The Scenario-in-the-Loop (SciL) automotive simulation concept and its realisation principles for traffic control

Márton Tamás Horváth[1], Tamás Tettamanti[2], Balázs Varga[3], Zsolt Szalay[4]

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[1,2,3]{horvath.marton, tettamanti, varga.balazs}@mail.bme.hu, Budapest University of Technology and Economics, Department of Control for Transportation and Vehicle Systems, Stoczek J. u. 2., Budapest, H-1111, Hungary, (36-1) 463-1013;
[4]zsolt.szalay@gjt.bme.hu, Budapest University of Technology and Economics, Department of Automotive Technologies, Stoczek J. u. 6., Budapest, H-1111, Hungary, (36-1) 463-1615

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Abstract

As autonomous and driver assistance functions become more and more complex, novel testing methodologies are required. Introduction of highly automated and autonomous vehicles on public roads alters traffic flow dynamics. Therefore, it is not enough to test only the single vehicle itself, but it will also be required to test its interaction with the environment and other vehicles of traffic. In this context, a practical goal is to test independently of real traffic as much as possible. The Vehicle-in-the-Loop method (i.e. where the vehicle is the 'hardware') is already used for testing vehicles. In this configuration the vehicle is directly forced to do specific manoeuvres, but the sensors of the vehicle are not used and the vehicle does not have to make decisions. The concept of the Scenario-in-the-Loop introduces a testing method where the physical attributes as well as the sensors of vehicles are tested via a virtual twin. In the paper we present the main principles of the Scenario-in-the-Loop concept and outline the requirements of such a test environment from the perspective of traffic control.

1 Introduction

Autonomous vehicles (AVs) are core elements of future's transportation, and it is not only a vision anymore since Waymo got the license to test their driverless cars in real traffic with no human intervention in the vehicle [7]. But these kinds of tests focus mainly on the behaviour of single vehicles without exploiting the advanced ability of AVs considering the relevancy of cooperation among the infrastructure and other vehicles. For example, it is no longer needed to visually see each other, it is enough to get a sign from other vehicles or the infrastructure to know what is happening. Currently, the so called "in-the-loop" concept seems to be the most efficient methodology to test the interaction of AVs and the control environment. The Vehicle-in-the-Loop (ViL) concept, which is already in use, was directly developed to test ADAS functions [2]. In this configuration the vehicle itself is real but all the other elements of traffic are simulated. The next step is using Scenario-in-the-Loop (SciL) testing environment [11], where not just the physical attributes of the vehicle are tested but also its sensors via the virtual twin realization. In this case the investigated scenario is simulated and fully or partly realized in parallel.

2 Scenario-in-the-Loop: the next step following Vehicle-in-the-Loop

ViL represents the state when the vehicle is moving on the real surface or on a test bench, and the full environment is simulated, the actuators of the vehicle get their input signal directly from the simulated test environment. It can be considered as a Hardware-in-the-Loop approach. SciL is one step closer to a realistic environment simulation, because not only the vehicle and the surface are real but some elements of traffic control can also be installed physically. This means that the vehicle has to use some of its own sensors, depending on the type of the test, to realize the traffic situation. SciL covers all the intermediate simulation states between ViL and real-traffic test approaches. For example, if the signal head or some other vehicles are also real, then these simulations are considered as SciL simulations. Apart from the test vehicle, the road surface, and the traffic simulator, the elements of SciL can either be real or simulated, depending on the current simulation configuration. The concept realizes a virtual twin or mixed reality technology, see Figure 1.

