expected residual lifespan;
- Little fundamental and practical knowledge exists about the impact of changing traffic loads, the densification of the network and of the urban environment;
- We have put limited effort in establishing the relationship between these aspects and the identification of possible (as yet unknown) future risks.
- For this we must learn to use and interpret big data for the development of data-driven models, including development of new sensors to monitor and predict future degradation.

Part of this challenge was successfully approached on a European level in NeTTUN's WP10 involving the SNCF and the University of Leeds together with the support from the Swiss Railways SBB-CFF. More work is needed to make the system operational and industraialised, and get it implemented in both railway and road tunnels.

Scope

The proposals should cover the renovation and maintenance of tunnels. Proposals should address at least one of the following areas:

- Methods to establish more reliable lifetime expectancy and probability of (sudden) failure, avoiding catastrophes, focus on the most critical objects and components first (joints, interaction soil-structure, interaction tunnel safety and operational aspects, etc).
- How reliable is our system today? Prediction through monitoring, using expert knowledge and machine learning
- Predictive maintenance, use of big data, data analytics, development of data driven asset management for tunnels.
- Reliable maintenance strategies with a focus on reliable long term planning, maximum availability and establishing an optimal TCO for society

Expected impact

Increased predictability of the maintenance and renovation of tunnels, as measured by:

- 30% reduction in unexpected failures (from small problem to huge dysfunction of systems) leading to tunnel closures and associated failure costs;
- 15% reduction in delays, costs and time overruns, and unplanned costs due to renovation and maintenance

Proposed topic 2: Futureproof asset management using digital tunnel twins

(Contributes to 1a, 1b, 2a, 2b, 2c, 3a, 3b, 3c)
Every day a tunnel is out of operation costs around 2 million Euro to the society and organizes massive 'strokes' in its region. We see an upcoming innovation within the industry and tunnel owners to use digital instruments to solve this challenge. The building industry is learning from other industries that are way more developed (think about naval, space, chemical industry). These industries are far more used to thinking from an operator/asset management point of view and getting things 'right' the first time round.'. With both tunnel owners and tunnelling industry we see elements of digitalisation emerging but combining these instruments with the goal of optimal tunnel availability is a major challenge.

<u>Specific challenge</u>
The challenges of the future require safe, available, predictable and adaptable tunnels. We believe Europe needs a network of digital Tunnel Twins (for both for new and renovated tunnels) to bring about the next step in futureproof asset management. The digital twin ensures that communication and interaction with all stakeholders can be raised to a higher level. The result is a broader support base, better solutions and added value. A digital twin also contributes to integral construction and renovation projects.
Thanks to the use of virtual tunnels, the (operating) processes and system behaviour can be made transparent early on in the project, which allows early verification of the control software, even before installation work is performed at the project location. Tunnel managers, road traffic controllers and tunnel operators can be involved early in the process through virtual tunnels, allowing their feedback to be included in the final design phase. Competent authorities, safety officers and emergency services are offered insight into (tunnel) processes and can respond to and anticipate them.
By adding gaming functionality, it is also possible to test and tighten operational and safety scenarios, educate, train and practice without the tunnel being physically available. It also has a positive effect on incident handling, as emergency services familiarise themselves with the specific characteristics of the tunnel and can practice their responses (in a virtual environment).

The use of virtual tunnels reduces testing at the project location, because:

- The on-site work has been reduced to assembly, commissioning and verification of performance requirements. The validation of processes and system behaviour has taken place at an earlier stage.
- There has already been regular and early alignment with the competent authorities, emergency services, tunnel managers and safety officers. There is better mutual understanding.

If maintenance and operating instructions and the current status and maintenance data have been included in the model, the virtual tunnel will also be of great value during the operation phase:

- New road traffic controllers/tunnel operators can be trained
- Exercises involving emergency services can be organised regularly without disturbing the flow of traffic.
- Upgrades, downgrades, cyber security and new developments, insights and requirements can be tested in a safe but identical environment before implementation.
- New procedures, scenarios, etc. can be tested together with the competent authorities, safety officers and emergency services without compromising the actual tunnel and its availability and safety (safe area to experiment).
- If deployed widely and based on collected data from all tunnels (national/non-national tunnels):
    - It will support better prediction of the ageing behaviour of civil construction and the ageing, malfunction and failure behaviour of the technical installations of the assets.
    - The required asset management budget can be planned better.
    - The scope of both new construction and renovation projects can be determined and controlled better.

Scope

- Digital twin during operation. Leading to higher availability, higher safety for both road users and workers, lower TCO's
- Digital twin during construction and renovation, leading to speedier opening of the tunnel, improving acceptance of technological solutions and changes.
- Virtual training environment for emergency services and tunnel operators, including simulation and gamification.
- Developing the skills of all involved to benefit from digitalisation.
- Development and integration of existing and new visualization-, modelling-, simulation-, gaming- and software packages to turn the circle of digitalisation into a complete tool for futureproof asset management

Expected impact

Every day a TERN- tunnel is unavailable costs 2 million euros to society. It is expected that the benefits of digitalisation will improve the availability, the TCO and will add value to our infrastructure and its surroundings.

