

Electronically coupled truck platoons on German highways

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Abstract — In this paper, a brief introduction of Automated Truck Platoons on Motorways is given. It includes a description

of the scenario “platoons organized by the driver”, the system architecture of the platoon system and a description of the Software architecture for a driver information system. The results of the accomplished system and acceptance tests of the

platoon system in the truck driving simulator are summarized in this paper. Furthermore it contains an overview about the trial implementations on test tracks and on German motorways.

Keywords — Truck Platoons, Advanced Driver Assistance Systems, System Tests, Acceptance Tests, Driver Information System

I. INTRODUCTION

A. Problem definition

Due to the continuous increase of freight transportation in the last years, the maximum road capacity in many European countries is nearly reached. In the year 2003 the European Commission published a manuscript stating that every day 7500 kilometers of the European road system are being blocked by traffic jams.[2] Particularly for Germany, with its centrality within Europe, the continuing traffic increase poses a huge challenge. The integration of the new

European member countries is another challenging component for Germany's national traffic planning in the near future. Environmental pollution, safety risks and a loss in efficiency for the economy are only some of the effects that result from these factors. The concept of building truck platoons with the aid of Advanced Driver Assistance Systems (ADAS) is one possibility to manage this permanent increase of freight transportation [7]. Without an efficient traffic system today's already bad traffic situation is preassigned to collapse. The importance of this fact was emphasized by studies of the European Commission in 2006. Between 1995 and 2005 a growth rate of 28 % in road freight transport was detected. Furthermore, an increase of 41 % in road transportation is expected until the year 2020 [1].

B. Objective

The development and evaluation of the practical use of truck platoons is the objective of the project KONVOI. With the assistance of virtual and practical driving tests, by using experimental vehicles and a truck driving simulator, the consequences and effects on the human, the organization and the technology will be analysed [6].

C. Proceeding

Within the project KONVOI, four experimental vehicles were equipped with the required automation-, information- and automotive-technology to build truck platoons. After sufficient testing of the Advanced Driver Assistance System (ADAS) for the proof of the system security as well as clarifying insurance-legal aspects, the experimental vehicles were subsequently tested on motorways with traffic. During the test runs on motorways, the data was collected to analyse the traffic flow, road safety, economic efficiency and environmental effects as well as the acceptance and stress of the truck drivers.

II. THE SCENARIO "PLATOONS ORGANIZED BY THE DRIVER"

The Project KONVOI uses the scenario "platoons organized by the driver" (Figure 1) which was evaluated in the Project "Operation-Scenarios for advanced driving assistance systems in freight transportation and their validation" (EFAS). Within the Project EFAS other scenarios were "centrally organised platoons" and "platoons on a special truck lane". These three scenarios were evaluated in consideration of the categories human (stress, acceptance), environment (fuel consumption, noxious emission) and traffic (temporal distance, velocity, acceleration, collision time, journey time, traffic flow and volume). Additionally, legal aspects were considered. During the evaluation of the scenarios it became obvious that the first scenario with possible necessary modifications offers the best possibilities for a medium-term implementation [7].

A detailed description of the first scenario will be given below. This is the basis for the intended research and development processes.

In the scenario "platoons organized by the driver", the driver has the permanent control of the autonomous driving procedures. The creation of a platoon depends on the initiating driver who delivers the necessary data about time and place of meeting, the destination, as well as the required truck telemetric data (loading weight, engine power etc.) with the help of a Driver Information System (DIS). Because no schedules have to be generated like they have to be in rail traffic, the high flexibility of truck transportation is not lost. After activating the ADAS, it automatically shows a selection of the best matching platoons, informs the driver and prepares the participation to the selected platoon. It then helps the truck driver to plan the route and guides the driver to the meeting point. The driver has to initialise and respectively confirm all of the platoon manoeuvres in order to build and to dissolve the platoon. Accordingly, the DIS is the human machine interface (HMI) of the platoon system [3].