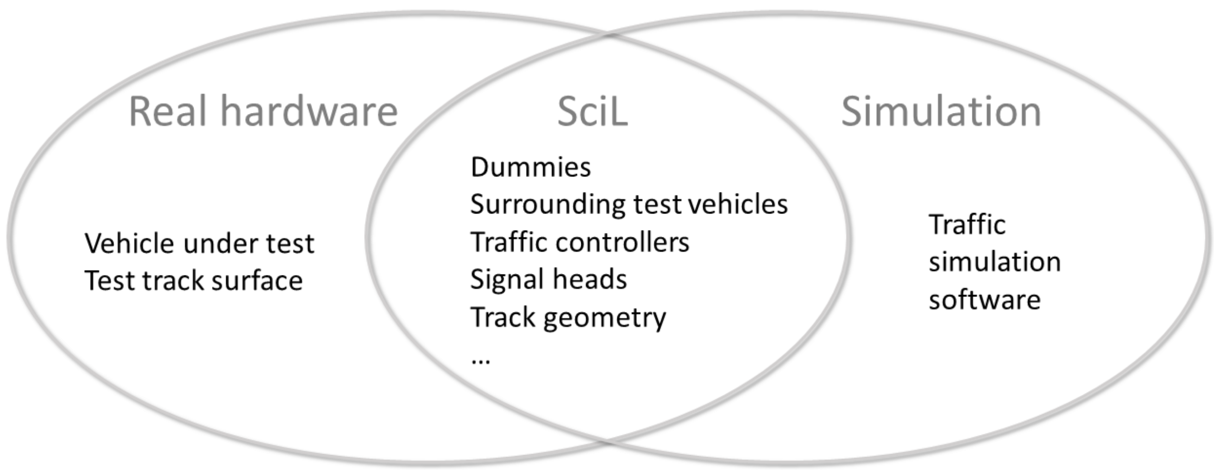

Figure 1: The relation of real, simulated, and SciL elements. Possible SciL elements are in the middle.

As previous researches [5], [9] have stated, the core component is the control software which dynamically redefines the scenario adapting to the continuously changing input parameters of the tested vehicle and the proving ground environment. To show the concept of SciL an example is introduced to support the understanding of the novel approach. A vehicle approaches a signalized intersection in different conditions. Only the signal head and the vehicle is real the other elements are simulated. Different simulated conditions can be included by the given test scene: the area can be metropolitan or rural, and the weather conditions can be foggy, rainy, sunny etc. The next step can be for instance to include some real vehicles too, but the scenario itself can be freely constructed by the test personnel. Test vehicles or other dummies, e.g. test-pedestrians or test-animals are coordinated by the traffic management centre. The traffic management centre has a significant role in moving these dummies in different ways in scenarios as requested by the tester, e.g. next to a simulated school test-pedestrians are much more likely to make unexpected movements, representing the behavior of schoolkids. Another important aspect of SciL tests is that many manufacturers apply their own specific objects which also requires a high level coordination from the centre, accurately controlling each object what to do and when to do. That is also a relevant difference compared to ViL, where it is not necessary to apply such a central management system since there are only one object and the simulator. In SciL the traffic management centre has therefore much more complex tasks. The concept of SciL is presented in Figure 2.

ViL is not a new concept, several manufacturers offer their products worldwide, and research institutes e.g. [1], [4], [13] have also developed their solutions and use it for various tests. SciL is not that widespread.