Proposed topic 3: Plug&play and Building Blocks as solution for adaptability and high availability

(contributes to 1a, 1b, 2a, 2b, 2c, 3a, 3b, 3c)

We need adaptive tunnels that allow us to make changes without compromising the safety or availability of the tunnel. At the moment, any change in the civil structure, the installations, or the control and operation of an existing tunnel immediately impacts its availability. For a new tunnel, it may also obstruct or delay the permit to commission the tunnel. That is an undesirable situation. Tunnels are built at locations where traffic must flow continuously. From an economic point of view, the availability of tunnels is a must. Tunnels should, just like smart home appliances (home automation, such as smart thermostats and lighting), be equipped with plug-and-play features that allow automatic updates, quick and just-in-time replacements. Devices that are so intelligent they can anticipate the need of the moment. This requires intelligent systems developed from a control and availability perspective.

But we also forecast possibilities for the civil structure of a tunnel. At first glance, there seems to be a contradiction in the terms adaptability and civil structures. The notion of 'cast in concrete' appears to clash with the notion of adaptability. It is, however, the civil structure itself that generates disturbances during the construction and long-term shut-down during renovation. Civil structures can in particular make value creation possible through flexible use, sustainability and beauty. To create fewer disturbances and more value for now and the unforeseen future, civil construction and renovation must be done differently, more adaptively. The use of new construction technology is necessary because the current technology causes too many disturbances and adds too little value.

<u>Specific challenges</u>

Innovating and implementing new techniques and materials:

- Standardization and modularity
- Test centers and European standards
- Digital testing
- Prefab/modular design and construction with an advanced focus on maintenance
- Use of automation and robotics
- Streamlining and innovating renovating processes and techniques for tunnels to limit hindrance
- Safety for users and workers
- New materials, including synthetic materials
-

<u>Scope</u>

The proposals should cover design, construction, management and renovation of tunnels, so that these can be optimally adapted to changing societal, environmental and technological conditions. Proposals should address at least one of the following areas:

- Adapting existing and new tunnels to the impact of changing climate conditions, or methods to use tunnels to increase the resilience of cities and transport networks.
- Adapting existing and newly built tunnels and their installations to emerging societal and technological trends (e.g. green fuels).
- Renovating and adapting tunnels with limited hindrance to society, including modular renovation strategies, renovation strategies whilst keeping the tunnel operational, use of prefab elements and new materials.

<u>Expected impact</u>

Methods and materials to adapt existing tunnels to changing conditions, resulting in:

- Relevant methods for the adaptation of tunnels in both real-world conditions and in validated future scenarios, e.g. based on virtual simulations with validated models and/or based on experimental results.
- Methods supported by governments and contractors for changing the tunnel systems with very little impact on availibility.

Proposed topic 4: Ensuring safe tunnels with changing demands from society

(contributes to 1b, 2a, 2c, 3a, 3b)

A tunnel is only open if it is declared safe to (European) standards. But society develops faster than regulations can. New energy carriers, platooning, the human factor, cybersecurity will evolve heavily over the next 10 to 20 years. It is as yet unknown what impacts these (r)evolutions have on our safety systems, what the consequences are for the design of the tunnel or the safe operation by tunnel managers, fire brigades, administrative authorities and other stakeholders, including not in the least the users. Tunnels cannot and should not be a barrier in the development of smart cities. But how can we prevent this from happening?

Specific challenges

- New energy carriers are pushing into the transportation market with battery electric vehicles (BEV) being the current front runners – a fact leading to questions about potential new safety risks emerging from new energy carriers systems: What kind of impact do these new risks have on our safety systems? What is the meaning and consequences of all these developments for road tunnel managers, fire brigades, administrative authorities, other stakeholders and – last but not least – the users?
- Another demand: smart car technology makes platooning possible in the next years. But how will platooning affect safety in an enclosed environment such as a tunnel? Will the failure due to the burning of one single truck in a platoon propagate to all trucks involved"and if so, are the current safety guidelines sufficient?
- Next demand is addressing the human factor. We see an overload of information and triggers which influence both the road users and operators in a negative way. Smart technology might help us get the tunnel smarter and the cars smarter (read: safer) but nobody knows when this technology will be implemented, and the only permanency seems to be the transition itself because the lifetime of each new technology is getting shorter and shorter. We must learn more about the psychological and physical aspects of both the road user and the operator to give them the skills and add safety to the design and operation.
- And last but not least: cybersecurity. The effect of a cyber attack on tunnels is enormous for society. Isolation sounds logical. But how can we keep these vital object part of smart cities and smart networks?

