# A SELF-SUFFICIENT CYBER PHYSICAL MOBILITY CONCEPT FOR ROAD TUNNELS

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## 1. INTRODUCTION

In recent decades, tunnels became not only more secure but, above all, more expensive, more complicated, more vulnerable to malfunctions and with this as background, technically also more likely to be subject to restoration. As a matter of fact, the technology, particularly vulnerable software and associated electronics, have to be replaced on a regular basis, due to end of life, spare parts no longer being available, technically outdated, no longer compatible, etc..

Furthermore, today it takes three times as long (then 30 years ago) to install the electromechanical components and carry out essential scenario tests before initial commissioning. Increasingly complex technologies result in more frequent malfunctions and breakdowns, as well as longer maintenance work.

The only positive thing that can be said about a modern two-tube directional traffic tunnel is that, in case of a fire, it almost certainly ensures the survival of its users. Unfortunately, accidents are still possible, and sustainable damage / destruction of the inner tunnel-shell, resulting from the heat of a truck fire, cannot be prevented either.

All this and my understanding of future innovations, which I have developed over the past few years, have led me to analyze how a tunnel could look like in the future if we apply the concept of an autonomous self-sufficient cyber-physical system. This paper presents the result of my theoretical considerations, which I designate:

**C** completely
**A** autonomous
**R** road
**T** tunnel
**S** system

## 2. PROBLEMS ENCOUNTERED TODAY BY TUNNEL MANAGERS

In recent decades, tunnels have not only become safer, but also more expensive (in construction and maintenance), and more complicated, making them more fragile and inclined to fail. Today, tunnels are equipped with a large number of electromechanical installations which are not always aligned with each other because they result from competitive tendering. Connecting the various technical systems often proves to be time-consuming and requires complex series of tests before putting a tunnel into operation. In the past, attempts to put tunnels into operation faster often led to operational problems, subsequently requiring even longer tunnel closures.

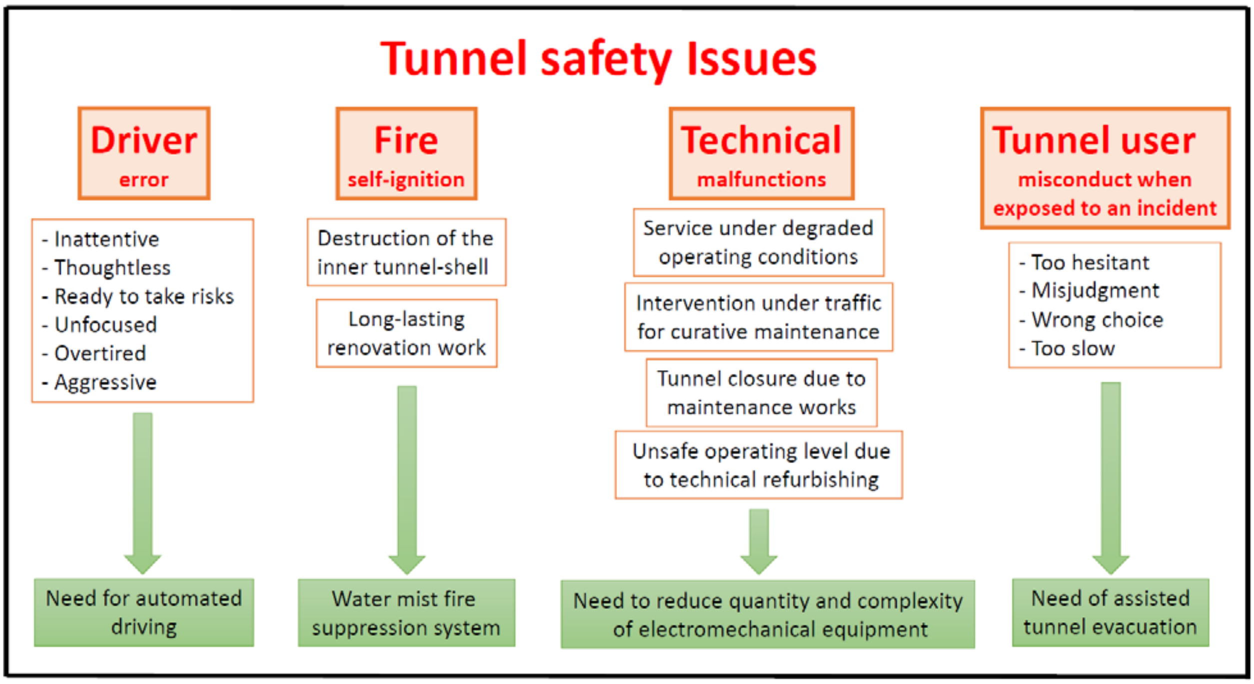
The increasing number of technical components is associated with high costs (in both construction and operation of equipment), problems in maintenance (fitting of spare parts) and has general operational disadvantages (frequent technical failures). Since manufacturers regularly change their technology, the required spare parts become unavailable, reducing the operational lifetime of technical components.