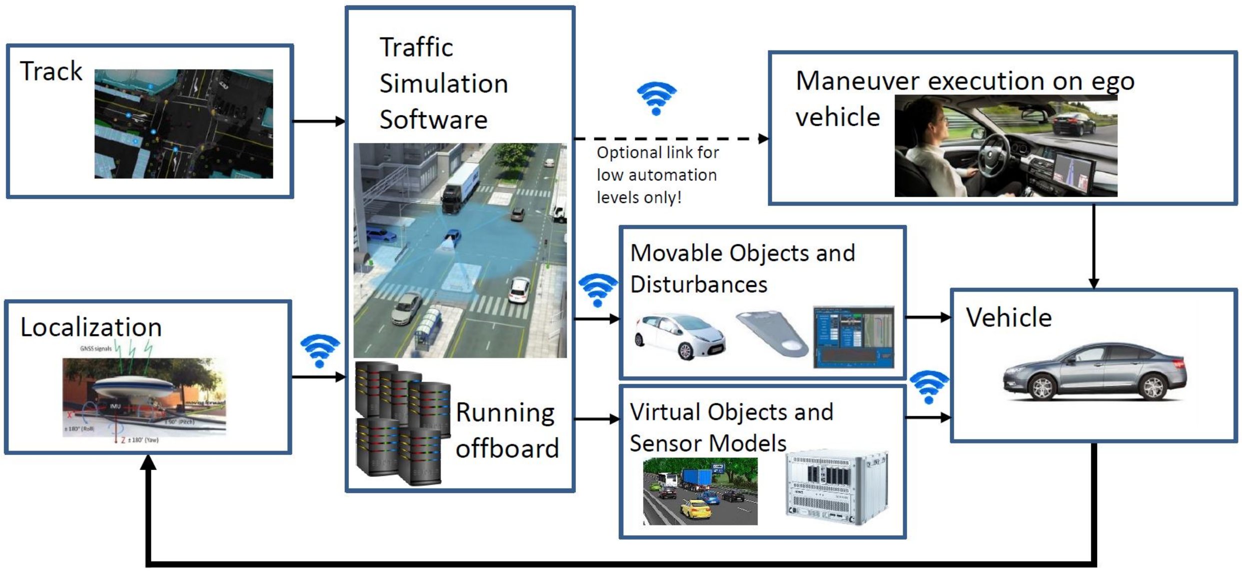

Figure 2: The concept of SciL [10]

Researchers [3] mentioned the concept of SciL first in 2017 fall as a next step in the future. The PEGASUS project [6] has exactly the same proposal, it aims to create relevant traffic scenarios for testing highly automated vehicles. It has also been highlighted by [14] that there is no accepted evaluation methodology available for automated driving above SAE Level 3 [8].

Unlike ViL, the concept of SciL has rarely been applied so far. But this situation is expected to change in the near future in accordance with the development trends of autonomous vehicle technology. The main considerations of designing a test track for AVs have been described by [9]. The principles of SciL are among the requirements of test track and vehicle configurations in the article. The practical considerations of SciL have been presented by [5], including its benefits and critical elements. The SciL approach is able to provide a realistic test environment, where test runs and results are reproducible. The configuration of tests is flexible and scalable, therefore it is easy to define and redefine scenarios. These make SciL a cost-effective testing method. On the other hand, communication is a critical element: the fastest wireless technologies have to be applied to avoid latency. Another drawback is that there are no standard testing methodologies for providing non-real test information for test vehicles. Finally, a central control software is required that manages the scenario, receives the data from localization units, and automatically triggers virtual signals for all the disturbance elements in the scenario.

This paper presents the basic principles of the SciL concept from the perspective of traffic simulation and traffic signal control (especially for autonomous vehicles).

3 Preliminaries of traffic control technology

The test environment should be functioning as a re-configurable urban area to be able to test any scenario with real vehicles, traffic signal devices, traffic sensors, and simulated traffic conditions. This requires a novel approach for installing and designing the signal, measurement, and control devices of the test track.

Traffic light control aims to ensure safe and disturbance-free traffic flow. The main element of this technology is the traffic controller unit that directly controls the operation of traffic lights. The basic elements of local intersection control are the banned stage matrices of simultaneously allowed movements in an intersection and intergreen matrices of the minimum times (intergreen times) required to elapse between any two consecutive movements.

Traditional traffic controllers contain these matrices permanently in a dedicated, protected memory (e.g. flash EPROM). Hence, the worst-case is a fail-safe situation which means that the traffic signal switches to flashing amber light mode or goes completely dark. In practice, traffic signal heads and local traffic controllers are connected to each other with wire-based technologies. Therefore, it is not a straightforward task to move these installations from one location to another. This approach is not applicable if one aims at building a re-configurable test environment for AVs.

AVs make new technologies possible to use in traffic control. AVs do not necessarily get information of signal heads and the environment visually; they can be provided this information via a communication protocol. This way AVs can also be involved in traffic control. Vehicle to Infrastructure (V2I) communication increasingly involves communication with traffic control units, in our case local signal heads and certainly the traffic management centre are involved by V2I communication.

The previously mentioned factors require a new type of traffic control architecture to be installed with new generation of signal heads and local traffic controllers using wireless technologies as much as possible. An innovative concept of intelligent signal heads with wireless distributed traffic control has been introduced by [12], where the energy consumption was served with solar cells for each signal head. The intelligence means that the signal head is not only used to show the specific signal but it also has an own logic that serves control and communication tasks. This solution enables to minimize installation and maintenance costs and provide a high level of flexibility when it is needed to change the position of signal heads. This makes it also possible to have a distributed traffic control system, where local traffic management in junctions is done directly by the control unit of signal heads.