As soon as the final position in the platoon is reached, an automated longitudinal guidance with a target distance of 10 meters between the trucks and a lateral guidance is possible. The target distance of 10 meters between the trucks was chosen because of several reasons. On one hand, the short distance prevents most drivers from driving between the platoons. On the other hand, the short distance causes slipstream effects, which can lead to a reduced fuel consumption of about 10 %. The truck platoons can operate on today's existing motorways without extending the infrastructure [7].

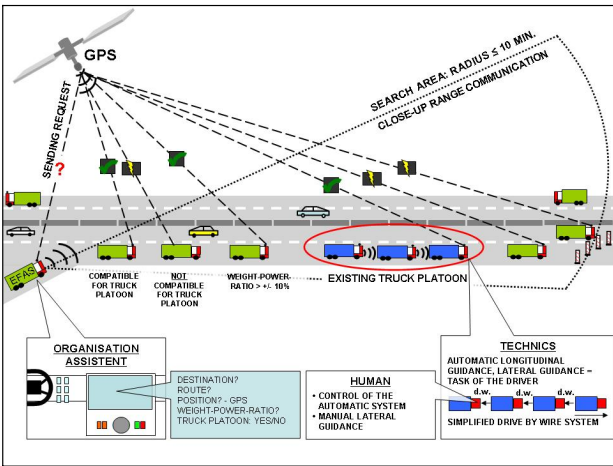


Figure 1. Scenario 1 – “Platoons organized by the driver” [7]

Since road markings are needed for the lateral guidance, the platoon system is exclusively developed for the use on motorways. Because of a limitation for most trucks at 50 mph the speed of the trucks on motorways differs only slightly, Therefore the truck platoons are operated at a speed between 37 and 50 mph. This speed can be managed safely at 10 meters distance by the KONVOI-System.

III. THE PLATOON SYSTEM

In order to realize different platoon sizes, four experimental vehicles are equipped with the required automation-, information- and automotive-technology. The main work packages for the implementation of the system architecture in the experimental vehicles are the actuators (steering and power train), the sensors (object registration in close-up and far range, recognition of lane), the vehicle-vehicle-communication (WLAN), the automation unit (coordination of the different vehicle states), the control unit (adaptive cruise control and automatic guidance) and the driver information system (human-machine interface, organization assistant, GPS and 3G) [6]. In general, the KONVOI system consists of two main components: the Advanced Driver Assistance System and the Driver Information System (Figure 2). The longitudinal guidance of the ADAS is based on a LIDAR distance sensor, a CMOS-Camera and a RADAR-sensor. The distance sensors are used to determine the distance in longitudinal direction and the lateral offset to the leading vehicle. The vehicle-vehicle-communication transfers necessary vehicle data from all platoon members, which are required for the ACC to realise the target distance of 10 meters. In all trucks a target acceleration interface is implemented, which automatically calculates the drive-train and the management of the different brakes in the vehicles. The acceleration is either calculated autonomously for each vehicle or deduced from the data which is transferred via the vehicle-to-vehicle-communication.

The lateral guidance is exclusively geared to the road marking. Every experimental vehicle was attached with cameras which are able to identify the traffic lane. Therefore they can determine the position of every truck within the

traffic lane. An electronically accessible steering system was integrated additionally. The adjustment of the position is being carried out by an electronic intervention into the steering system. A steering actuator on the base of an electric motor delivers the necessary steering moment for the automated guidance of the trucks [3].

A. Driver Information System (DIS)

1) Overview – The DIS as the Information Manager

In this section the data processing concept of the DIS will be explained. The DIS is not only the HMI of the platoon system, but it is also the information manager between the truck driver and the ADAS as well as the central server. Via touch screen and/or buttons the user’s input of the truck driver is processed by the DIS. In dependency of the user’s input, the data is given to the technical systems. Vice versa the DIS processes the data of the technical systems and informs the driver in all platoon phases about the current platoon situation.

During the platoon organization, the driver has to enter the DIS settings, has to plan his route and time schedule and has to choose a suitable platoon from an offer list. This data is preprocessed by the DIS and sent via 3G to the central server. The most important data for the central server are the route information of each truck as well as the platoons chosen by the driver. The DIS also gets a list with suitable platoons sorted by economic criteria from the central server. Furthermore, the central server immediately informs the DIS about any alterations within the planned platoons.