It is so far an unfulfilled dream of tunnel managers to have a simpler, less vulnerable, resilient technical tunnel concept.

## 3. CAUSES OF SAFETY PROBLEMS INSIDE TUNNELS

Either humans or technology cause problems in tunnel operations.

Hence, by getting rid of the human factor and by reducing the systems' overall technical complexity (and thus their susceptibility to breakdowns) by using always identical, standardized technology if possible, we would, for the very first time, generate safety in tunnels through prevention.




Please note that autonomous mobility is easily implementable on a road section without cross traffic (entrances, intersections …) and pedestrians, with unchanging environmental conditions (light, visibility, weather conditions) and the availability of perfect 5G communication.

## 4 SUBSTITUTION POTENTIAL BY AN IOT CONCEPT, BASED ON COOPERATIVE INTELLIGENT TRANSPORT SYSTEMS (C-ITS)

| **How do we get …** | | **Results achieved** | **Added value** |
|---|---|---|---|
| **Safe operation** | Vehicles exchange information and move in a coordinated way. | Vehicle cooperation will prevent almost all the accidents! | **Increased traffic capacity** through platooning |
| **Detection of an event** | Appropriate sensors for incident/event detection are not only small and cheap, but already exist in semi-autonomous vehicles. | Vehicles can provide reliable **real-time information** to the tunnel management system (standstill, fire). | Every vehicle in the network will be informed in real time about an event. A **perfect flow of information!** |
| **Event Assessment** | The TMS shares the complete overview with vehicles. It is familiar with all concepts/rules and can assess the current situation faster than humans can. | In case of a tunnel fire, all vehicles will have left the tunnel before any significant emission of smoke. | **Incorrect or slow analysis** by tunnel users/tunnel operators **is excluded.** <br><br> **Mistakes are avoided!** |

| | | | |
|---|---|---|---|
| **Identification of necessary security measures** | Vehicles react simultaneously. An evacuation is initiated immediately without any decision delay. | Evident time gain at all levels (stop if necessary, immediate and faster evacuation). | An impatient driver cannot intervene by reversing a car inside the tunnel. **Malpractice is effectively avoided!** |
| **Fast and effective communication** | Command orders will be sent simultaneously via various channels. Operators cannot react that quickly. | Clear **gain of time** at all levels. Objectives are fulfilled without human influence. | **No delay and/or communication problems** (for instance between the tunnel operator and the fire brigade) |
| **Adequate response by the tunnel users** | Autonomous vehicles remain in or leave tunnels without interference from passengers. | **Human errors** and **deviations** from the general standard behaviour procedures are **excluded.** | **Gain of time** |
| **Respect for conventions and rules** | Computers follow procedures (without errors or mistakes) | Quick and correct **application of the rules and orders ensured**. | Unlike tunnel users, the operator system is always right! **No risk of ignorance.** |
| **Stabilization of the situation and event response** | An evacuation vehicle will rescue the passengers of the affected vehicle; an extinguishing system will control the fire until the fire brigade arrives. | A reliable and functioning system is a prerequisite for the success of CARTS. Cybersecurity is a key to success! | **Total protection of the tunnel structure!** |

However, there is still one remaining question: Why are tunnels the right place to begin the implementation of a mobile cyber-physical system?

Tunnels are a well-controlled environment (autonomous mobility becomes possible without Level 5 vehicles). Furthermore, in long tunnels, users could save a lot of time (by avoiding significant detours), therefore many sceptics will sooner or later become active users of autonomous mobility.