4 Traffic control elements for a SciL test environment

This chapter introduces the basic necessary elements of the test scene, focusing on the requirements of a manufacturer-independent, re-configurable environment for operating traffic control and recording information. The elementary tasks that can be created in the SciL test environment are classified into the following main categories:

- adapting vehicle speed according to external factors (e.g. weather, traffic conditions, etc.);
- test vehicle operation at traffic light (e.g. accelerating, decelerating, turning, etc.);
- emergency brake simulation by interference (e.g. unexpected hazard);
- keeping small headway distance compared to the vehicle ahead (e.g. traffic jam pilot function);
- platooning situation with two or more real autonomous vehicles.

In the following part of the paper we introduce the core traffic control elements of realising the abovementioned SciL simulations (see Figure 2 again) in a successful way.

Specific road traffic control architecture

The test track's road traffic control system consists of a Traffic Control Centre (a control room practically) and road side units, i.e. Traffic Light Controller (TLC), traffic signal heads, variable message signs, traffic sensors. All road side units are monitored and controlled by the Traffic Control Centre.

Specific Traffic Control Centre (TCC) features

TCC consists of specific hardware and software tools, as well as communication technology. At all times the control centre monitors and controls the test track's traffic as well as logs and stores all events.

Road side units (RSUs)

Road side units include those hardware elements that are in connection with collecting or giving information to vehicles and enabling also the information exchange between the TCC and RSUs. These are traffic sensors, traffic lights, variable message signs (VMS) and other components being responsible for communication. The role of VMS components might be different as fully autonomous cars appear.

Control and communication of road side units

Traffic lights should be able to communicate with each other and with the TCC by using wireless communication channels. Therefore, communication cables can be eliminated. Beside vendor specific local traffic light controllers (generally one TLC at each intersection), customizable PLC (Programmable Logic Controller) based control is applied in the system, i.e. one PLC is integrated into each traffic signal head. Thus, signal heads can be directly controlled and monitored from the TCC.

Communication protocol between traffic control centre (server) and local units (traffic lights)
UDP (User Datagram Protocol) is suggested as communication protocol between traffic control system and local units (PLC components). UDP can be much faster than TCP/IP [12] which is very important in real-time traffic control processes. Even though UDP itself does not contain security elements, the sender and the receiver can guarantee security, and the protocol can be used in a secure way.

Communication technology
The communication is preferred to be wireless, but sometimes it is not feasible. In these cases optical fiber cable communication technology is preferred among units and the traffic control centre. This is much less flexible. RSUs can be connected with cable, but mobile units (vehicle under test, dummies etc.) cannot.

Communication security
Communication security is a very important issue in transportation, especially if the penetration of connected vehicles continuously increases. Encrypted channels have to be used to avoid malicious interventions.

Re-configurable traffic control system provided by the TCC
The traffic control system must be dynamically re-configurable, e.g. changing the test field geometry induces the reprogramming of traffic signal phases in an appropriate software environment.

V2I functions
Road side units must be capable of V2X technology, i.e. broadcast to and receive signals from cars.

Traffic control strategies
TCC, TLCs, and the PLC based road side units are capable of performing arbitrary traffic control strategies. Main traffic control methods are: fixed, traffic-responsive (adaptive), pro-active. Traffic control must be ensured in two levels: local (road side) level and central control level.

Safety requirements concerning the whole traffic control system
The careful and secures implementation of safety critical functions of the system (according to the European norm EN 12675:2002) must be ensured at all levels (TCC, TLC, PLC) and must satisfy the following requirements basically:

- recognition of prohibited (conflicting) or false signals;
- in case of inside errors, it switches to fail-safe position state (depending on the error type);
- checking the right green light combination, i.e. prohibited greens cannot be on at the same time (check the existence of the intermediate times);
- checking the failure of the signal components.

5 Conclusion and future work

The SciL concept provides a new type of testing method by combining simulation software and real-world elements. The main advantage of this approach is that one can run many simulation variants, i.e. scenarios only by a relatively small adjustment between two simulation runs. ViL is already used in practice, but SciL is still under development. This article has summarised the basic needs of a SciL test track configuration. One should not forget that applying new types of simulation methods also invokes new types of failure modes that have to be detected. For example the vehicle should be able to differentiate between a dummy-pedestrian or a real test-engineer being coincidentally on the track. Thorough failure mode analysis should be done when implementing such scenarios. The other critical factor is determining the very precise location of the vehicle in real time. These are definitely the tasks of the near future.

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