Two further tasks of the DIS are the navigation to the planned meeting points/destinations and the information of areas where the platoons have to be dissolved such as road constructions, bridges, motorway junctions and tunnels.

During the platoon drive, the drivers have to initiate and respectively confirm all platoon maneuvers (connecting, dissolving and lane change). The control signals are sent through CAN-Bus from the driver to the ADAS. The DIS permanently informs the driver about the actual state of the platoon. This applies to the manual as well as to the automated platoon drive.

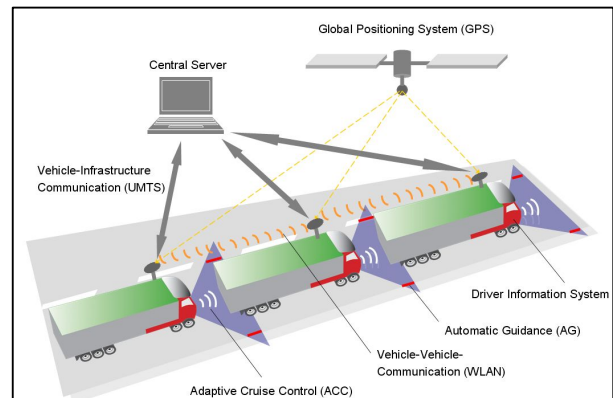


Figure 2. The Platoon System [4]

IV. TRIAL IMPLEMENTATION IN FOUR STEPS

A. Process of the trial implementation

The development of the KONVOI-System is accompanied by a trial implementation in four steps. First, the whole platoon system and all of its components are completely implemented into a truck driving simulator at the RWTH Aachen University. All test procedures (unit, integration, system and acceptance tests) as well as the optimization of the different system components were carried out in the simulator. In addition to the technical development and testing the second step includes another work package: the examination of both the acceptance of the ADAS and the arising stress of the truck drivers. In a third step, the trial implementation on test tracks has taken place and the trial implementation on motorways has taken place in the second half of the project. After this, an evaluation phase on motorways in real traffic with all four experimental trucks followed to confirm the effects determined by simulation and test drives.

B. Results of the system tests (step 1)

For the system tests the DIS was first implemented into a truck driving simulator which was used as a test environment for the module, integration and system tests. The tests with 30 truck drivers from the freight forwarding companies of the project consortium showed a consistently positive assessment and proved the functionality as well as the reliability of the software system. This showed that the system was ready to be integrated in the test vehicles [4].

The first test drives with two electronically coupled trucks on a closed motorway in the Netherlands took place in November 2007. These test drives were the first of a range of system tests to ensure the successful operation of the electronic system. Until today in the project KONVOI thousands of miles were driven on test runs.

C.) Results of the acceptance tests (step 2)

1) Process of the acceptance investigation

The acceptance of the truck drivers, freight forwarders and all other traffic participants plays an important role for the platoon system's success. Therefore their attitude towards the platoon system is surveyed throughout the whole system development. These surveys allow a forecast of the success or failure of a possible market introduction of the system. Furthermore they allow adopting the platoon system to the specific needs of its possible users.

The acceptance surveys are divided into three phases, the pre-acceptance, acceptance and post-acceptance phase (Figure 3). Through all three phases the acceptance of the three different groups (truck drivers, freight forwarders and other traffic participants) is surveyed with a variety of socio-scientific methods. All three phases need to be evaluated positively for the platoon system to be accepted. In case this is not possible, only a part-acceptance can be assessed [8].

In the pre-acceptance phase the results of the acceptance investigations in the project "preliminaries for the practical operation of driver assistance systems for freight transport" (MFG), a precedent project of KONVOI, were analysed. In

addition, group discussions between truck drivers and freight forwarders were held and the opinions of all three groups were captured by using questionnaires.

In the acceptance phase, the truck drivers and other traffic participants had the chance to experience the platoon system in the driving simulator before they were interviewed. Afterwards these interviews were transcribed and analysed with the method of the qualitative content analysis [9]. Furthermore, a valency analysis was carried out. The acceptance of the freight forwarders was surveyed by expert interviews via telephone.

