- Self-organizing systems. The promise made by the IVC community to design self-organizing networks is not enough for deployment or market entry, as many field operational tests clearly show: the radical new design of the network alone and the sheer scale of the system requires many innovations in the whole IT management chain. Here again, principles from self-organizing systems and the whole self-x movement might help while being complemented by existing IT management techniques.
- Flexible and adaptable communication architectures that can adjust to changing contexts, technologies and application mixes and that allows the system to evolve over time. This would also open a chance for building networks that go beyond IVC and would lead towards an Internet-of-Things approach.

With future cooperative automated vehicles, all the aspects mentioned above require and deserve further efforts in the field of inter-vehicular communication.

References

1 S. Joerer, M. Segata, B. Bloessl, R. Lo Cigno, C. Sommer, and F. Dressler, "To Crash or Not to Crash: Estimating its Likelihood and Potentials of Beacon-based IVC Systems," in *4th IEEE Vehicular Networking Conference (VNC 2012).* Seoul, Korea: IEEE, November 2012, pp. 25–32.
2 W. Klein Wolterink, G. Heijenk, and G. Karagiannis, "Constrained Geocast to Support Cooperative Adaptive Cruise Control (CACC) Merging," in *2nd IEEE Vehicular Networking Conference (VNC 2010).* Jersey City, NJ: IEEE, December 2010, pp. 41–48.
3 N. An, M. Maile, D. Jiang, J. Mittag, and H. Hartenstein, "Balancing the Requirements for a Zero False Positive/Negative Forward Collision Warnings," in *10th IEEE/IFIP Conference on Wireless On demand Network Systems and Services (WONS 2013).* Banff, Canada: IEEE, March 2013, pp. 191–195.

4.3 Best Practices for Field Operational Testing

David Eckhoff, Andreas Festag, Marco Gruteser, Florian Schimandl, Michele Segata, and Elisabeth Uhlemann

4.3.1 Introduction

The performance evaluation of vehicular network technology and applications is a non-trivial challenge. Field testing a system plays an important role in such evaluations and in advancing scientific knowledge. It is not only necessary to assess network performance in a real environment but also to discover previously unaccounted or unknown system properties. While some of these benefits can also be achieved with small-scale experimentation, only Field Operational Tests (FOTs) can evaluate systems at scale and cover a much wider range of scenarios.

Data collected in these trials can furthermore be used as input for the creation and validation of both analytical and simulation models, and therefore improve their quality and relevance. At the same time, conducting meaningful field operational tests is challenging. They often involve complex systems with proprietary technology components, which can make it difficult to interpret the results and to match them to analytical or simulation models.

As vehicular network research and development has moved into a stage of extensive field trials, this working group has discussed the potential impact on academic research and ways to improve collaboration between academia and the operators of field operational tests. We begin with a short overview of ongoing efforts and discuss why field testing can be a necessary and valuable asset for academia and the scientific field. From those discussions we distill recommendations for both academia and trial operators to further improve the value and benefit of future field trials.

4.3.2 Past and Current Efforts

Ongoing field trials in vehicular networks span evaluation topics ranging from driver acceptance of applications to network performance in highly congested environments.

In the United States, the Safety Pilot Model Deployment at the University of Michigan Ann Arbor hosts about 3,000 vehicles equipped with DSRC devices to test the effectiveness of the technology in real world conditions, to measure how drivers adapt to the technology, and to identify potential safety benefits. Results from this test are expected to influence a potential National Highway Traffic Safety Administration (NHTSA) rule making, which could make DSRC technology mandatory.

In addition to this more application oriented testing, the Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications 3 (VSC3) Consortium is conducting field trials under the connected vehicle technology research program of the USDOT. This activity studies scalability aspects of vehicle safety communications that will preserve the performance of vehicle safety applications in both congested as well as uncongested communication environments [1].

In Europe, the German simTD project [2] studied vehicle-to-vehicle and vehicle-to-infrastructure communication based on ad hoc and cellular networks. The trial addressed traffic efficiency applications (traffic monitoring, traffic information and navigation, traffic management) and safety applications (local danger alert, driving assistance) and included vehicles, road side units as well as traffic management centers. The tests were conducted with fleets of vehicles with professional, instructed drivers for scenario testing in a controlled environment and with free-flowing vehicles. The simTD project coincides with trials in other countries across Europe, for which the European project DRIVE C2X [3] enabled a common test methodology and technological basis. Objectives of the tests are to validate the vehicle communication technology and to collect data for impact assessment of the technology on safety and traffic efficiency.

4.3.3 Benefits and Challenges of Using FOT Data

The benefits that the academic community could gain from FOTs are manifold. Research groups studying Inter-Vehicle Communication (IVC) and Intelligent Transportation Systems (ITS) technologies in general, could use the data

ollected during FOTs even after the end of the project, investigating aspects that were not covered by the original FOT objectives. An important requirement for this to be possible is that all needed meta data is logged and documented.