## 5. OUR AMBITIONS

As we have seen, complicated and expensive tunnel technology causes many problems in tunnel management. If construction time, loss of operation time (under non-degraded conditions), resource consumption (of labour and money) in relation to electromechanical installations in tunnels would be reduced, the following benefits would arise:

a) Tunnels could **become cheaper to construct**, especially if the predicted rush hour traffic allows a bidirectional single tube tunnel. Up to 60 % savings in building costs would be possible. It should be considered that in many cases, the only reason we construct two lanes in one direction, is to guarantee that the traffic flow will not stop if a lane is blocked (standstill of one vehicle).

b) **Operating costs could be significantly reduced** because fewer staff would be needed to monitor and maintain the tunnel technology.

c) Tunnels could become safer, even **accident free,** if human influence is eliminated.

d) Tunnel **destruction could be prevented**, even **in the case of a truck fire**.

e) Finally, yet importantly, there would be **fewer traffic victims** outside tunnels, if vehicles were able to exchange informations.

## 6. IS THE TIME RIPE FOR AUTONOMOUS MOBILITY IN TUNNELS?

CARTS is a vision that could give the necessary impetus to autonomous mobility. But the question is whether the time is ripe.

The construction of a 5G network is only starting now. Vehicles that would be able to drive autonomously in a CARTS tunnel could already be produced today by any well-known manufacturer, but are not yet offered. A sufficiently large number of vehicles would first have to enter the fleet and tunnels designed for CARTS would have to be built. This raises the legitimate question of whether it is perhaps too early to discuss the concept.

First of all, it must be said that tunnels usually need at least ten years to move from concept to operation. There is no doubt that the capabilities of the vast majority of cars coming onto the market in five years' time will more or less match what would be needed to drive through a CARTS tunnel. The European Union is also in the process of revising an existing directive so that vehicles coming onto the market in about four years' time will have more or less the capabilities needed for CARTS tunnels. Defining in detail today what is necessary could make it possible, from 2025 onwards, to have only new cars on the market that could be used in such tunnels. If we consider the commissioning of a CARTS tunnel from 2030 as our goal, a large part of the fleet would already have been renewed by this time.

The design of a CARTS-tunnel, where only the most up-to-date part of the vehicle fleet can pass through, becomes possible because tunnels are often attractive for road users since alternative routes often take much more time. If the first CARTS-tunnel would be built in a relatively prosperous region, where so far a tunnel has been rejected for financial reasons, the motivation of the local population to buy an appropriate new vehicle in the near future would be maximized. Many tunnels have been in the pipeline for decades and have never been built for financial reasons. If a safe tunnel could be built at half the price, all those who have bought the new vehicles could finally use a time-saving connection, which they often have awaited for many years.

However, it is not just about construction at a lower cost. After a conversion, a road tunnel, which is unsafe for conceptual reasons (oncoming traffic tunnel without escape doors), could finally be safe. Take the longest road tunnel in the world as an example: the 24.5 km long Lærdalstunnel in Norway. The tunnel has no emergency exits and, in the case of fire, the smoke will pass in one direction. This will bring safety to some tunnel users and a hopeless situation for the people on the wrong side (with smoke moving in their direction). Taking into account all the information, autonomous cars would be able to leave the tunnel quickly and effectively (without panic). In winter, only 1,500 vehicles pass through the tunnel each day. In a rich country like Norway, such a limited number of vehicles belonging to local residents could easily meet the necessary technical standards.

## 7. A SELF-SUFFICIENT CYBER-PHYSICAL SYSTEM FOR TUNNELS

It is not very complicated for autonomous vehicles to drive straight ahead or change lane. All major car manufacturers already have the necessary knowledge to implement these features. The implementation of autonomous driving is only demanding because people like drivers or pedestrians show unexpected, careless, ill-considered or simply stupid behaviour. In the end, human behaviour cannot be precisely predicted by any human or machine. But if we exclude human influence in a mobility concept, only machines remain. Machines can coordinate with each other perfectly and are never thoughtless, stressed, tired or unfocused.