In the post-acceptance phase the acceptance of the truck drivers, freight forwarders and other traffic participants was collected after they had been given the chance to experience the platoon system on a motorway.

In the following section the results of the acceptance investigations of the pre-acceptance phase, the acceptance phase and the post-acceptance will be described.

2) Results of the pre-acceptance phase

In the pre-acceptance phase the acceptance of the truck drivers, freight forwarders and other traffic participants was surveyed by the usage of group discussions and questionnaires. The group discussions were recorded on videotape and transcribed afterwards. The collected data were analysed then using a qualitative content analysis and a valency analysis. In addition, the test persons were asked to fill in a questionnaire. The questionnaire included questions about the socio-demographic background of the subjects as well as a number of statements about the KONVOI system. The subjects were asked to give their opinion about the statement by ticking one of five possible answers (completely applicable, applicable, partially applicable, less applicable and not applicable).

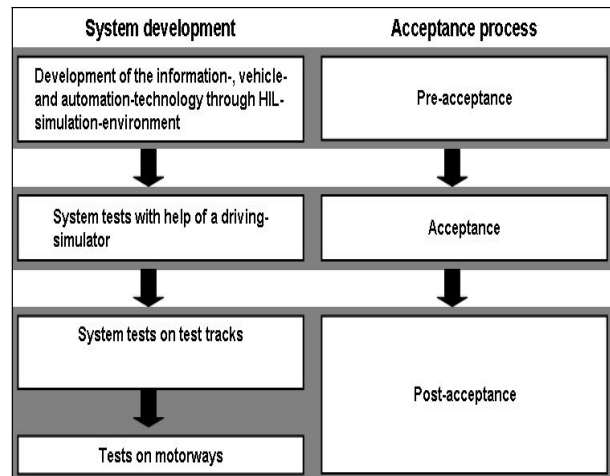


Figure 3. Process of the acceptance investigation [5]

The results of the group discussions showed that the truck drivers were very sceptic about the benefit of the platoon system. Especially the additional stress caused by the platoon system and the organisational feasibility were important

points of critique from the truck drivers. The questionnaire showed similar results, however it was slightly less negative.

The results of the group discussions with the freight forwarders showed a much higher acceptance. The platoon system is a desirable innovation for the freight forwarders, providing the predicted saving of fuel is correct, the freight forwarders can hope to reduce their fuel costs up to 10 %. This and the possibility that the truck drivers in the automatic following trucks might do additional work, such as completing freight documents etc. are the most important benefits for the freight forwarders.

The results of the questionnaire show a higher acceptance of the platoon system by the freight forwarders than by the truck drivers. Again, the reduction of the costs for fuel, the possibility to use a part of the driving time as break time and the higher safety through the platoon system are the most important arguments for the freight forwarders.

The third group, the other traffic participants, did not take part in the group discussions. Thus only results from the questionnaire are available for this group. The results show that the other traffic participants are rather undecided about the platoon system, similar to the truck drivers. However there are slightly positive tendencies. Especially the predicted higher safety and the relief of the motorways are strong arguments for the group of other traffic participants.

3) Results of the acceptance phase

Till this day the acceptance of the truck drivers, other traffic participants and the freight forwarders has been tested.

The attitude of the truck drivers towards the platoon system in the acceptance phase was collected by the means of a standardised interview, following a test in the driving simulator. In this test run the truck drivers had the chance to try all possible convoy maneuvers and to experience the platoon system as the driver of the leading or a following truck. The standardised interview was transcribed and analysed with the method of qualitative content analysis. Similar to the pre-acceptance phase the collected data were also analysed with a valency analysis. The results show that the attitude towards the platoon system in the acceptance phase was much more positive than it was in the pre-acceptance phase. In the pre-acceptance phase only 15.98% of all answers showed a positive attitude towards the platoon system. In the acceptance phase there were 54.04% positive answers. Accordingly, the positive attitude of the truck drivers has been rising during the acceptance process.

The attitude of the freight forwarders in the acceptance phase was evaluated through expert interviews. Executive employees of forwarding companies with many years of professional experience were questioned as experts. The interviews were held and recorded via telephone, afterwards they were analysed with the method of the qualitative content analysis.