Simulative evaluation of communication strategies and applications in vehicular networks heavily relies on data collected in field trials to further bridge the gap between simulation and reality and hence to increase the trustworthiness of simulation results. For example, the amount of work recently published on channel models for vehicular networks (including path-loss analysis, shadowing models for buildings and vehicles) requires real world data to be validated. The more data is available the better can these models be adjusted and therefore improved. But also MAC layer models would benefit from more extensive experimental validation. The results of network oriented FOTs (e.g., CAMP VSC3) but also more general ones (e.g, DRIVE C2X [3], simTD [2]) can therefore be extremely helpful to validate such models.

Not only can network models be improved with help of field trials but also can they help advance mobility related research. Vehicle traces collected during field tests, for example, could be used to derive behavioral models, which are becoming extremely important for the evaluation of safety applications. Further possible benefits include the tuning of psychological driver models (e.g., the following of recommendations made by the on-board unit) , the parameterization of car following models, or establishing a default mobility scenario to make simulations more comparable towards each other.

However, data access requested by institutions not directly involved in the FOTs requires some preconditions. First, there is a necessity for an in-depth documentation of the published dataset with not only the present goals of the FOT in mind, but also considering that the data will be used for other purposes. This requires a detailed and exact description of the experiments and the data format. Of course, making data publicly available requires specific solutions for data storage policies and locations, as data must be available to download to a potentially wide number of academic research groups, even after the FOT has long been completed.

4.3.4 Recommendations

Although the research community has a long history of analytical evaluations and simulations, the prior experience from FOTs is still rather limited. Since analytical results are used to validate simulators, and vice versa, the gain from having a third tool for performance evaluation is obvious. Some models of real world phenomena already exist in academic research and are used both in simulations as well as analytical evaluations. Examples include wireless channel models, modeling of shadowing and propagation based on different types of road environments, vehicular mobility models and data traffic patterns. The results of FOTs can be used to update and enhance these models, such that large scale simulations based on real vehicle traces are possible.

However, in order to fully benefit from FOTs, academic researchers need to become familiarized with the potentials, the limitations, the benefits and the drawbacks of this new tool. In addition, since the money and resources to conduct large scale field trials are often not available to academic researchers, they must rely on and collaborate with industry and governmental institutions. Unfortunately, the goals of FOTs outcomes are not necessarily the same for vehicular manufacturers, road operators, and academic researchers.

It is therefore of essence that we learn how to successfully convey the benefits of giving academic researchers access to FOT data. If we compile a list of possible use cases for that, it will facilitate a request to collect a specific set of data and record the relevant meta data needed to achieve a certain goal and to enable reproducible results. Further, there is a need to better understand the goals and the interests of the different stakeholders in FOT from the beginning, so that motivations to tightly restrict access to field test data can be identified and addressed.

Generated data and the respective scenarios, comprising the conditions under which the data was collected, should be documented in detail so that all stakeholders are able to work with the information easily. Naturally, this entails that resources should be allocated already in project planning processes for data documentation as well as archival, maintenance, and distribution after the project.

In-depth, general purpose documentation can not only improve the flow of information from the stakeholders to third parties in academia. Traceability can also improve the exchange of knowledge from one (completed) FOT to another, something that is oftentimes relying on stakeholders active in both FOTs.

Due to the complexity of many large scale tests, we recommend that validation activities (e.g., using simulation or analytical methods) are planned for and integrated even during the early testing stages of a field trial. Furthermore, small scale tests ("dress rehearsals") should be conducted (preferably already in an early project phase) in order to test processes and data collection deeply as well as pre-evaluate results. This also includes the allocation of time periods used analyze and revise the system and experiment design before conducting the final experiments.

4.3.5 Conclusion

FOTs represent an enormous resource for the entire vehicular networking community and are of utmost importance for the development of IVC technology. While FOTs are mainly conducted by the automotive industry, the outcomes of such trials can be also of huge value for academia. The successful collaboration with third parties, however, poses some challenges.

In particular, the academic community should try to be more involved during the trial design phase and communicate the exact requirements for the collected data. Non-involved parties from both academia and industry can also hugely benefit from publicly available data, if all the needed meta data is logged and a general purpose documentation is included. This does not only allow for the development of better, more realistic analytical and simulation models but can also help conduct future FOTs.

References

1 M. Lukuc, "V2V Interoperability Project," in *USDOT ITS Connected Vehicle Workshop*, Chicago, IL, September 2012.

2 H. Stübing, M. Bechler, D. Heussner, T. May, I. Radusch, H. Rechner, and P. Vogel, "simTD: A Car-to-X System Architecture for Field Operational Tests," *IEEE Communications Magazine*, vol. 48, no. 5, pp. 148–154, May 2010.

3 R. Stahlmann, A. Festag, A. Tomatis, I. Radusch, and F. Fischer, "Starting European Field Tests for Car-2-X Communication: The DRIVE C2X Framework," in *18th ITS World Congress and Exhibition*, Orlando, FL, October 2011.

4.4 IVC Applications

Natalya An, Wai Chen, Raphael Frank, Mario Gerla, Liviu Iftode, Stefan Joerer, Renato Lo Cigno, Florian Schimandl, Ozan Tonguz, and Peter Vortisch

As a working group, the Applications Working Group discussed some key emerging issues related to different applications of VANETs in the market place. These discussions included safety, efficiency, and entertainment applications. Below, we provide a summary of the key issues discussed by the Applications Working Group