Although the presented concept, CARTS – **c**ompletely **a**utonomous **r**oad **t**unnel **s**ystem, is clearly about fully-automated driving, it requires nothing more technically demanding than Level 3 of automation (highly automated driving). CARTS tunnels are technically no more demanding than other cyber-physical systems; instead, the challenge is legal and political! The required vehicle technology must become the eligibility criterion for new vehicles in Europe as soon as possible.

### 7.1. Conceptual details

In the context of this article, due to lack of space, the concept cannot be described in detail. Let us limit ourselves to a few aspects:

#### 7.1.1. Autonomous and connected vehicle

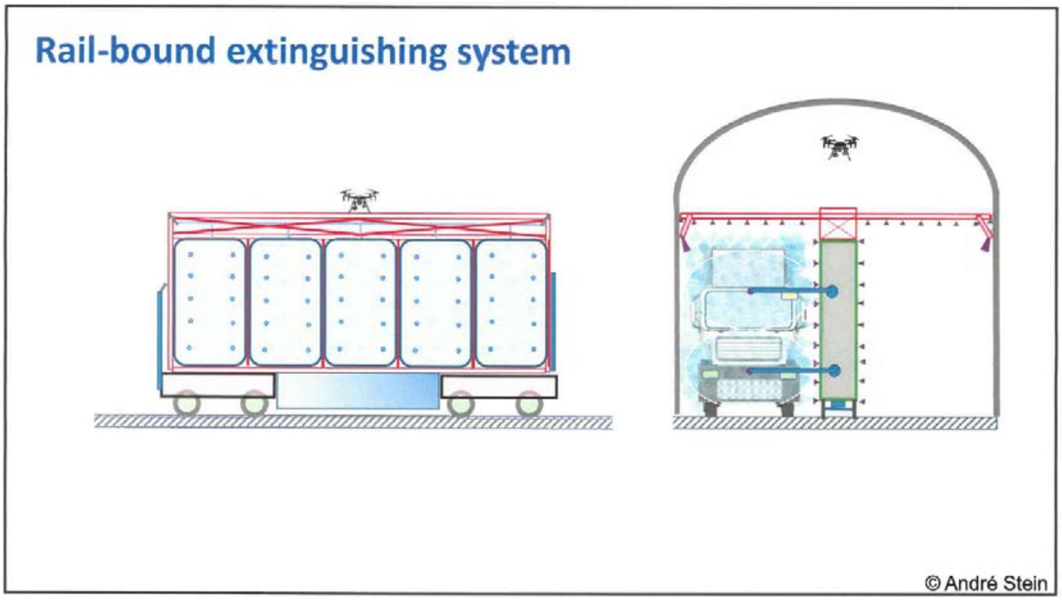
Based on C-ITS technologies, the vehicles are able to exchange information (with each other and with the control system) and to coordinate their movement. They move autonomously (cars in the platoon, trucks alone) and can, if necessary, change lane.

#### 7.1.2. Tunnel operator system

The Tunnel Operator System is a heuristic computer system based on the “Deep Learning” technology. It constantly monitors the tunnel control system (guiding system) and can intervene if necessary, since it is authorized to issue instructions. It decides on the basis of its experience, gained by observing tunnel operation, as well as its own inspections within the tunnel. In contrast to classical programs, which use data to initiate actions, the operator system evaluates the plausibility of a situation. The operator system is completely shielded for security reasons (no internet connection and no connection to the data flow of the tunnel guidance system) and is simply monitoring the situation (as through a bulletproof glass pane). There is a connection to the guidance system, but it can only be used in one direction (to give instructions). The tunnel operator system keeps out of daily business (normal operation), but always intervenes if it contests the decisions of the control system.