Again, the experts think the biggest benefits are the decreased fuel consumption, the increased traffic flow and the enhanced options for cooperations between different forwarding companies. So far it can be said, that the attitude of the

freight forwarders was increased during the acceptance process.

The attitude of the other motorway users has additionally been surveyed. The test design was similar to the one of the truck drivers. The other motorway users got the chance to experience the platoon system in a driving simulator and were interviewed afterwards.

The reasons for the increase of the acceptance of the truck drivers and freight forwarders are the adaptation of the platoon system to the needs of the groups considered (truck drivers, freight forwarders and other motorway users) as well as the possibility for the subjects to get a deeper insight into the platoon system through the implementation of the system into the driving simulator.

4) Trial implementation on test tracks and motorways and the evaluation phase on motorways in real traffic (step 3 and 4)

After a sufficient testing of the ADAS in the driving simulator, the platoon system was tested with experimental vehicles on test tracks. Therefore four experimental vehicles were equipped with the required automation-, information- and automotive-technology.

Already thousands of miles were driven with the platoon system on test tracks during the trial runs. The development team worked for more than 60 days on test tracks and proved successfully that the platoon system runs absolutely safe and free from errors.

During the test runs a number of professional truck drivers were trained on the platoon system to enable them to drive the platoon system on German motorways later on. This was necessary to ensure a total safe and smooth operation on motorways.

After the trial runs on test tracks were successfully finished in December 2008 the test runs on German motorways started in March 2009 (Figure 4). The test runs were completely realized on public motorways to measure the effects of the platoon system on the traffic flow, the economic efficiency and the acceptance of the truck drivers. The trial runs were realized in two phases.



Figure 4. Test run on German motorways, March 2009

In the first phase a number of platoon drives were completed with the development engineers as drivers to show the German government that the platoon system even in its prototypical state is in no case a threat to the road safety. This first phase of test runs was accompanied by a police car and an escort vehicle. Due to these circumstances no data could have been collected to measure the effects of the platoon system on the traffic flow and on the acceptance of the truck drivers.

In a second phase the trial runs were continued without an accompanying escort vehicle only with a civil police car. In this phase it was possible to collect the needed data for the impact analysis of the platoon system. These trial runs took place from March to May 2009 and the current findings and results will be presented in the lecture within the IEEE International conference on Systems, Man and Cybernetics in October 2009.

The final evaluation phase demonstrated that the determined effects in simulation and test drives (decreasing fuel consumption, increasing safety and traffic flow) can be realized.

V. CONCLUSION

The concept of creating “trains on road” (truck platoons) supported by Advanced Driver Assistance Systems is one possibility to manage the permanent increase of freight transportation and the utilisation of its capacities. An electronic coupling of trucks will relieve the truck driver and therefore increase safety. Consequently, the capacity of the roads will be used more efficiently due to the short gaps between the trucks. An optimization of traffic flow and a reduction of fuel consumption caused by slip stream driving can be expected [10].

In the project KONVOI a trial implementation in virtual and real test runs is realized which shows the benefits of the ADAS in freight transportation. Furthermore, the project includes an impact analysis of vehicle platoons which considers all aspects with respect to the human, the organization and the technology [6].

The results show that the use of ADAS can contribute to the solution of a number of problems concerning road traffic. By using an automatic longitudinal and lateral guidance road safety and traffic flow can be increased, which leads to a more effective use of existing resources. However, a number of obstacles need to be overcome before an ADAS like the KONVOI-System can be introduced into the market. The current German and European law limits the use of fully automatic guidance systems and in the society there is no general agreement to allowing such systems or not. According to these factors, the introduction of a platooning system on the market in Germany will probably take 10 to 20 years.

At the end of the project KONVOI it became clear, that several additions such as fatigue detection systems, road sign detection systems or the ability to stop and start again without decoupling need to be implemented into the KONVOI

System. In addition to that the vehicle-to-vehicle and vehicle-to-infrastructure communication needs further advancement to incorporate truck platoons in today's road traffic and the highly sensible issue of data protection is not solved, yet.

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