Scope

Proposals should address the impact of new energy carriers, smart mobility, the human factor, and cybersecurity on the tunnel and traffic operation and safety, and include a roadmap for keeping up with the continuous change.

Expected impact

- A reduction of at least a 30% (with respect to 2020 figures) in injuries and fatalities in tunnel accidents, contributing to the ambitions of the Transport White Paper's goal to reach close to zero road fatalities by 2050.
- Contribution to the UN's Sustainable Development Goals (SDG), in particular goal 3.6 ("By 2020, halve the number of global deaths and injuries from road traffic accidents") and SDG 11 ("Make cities and human settlements inclusive, safe, resilient and sustainable").
- Innovative tunnel safety systems that increase the safety of occupants of automated and zero-emission vehicles, which contribute to industry competitiveness and EU leadership in road safety.
- Safer use of tunnels, effective education and training schemes and increased awareness of all tunnel operators in the evolving road mobility environment.

Proposed topic 5: The tunnel as a valuable part of its environment

(contributes to 1C, 2A, 2B, 2C 3A, 3B, 3C)
According to the UN, by 2050 66% of the world population will be living in urban centres, with an estimated 6.5 billion people inhabiting overpopulated cities. A rapid urbanization requires a smart and optimized use of the available space and, within the limited possibilities in an urban environment, the use of underground space is not optional anymore and becomes a requirement. By means of underground passages, transportation, storage, utilities, parking areas, flood drainage systems and many other unexplored possibilities, urban underground space can offer the possibility of an integrated concept within the urban surroundings. To realize its full potential at optimal cost, the use of underground space should be integrated in urban development at the earliest possible stage. A holistic approach on both safety and sustainability is what we are missing.

The planning, design and exploration of urban underground space needs to be incorporated in the "smart cities" and "building and maintenance in a low-carbon" research programmes. The use of underground space can assist in creating more compact cities and reducing their carbon footprint. Innovative systems to optimize the use of underground space in densely populated areas need to be developed.
There are opportunities for Europe to add more value to underground infrastructure by looking closely at the functions of the tunnel, the (potential) benefits and beneficiaries, and the flexibility in functions during the construction and renovation processes. Innovative focal points include:

- Add quality to the (urban) network.
- Future-oriented building.
- Thinking, designing, building, and renovating from a system-based vision that focuses on the environment, integral safety and sustainability.
- Contributing to the climate change mitigation and do so with a minimum Carbon footprint throughout the whole lifecycle.

<u>Specific challenges</u>
The decision to create a tunnel never stands on its own but is part of the development of an area. A shift from object thinking to environmental and system thinking can be seen on national, regional, and urban levels. Under the denominator of environmental action, active research is needed: can a tunnel project (construction or renovation) serve more interests than just mobility? Taking other interests into account may reduce the (experience of) disturbances and increase the added value for the city or region. The impact of urban compaction and the enormous growth of mobility leads to such complex tasks that system-level issues such as safety, availability, and sustainability must be investegated. Only when all objects (buildings, tunnels, bridges, etc.) and (traffic) networks work well together, integrated safety is assured. Comprehensive assessments will lead to fewer disturbances and add more value.

Value creation is also possible by initiating initiatives bottom-up, by thinking about the local environment and the function of a tunnel, where the environmental or social issues and urgencies are the starting point. As a consequence, multiple parties would reap the benefits of the tunnel and could also be considered to help finance and realize the product. Ultimately, this would result in multi-ownership of the underground space. This is not limited to new tunnels, but also to the renovation of existing tunnels. A system-based approach and multiple use of space with multi-ownership requires different organisational forms and funding opportunities for the project (from initiative to management) than for the object-oriented mono-functional approach.

<u>Scope</u>
The proposals should cover the planning and design of innovative schemes of the use of the underground space for densely populated urban areas. Proposals should address at least one of the following areas:

- The development of an integrated, interoperable, scalable and replicable systemic solution for the use of the urban underground space to underpin the carbon-negative, responsive, resilient and climate proof cities of the future.

- The integration of different uses of the densely populated urban underground space, providing a feasible master plan and design scheme.
- Novel approaches to the interlinked use of the urban underground AND above the ground space, including novel design and construction technologies, at the same time ensuring the required safety for the entire system.

Expected impact

Introduce innovative use of the underground space, delivering:

- New unexplored markets to address the optimized use of the underground space.
- At least 10% higher resource efficiency by proposing new schemes of use of the urban underground space.
- Reduction of at least 15% of the carbon footprint, energy consumption or waste generation in urban areas.
- Contribution to the UN's Sustainable Development Goals (SDG), in particular goal 11: “Make cities and human settlements inclusive, safe, resilient and sustainable.”
- Diminishing the energy-consumption of underground infrastructure with at least 50%

Support

The content of this paper is endorsed by international experts and organisations:

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