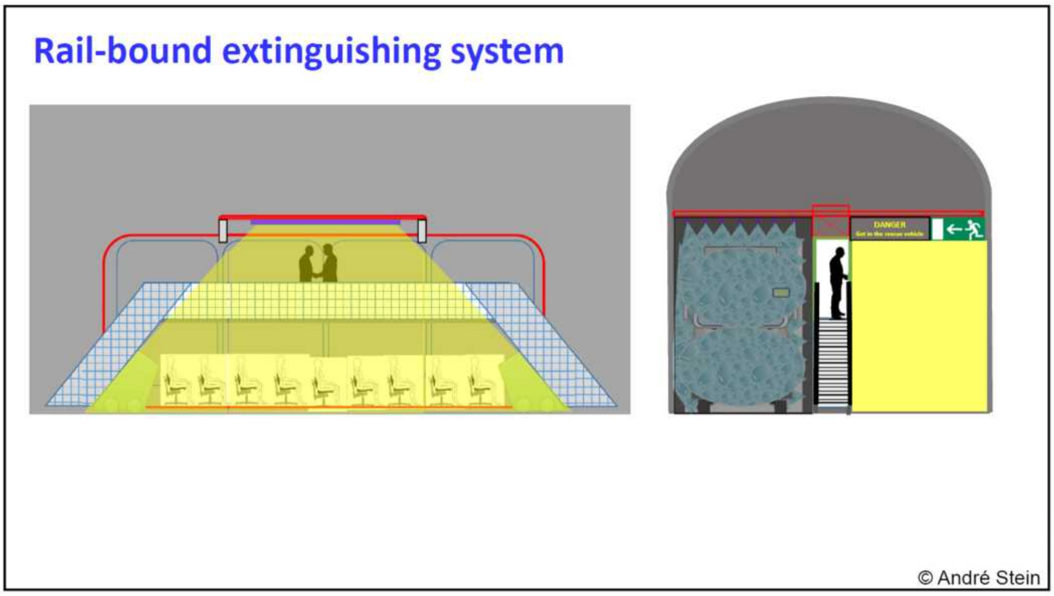
#### 7.1.3. Track-based extinguishing system

The electrically powered rail-based extinguishing system is a 90cm wide (rails at 80cm separation), 10 metre long, 5 metre high, mobile high-pressure water mist system. The water tank inside the vehicle enables at least 90 minutes of use.



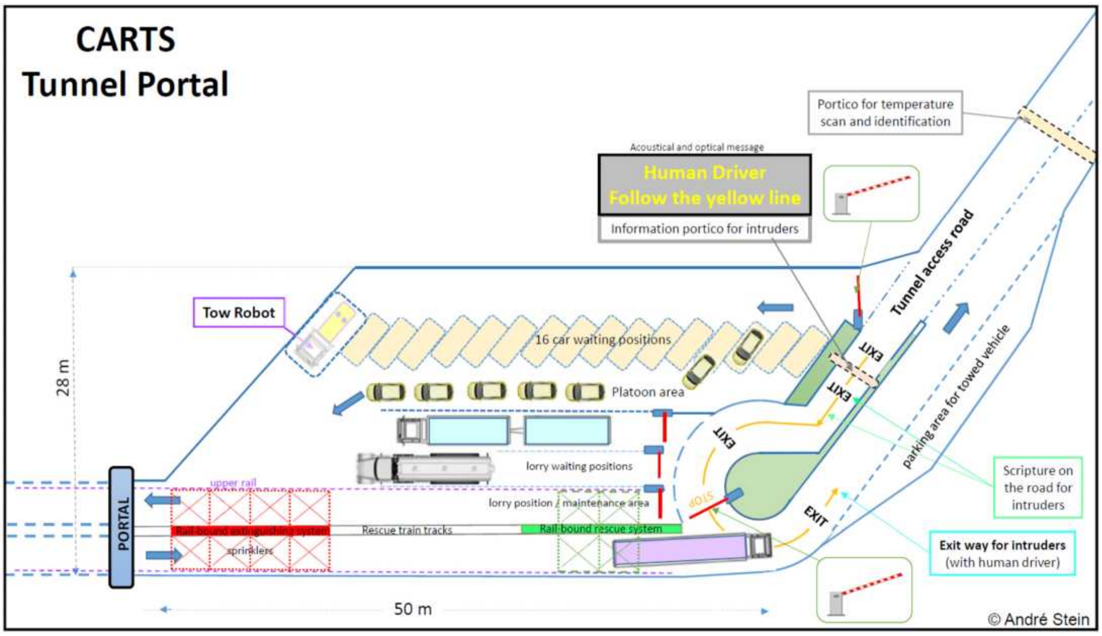

7.1.4. Rail-bound evacuation system

In the event of a fire, all uninvolved users of the tunnel leave the tunnel with their autonomous vehicle, and persons from the burning car / truck / bus are taken to safety with a rail-based evacuation system. Such a system moves at 25 m / sec. It will be on the way to the location of an immobile vehicle as soon as a temperature indicator suspects a conflagration.




7.1.5. Transfer station at the tunnel portal

A takeover of control by the driver and “mixed operation” (autonomous and non-autonomous vehicles pass through the tunnel together) should be not be allowed. Therefore a “transfer station” (handover of vehicle control) should be provided at the portal of the tunnel. The following picture shows one possible approach:




7.1.6. Cybersecurity, robustness, resilience, intrusion tolerance

Centralized network and system security architectures have been core elements of IT security concepts for more than 30 years, involving firewalls, cryptography like public-key infrastructures, and intrusion detection systems sending alarms if attackers cause malfunctions. Modern C-ITS and car communication innovations require to take their distributed character into account. Today, research in computer network security turns distributed systems into enablers of security, resilience and robustness, also creating an intrusion tolerance of distributed instances while checking each other for consistency. Dedicated Internet-of-Things (IoT) sensors placed inside the tunnel, plus mobile networks like 5G, G5 or others linked together in an open, interoperable communication network, using the new Internet Protocol IPv6, could be become instrumental inside a tunnel for autonomous driving and distributed sensor fusion with the help of car communication (V2X). With respective R&D efforts in this field, a tunnel as a clean room laboratory for safe autonomous driving could become a first step towards a zero-accident vision, if later applicable outside tunnels as well. Tunnel operating and management systems are independent of individual car controls for autonomous driving, which increases stability and attack tolerance to an adjustable level of remaining risk. Because of the distributed character of such a tunnel system using C-ITS, inside the tunnel it will reduce the risk of human errors, of accidents and incidents.

## 8. SAFETY CONSIDERATIONS

We analyzed a 100 MW fire with rapid fire development in a tunnel length of 3km. The expected time sequence was described and the potential risk for the people inside the tunnel was evaluated.

When we compare the results between a state-of-the-art twin-tube, unidirectional traffic tunnel with 2X2 lanes and a single-tube CARTS tunnel with bidirectional traffic, we come to the following conclusions:

| 100 MW in a 3km Tunnel | People out of the danger zone after | Consequences |
|---|---|---|
| State of the art twin-tube, one directional traffic tunnel | 600 seconds | Fire extinguishes when everything is burned in the tunnel<br>**Inner shell destroyed**<br>Time-consuming tunnel renovation |
| Single-tube CARTS tunnel with bidirectional traffic | 255 seconds | Firefighters can easily extinguish<br>**Tunnel reopens after one hour** |

## 9. SUMMARY AND CONCLUSIONS

CARTS tunnels make economic sense, as they are much cheaper to build and operate. Moreover, through prevention of accidents, we will see overall economic benefits and higher availability. Furthermore, fewer and shorter business interruptions will be caused by break-downs, maintenance and renovation work.

However, the economic importance goes far beyond this. European car manufacturers are under pressure. Europe urgently needs technological leadership in the automotive industry. European C-ITS technology can become the standard if the EU requires this technology as soon as possible for all registrations of new vehicles.

More important than the CARTS tunnel concept itself are the true benefits of connected vehicles on all public roads. Indeed, as soon as the number of vehicles equipped with C-ITS technology is high enough, many new business models will appear and reduce the number and severity of accidents outside tunnels. I would like to add that the operation of robot vehicles (Level 5) inside our cities also requires a large number of vehicles providing information on their current state. Otherwise, the frequent braking manœuvres of the robot vehicles will provoke numerous rear-end collisions. We should also not forget either human neophobia, with regard to surrender (to a machine) of control as a vehicle driver. It is time to build a demonstration project in order to provide the industry with a testbed and convince the population of the benefits of automated mobility.

**CARTS is the beacon project that we need** to justify that ITS technology should be required for registering a vehicle inside the EU. CARTS tunnels are technically no more demanding than other cyber-physical systems; the challenge is a political one.

The required vehicle technology must become the eligibility criterion for new vehicles in Europe as soon as possible. Five years after that, the first CARTS tunnel may be operated.

Whether you believe in the CARTS concept or not, sooner or later tunnels will become autonomous self-sufficient cyber-physical mobility systems. It is up to Europe to seize the opportunity in order not to be left behind.